
# Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges (2021)



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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

# NCHRP RESEARCH REPORT 948

# Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges


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2020

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# FOREWORD

By William C. Rogers
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*NCHRP Research Report 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges* provides specific guidance for four common Alternative Intersections and Interchanges (A.I.I.s): Diverging Diamond Interchange (DDI), Restricted Crossing U-Turn (RCUT), Median U-Turn (MUT), and Displaced Left-Turn (DLT). In addition, the guide provides a principles-based approach that is applicable to any A.I.I. or conventional intersection form, including new A.I.I. forms not yet developed.

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A.I.I.s are designs that improve operations and safety for motorized traffic by strategically adjusting the geometric features at a given location, working on the general principle of redistributing motor vehicle demand at an intersection in an attempt to limit the need to add capacity with new lanes to improve traffic flow. These designs may involve reversing traffic lanes from their traditional directions, which may introduce confusion and create safety issues for pedestrians and bicyclists. In addition, pedestrian paths and bicycle facilities may cross through islands or take different routes than expected. These new designs are likely to require additional information for drivers, bicyclists, and pedestrians as well as better accommodations for pedestrians and bicyclists, including pedestrians with disabilities.

A central concern with A.I.I.s is how to provide information to pedestrians, bicyclists, and drivers about the direction of car traffic, pedestrian crossing, and bicycle facilities, particularly when those new intersection designs feature unfamiliar traffic flows and patterns. The concern is acute for visually impaired pedestrians, who require information about the alignment of crosswalks, signal controls, crossing times, direction of traffic, and direction through islands.

Under NCHRP Project 07-25, Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges (A.I.I.), Kittelson & Associates was tasked with developing a guide to help transportation practitioners improve and integrate pedestrian and bicycle safety considerations at A.I.I.s through planning, design, and operational treatments. The guide (1) identifies and evaluates current practices, and emerging technologies and trends, in the United States and internationally; (2) describes current best practices for measuring the effectiveness of such A.I.I. treatments; (3) evaluates the safety and operational outcomes of specific A.I.I. treatments; and (4) identifies and ranks treatments for typical types of projects.

# CONTENTS

CHAPTER 1

# Introduction

This document presents a guide for pedestrian and bicycle safety at alternative intersections and interchanges (A.I.I.), based on NCHRP Project 07-25. The guide uses a principles-based approach that applies to any A.I.I. or conventional intersection form, including new A.I.I. forms not yet developed. However, this guide also provides specific guidance for four common A.I.I. forms being built in the United States: the Diverging Diamond Interchange (DDI), Restricted Crossing U-Turn (RCUT), Median U-Turn (MUT), and Displaced Left-Turn (DLT). The techniques in this guide can be extended to other A.I.I. forms, including Quadrant Roadway (QR), Jughandle (JH), Continuous-T-Intersection (CT), and Single-Point Urban Interchange (SPUI).

These A.I.I. designs may involve crossover movements of vehicular travel lanes, redirecting turning movements, or both. Pedestrian paths and bicycle facilities may cross through islands, take different routes than expected, and require attention to design techniques to promote safety for people walking or biking. The concern is acute for visually impaired pedestrians, who require information about the alignment of crosswalks, signal controls (if present), crossing times, the direction of traffic, and the intended path through islands. The concern is also acute for pedestrians and bicyclists who may be forced to operate within the motor vehicle travel lanes if adequate pedestrian and bicycle facilities are not provided.

The intended audience for this report is practitioners, researchers, and policymakers who establish federal, state, and local guidelines for pedestrian and bicycle treatments at A.I.I.s. This introductory chapter presents the scope of the study, the organization of the guide, and an overview of A.I.I. concepts.

## 1.1 Objective and Scope of Guide

The objective of this guidebook is to improve and integrate pedestrian and bicyclist safety considerations at A.I.I.s through planning, design, and operational treatments that (1) identify and evaluate current practices and emerging technologies and trends, in the United States and internationally; (2) describe current best practices for measuring the effectiveness of such A.I.I. treatments; (3) evaluate the safety and operational outcomes of specific A.I.I. treatments; and (4) identify and rank treatments for typical types of projects. The primary focus of the guidebook is roadway functional classifications of collector and above.

The guide addresses a broad range of issues related to improved safety for people walking or biking at A.I.I.s such as, but not limited to, the following:

1. Describing new and emerging A.I.I. designs [e.g., DDI, DLT or Continuous Flow (CFI) intersections, RCUT intersections, MUT intersections, and other alternative intersections] and evaluating their effects on pedestrians and bicyclists;

2. Documenting, for each A.I.I. type, key considerations such as for crossing, traversing, and wayfinding for people walking and biking, including special consideration for designing for people with disabilities (including those who are visually and/or hearing impaired);
3. Discussing the benefits and tradeoffs of pedestrian and bicycle A.I.I. design and operational treatments with consideration of delay and safety for pedestrians and bicyclists;
4. Developing a performance-based process for practitioners to evaluate pedestrian and bicycle design elements in a two-stage intersection control evaluation (ICE) process; and
5. Providing recommendations for intersection design concepts that focus on people walking and biking, and discussing specific treatments and countermeasures for each A.I.I. form.

Although the guide directly applies to common A.I.I. designs, it also outlines decision-making processes and criteria that can assist agencies in identifying flexible solutions for new or hybrid intersection forms, and conventional intersection forms.

## 1.2 Overview of Alternative Intersections and Interchanges

A.I.I.s are designs conceived to improve operations and safety for motorized traffic by strategically adjusting the geometric features at a location. A.I.I.s work on the general principle of redistributing motor vehicle demand at an intersection to limit the need to add capacity (i.e., adding lanes) to improve traffic flow.

### 1.2.1 Characteristics

Alternative intersections have four key characteristics intended to improve traffic flow and safety:

1. **Use of one-way street elements:** When in a signalized system, one-way streets are simpler to coordinate than two-way streets. In addition, for unsignalized or permissive signalized movements, one-way street elements offer a simpler gap acceptance process for drivers and people walking and biking.
2. **Breaking up a larger intersection/junction into a mini-network of smaller intersections:** A mini-network that is strategically designed can spread out the demand of all movements into potentially optimal locations. Smaller intersections are more likely to reduce the exposure to conflicts and require shorter clearance times and crossing distances for all modes. A smaller intersection footprint with fewer legs generally increases safety and efficiency.
3. **Applying more efficient signal phases (when signalized):** Signal phases can have concurrent phases with higher volume movements that are impossible at a traditional intersection. At many A.I.I.s, there is also a reduction in the total number of phases, which allows a higher percentage of green time for all movements and less clearance time per cycle.
4. **Reducing and spreading out potential conflicts:** By spreading out potential conflicts, a user has fewer conflicts to consider at a particular location. Sometimes, crossing conflict points, including those most likely to be associated with crashes leading to severe injuries or fatalities, are reduced or even eliminated.

For grade-separated junctions, alternative interchanges differ from other interchange forms in that the alternative interchange form incorporates more of the above characteristics than a standard diamond or cloverleaf form. For example, a DDI creates two opposing one-way street elements; the turning movements from the ramps are more spatially separated, creating a mini-network; only two phases are needed at the ramp terminals; and conflict points are reduced and spread out compared to a standard diamond interchange.

### 1.2.2 Potential A.I.I. Benefits

A.I.I.s reconfigure the geometric design of an intersection or interchange to improve operations and safety. This reconfiguration is accomplished by concentrating on redistributing demand to improve traffic flow and minimize or eliminate the need for adding travel lanes. This reconfiguration may result in a significant reduction of costs and right-of-way needs compared to alternatives that can produce similar operational benefits (although some A.I.I.s may require more right-of-way). Therefore, A.I.I.s can often be constructed more quickly than alternative options, such as grade-separated intersections. Exhibit 1-1 conveys the safety, mobility, and value benefits of A.I.I.s.

### 1.2.3 Intersection Forms and Context

Conceptually, a good way to reduce crashes from a simple geometric standpoint is to reduce conflicts and conflict points. Interchanges eliminate some of the most severe conflicts by grade-separating one or more movements. However, interchanges are expensive and not always appropriate or practical, especially for nonmotorized users who may be exposed to high-speed and/or high-volume conflicts with motor vehicles. At-grade A.I.I.s can reduce conflict points at a much lower cost, in a form more appropriate for the context of the location.

A.I.I.s can be applied to various contexts. In rural locations, the major road of an A.I.I. will tend to have high motor vehicle speeds and low volumes of motor vehicles, pedestrians, and bicyclists. In urban locations, A.I.I.s will generally have low speeds and higher volumes of motor vehicles, pedestrians, and bicyclists. In suburban locations, A.I.I.s may often have high speeds and high volumes of motor vehicles.

In some suburban locations that would otherwise represent key active transportation routes or connections, underdeveloped facilities for people walking and biking may suppress demand. Providing safe and comfortable facilities can unlock latent demand and encourage an increase in biking or walking in a community.

Another important context consideration of an A.I.I. is that the intersection can accommodate the crossing of roadways with very different characteristics. As an example, one roadway at an A.I.I. could be a major arterial that forms a critical part of a motor vehicle network, while the intersecting roadway could be a minor collector that forms a critical part of a pedestrian and bicyclist network. Volumes and speeds for each mode could vary greatly between the two roadways, as may the treatments for each mode.

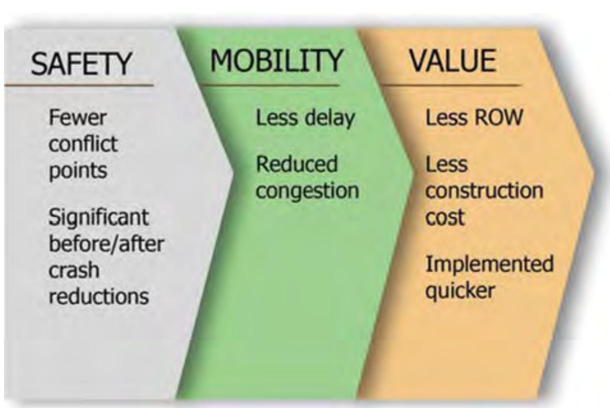


***Exhibit 1-1. Potential A.I.I. benefits.***

### 1.2.4 Pedestrians and Bicyclists at A.I.I.s

Because many A.I.I.s are relatively new concepts developed to address issues for motorized vehicular traffic, the historical focus has been on the details of the geometric design for motor vehicle traffic to facilitate designs that are safe and intuitive for people driving. As a consequence, design for people walking and biking at many existing A.I.I.s has either been an afterthought or been incorporated too late in the design process, meaning insufficient design elements for biking and walking were incorporated into the remaining space within the planned right-of-way. Sometimes, these features have been left out altogether. These projects have resulted in constructed infrastructure that degrades active transportation safety, discourages walking and biking, and can be expensive to retrofit. Exhibit 1-2 shows a version of status quo pedestrian and bicycle facility provisions across the four primary A.I.I. forms discussed in this guidebook. The pedestrian facilities are shown in orange, while bicycle facilities are shown in green. Other examples of pedestrian and bicycle provision at A.I.I.s are included as well as examples of status quo provision at conventional intersection forms. Of note is the DDI walkway, which may be located interior to the crossover portions of the interchange, and the DLT, which is a

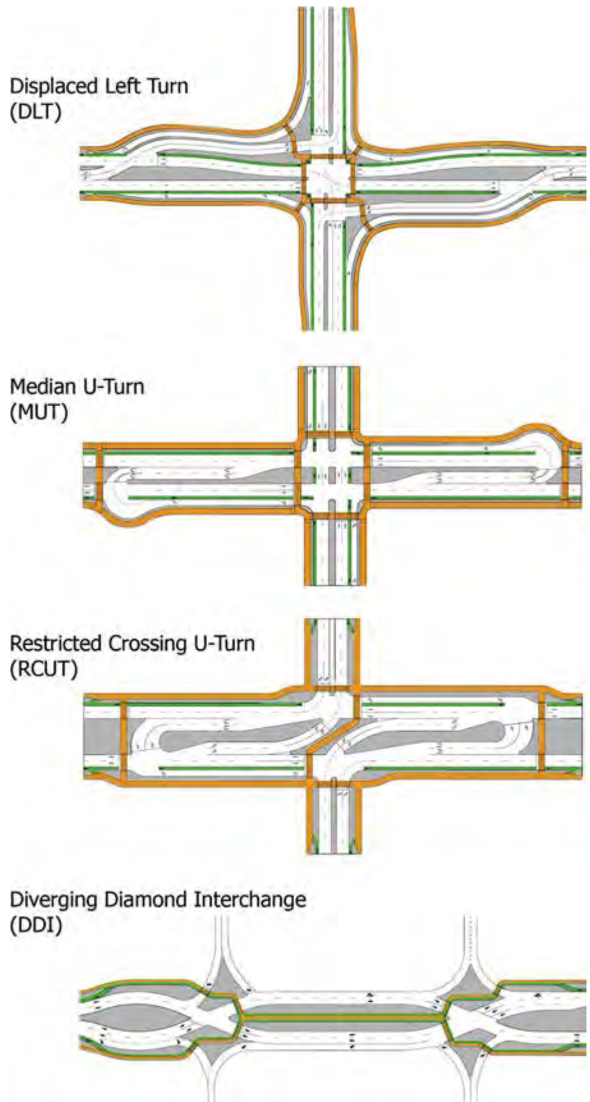


***Exhibit 1-2. "Typical" pedestrian and bicycle provisions at four A.I.I. forms.***

partial DLT as presented (two displaced left-turns) rather than a full DLT (four displaced left-turns). An assessment of pedestrian and bicyclist safety and comfort for these concepts, and additional design concepts, will be introduced later in this guidebook.

Theoretically, the following approaches that benefit vehicular traffic in A.I.I.s should also benefit people walking and biking:

1. **Use one-way street element:** Pedestrians and bicyclists may have fewer conflicts crossing one-way streets versus two-way streets.
2. **Break up a larger intersection/junction into a mini-network of smaller intersections:** A mini-network should provide more opportunities for crossings, and smaller intersections should reduce both exposure and delay.
3. **Apply more efficient signal phases (when signalized):** Signal efficiencies generally reduce pedestrian and bicycle delay more than they do for motorized vehicles.
4. **Reduce and spread out conflicts:** This benefit applies to conflict points between all road users, not just among motor vehicles.
5. **Free up right-of-way availability:** If an A.I.I. can be designed within the reduced right-of-way, the right-of-way footprint should theoretically be available to provide a higher quality facility for people walking and biking, such as wider sidewalks with a street buffer or a separated bike lane.

Although the benefits above are significant, there are substantial challenges to maximizing the potential safety and operational benefits for people walking and biking, including the following:

1. **Out-of-direction travel:** Unless designed per the recommendations in this guidebook, people biking may be redirected alongside vehicles, causing delay and potential for difficult cross-weaving maneuvers into a U-turn lane. Out-of-direction travel also increases travel time.
2. **Channelized movements:** Bicyclists sharing space with motorists in channelized turn lanes or crossover lanes can be a safety concern.
3. **Unconventional paths:** With redirected vehicle movements, the pedestrian walkway may be in unusual, unexpected, or uncomfortable locations.
4. **Multiple crossings:** With staged crossings come multiple conflict points and multiple delay points that can result in complex and long movements through intersections.
5. **Free-flow movements:** Where channelized movements are free-flowing, gap acceptance may be challenging in a motor vehicle traffic stream that is high volume, high speed, or both, resulting in potential safety and delay consequences for people crossing on foot or bike.
6. **Accessibility:** Unusual vehicular travel patterns and pedestrian travel paths can cause severe wayfinding and crossing challenges for pedestrians, especially those with vision disabilities.

In a successful A.I.I. design, the challenges listed here should be recognized and mitigated. The opportunities and challenges of A.I.I.s are summarized in Exhibit 1-3. These design concerns and others are presented and evaluated in Chapter 4. To maximize the safety and operations of design for nonmotorized users, these considerations need to be included in the design process from an early stage, before the intersection type has been selected and before right-of-way has been established or acquired. Nonmotorized safety elements should therefore be considered throughout the design process. Providing safe and comfortable walking and biking facilities at A.I.I.s (or at any intersection or interchange form) may unlock latent demand for these travel modes by making them viable for a larger portion of the population. Providing such facilities in a developing area without a high level of walking or biking activity may position the facilities to provide a key connection if growth occurs or land use changes. This guide explains and illustrates the challenges and design process to provide safe and comfortable facilities for nonmotorized users.

| OPPORTUNITIES | CHALLENGES |
|---|---|
| One-way streets | Out-of-direction travel |
| Break up long crossings | Channelized movements |
| More efficient signal phasing | Unconventional paths |
| Reduced conflicts | Multiple crossings |
| ROW availability | Free-flow movements |
| | Accessibility |

***Exhibit 1-3. Challenges and opportunities for people walking and people biking at A.I.I.s.***

## 1.3 Design and Evaluation Process

The process for design and evaluation in this guidebook is structured to support ICE using a performance-based design approach. This section discusses these two aspects as they relate to pedestrian and bicyclist design at A.I.I.s.

### 1.3.1 Intersection Control Evaluation

ICE policies are encouraged by FHWA (*1*) and are increasingly being adopted by state and local agencies to choose between intersection designs, including roundabouts and A.I.I.s. ICE policies are intended to guide users through sequential steps in conducting the evaluation. Users are encouraged to consider the evaluation context of a project and adapt the ICE framework. This could result in sketch-level evaluations that support quick planning-level decisions early in the design process, while the framework is also set up to provide detailed and robust evaluation activities to address complex projects. ICE is intended to be flexible and adaptive by the user for a project context. ICE activities could be streamlined on some projects; other projects might require analyses that are more extensive. Ultimately, ICE policies are intended to foster thoughtful consideration of alternative intersection and interchange types and to ensure that a holistic, quantitative analysis is completed when selecting an intersection or interchange configuration.

As documented by FHWA, the ICE process typically has two stages: Stage 1, Scoping Analysis, and Stage 2, Alternative Selection. The key features of each evaluation, along with the methods for integrating pedestrians and bicyclists into the process, are presented here. This guidebook is not intended to provide a comprehensive overview of all aspects of the ICE process; further detail can be found elsewhere (*1*).

### 1.3.2 Performance-Based, Context-Sensitive Design

The design and evaluation process that supports an ICE process is a performance-based, context-sensitive process as documented in *NCHRP Report 785*: *Performance-Based Analysis of Geometric Design of Highways and Streets* (*2*). This is illustrated in Exhibit 1-4.

The process centers on identifying intended outcomes (design objectives and principles), establishing geometric design decisions with those objectives in mind (developing the design based on those principles), evaluating how well a design meets those objectives (performance assessment), and iterating as needed to produce the desired design (balance tradeoffs). These tasks are discussed further in these sections.

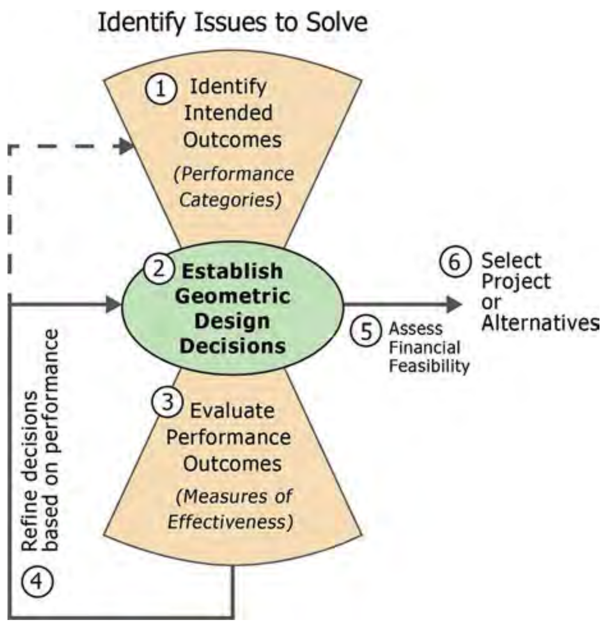


***Exhibit 1-4. Performance-based design process.***
***Source: NCHRP Report 785, Exhibit 1-1 (2).***

### *1.3.2.1 Identify Intended Outcomes*

At ICE Stage 1, the intended outcome for motor vehicle operational performance is usually based on the desired target of capacity, volume-to-capacity ratio, or level of service for motorists. Sometimes, rather than meeting the desired target, the screening process may simply identify those alternatives that get the best performance possible for motorists based on the constraints of the project regarding potential impacts, financial constraints, or other factors. Safety performance for motorists is typically based on whether an alternative improves, or at least maintains, existing safety performance. Existing ICE tools do not include techniques to evaluate pedestrian or bicyclists' operations or safety. The following discussion provides strategies for evaluating pedestrian and bicyclist operations and safety in an ICE process.

For pedestrians and bicyclists in Stage 1, the intended outcome may vary based on context, as shown in Exhibit 1-5. A possible objective for pedestrians and bicyclists may be to ensure all users can complete each origin-destination pattern safely and efficiently (i.e., to serve all users for all movements). The question of facility type selection needs to occur at Stage 1 before the intersection design form has been set and before right-of-way has been established or acquired. Chapter 3 provides specific guidance on bicycle facility selection.

At ICE Stage 2, a more detailed design is completed for a smaller number of alternatives, and as a result, more quantitative and qualitative performance measures can be obtained. For motorists in Stage 2, performance measures include delay and queuing in addition to capacity and volume-to-capacity ratios. Crash data is evaluated on the geometric safety side for all users to help identify more specific causes of crashes so as to reduce the number of crashes. Determination of travel time within an intersection, A.I.I., or system may also be necessary. The need for this will be based on coordination between signals, when necessary, and cycle lengths.

For pedestrians and bicyclists in Stage 2, the assessment process is built around evaluating a set of design flags that address safety, access, operations, and comfort aspects of travel. It may be necessary or desirable to evaluate the operations proposed for each alternative at Stage 2 to understand the potential impacts on travel time and delay for bicyclists and pedestrians operating

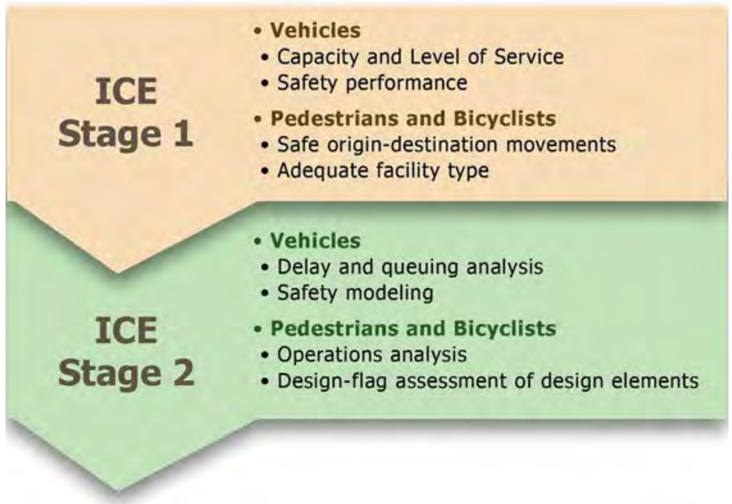


***Exhibit 1-5. Intended outcomes for two-stage ICE process.***

through the intersection more accurately. At Stage 2, the designer may want to evaluate different geometric configurations to determine what is best for safety and operations for all users. For example, changes from an assumption of free-flow movements to controlled movements will have a large effect on the assumed operational efficiency of the movement for each mode and its related impact on safety. An understanding of the implications of geometric and traffic control decisions for each mode is necessary to produce a design that meets the needs of each mode.

#### *1.3.2.2 Establish Geometric Design Decisions*

From the intended outcomes identified in the previous section, the designer can create an initial geometric design for all users. This establishes the number of motor vehicle lanes needed to meet desired operational outcomes. Equally important is for the designer to establish an initial geometry for pedestrians and bicyclists, including the number and location of pedestrian facilities and crossings, and the bicycle facilities (on-street, shared, or separated). Just as there is no "default" lane configuration for a particular intersection, the configuration of pedestrian and bicycle facilities should be specific to the pedestrian and bicyclist access and safety needs. For all modes—motor vehicles, pedestrians, and bicyclists—these initial geometric design decisions are anticipated to be refined as alternatives proceed through the ICE process.

Design objectives and principles are used to achieve the desired outcomes for a design. These design objectives often compete with one another, requiring an evaluation of tradeoffs. Resolving these tradeoffs must be sensitive to the context of the intersection location and the users being served, with careful consideration of the unique vulnerabilities of people walking or bicycling.

AASHTO presents design objectives for intersections in the 2018 edition of its *Policy on Geometric Design of Highways and Streets*. (the "Green Book") (*3*). These design objectives are similar to those presented for roundabouts in *NCHRP Report 672*, which is also based on a context-sensitive, performance-based design process (*4*). The design objectives presented by AASHTO are as follows:

- Reduce vehicle speeds through the intersection;
- Provide the appropriate number of lanes and lane assignment to achieve adequate capacity, lane volume, and lane continuity;
- Provide channelization that operates smoothly, is intuitive to drivers, and results in vehicles naturally using the intended lanes;

- Adequately accommodate the design vehicles;
- Meet the needs of pedestrians and bicyclists; and
- Provide appropriate sight distance and visibility. (*3*, 9-4).

The fifth bullet, "Meet the needs of pedestrians and bicyclists," is the focus of this guidebook and can be expanded into these major objectives:

- Maximize safety
- Provide access to traverse or cross the facility
- Assure accessibility for pedestrians with disabilities
- Manage delay and travel time
- Provide comfort

#### *1.3.2.3 Evaluate Performance Outcomes*

Evaluating performance outcomes uses quantitative and qualitative measures. Performance outcomes for motor vehicles are typically quantifiable using tools based on the *Highway Capacity Manual* (HCM) for operational performance (*5*) and the *Highway Safety Manual* (HSM) for safety performance (*6*). Tools for completing this assessment at a Stage 1-level of detail include FHWA's CAP-X (*7*) and crash modification factors (CMFs) provided in the HSM and FHWA's CMF Clearinghouse (*8*).

For pedestrians and bicyclists, quantitative and qualitative performance measures are available for Stage 1 and Stage 2 evaluations. Chapter 4 of this guide presents these performance measures in an ICE context.

#### *1.3.2.4 Refine Decisions Based on Performance Outcomes*

The performance evaluation may reveal that refinements to an alternative can make it viable enough to be realistically advanced to the next stage. In these cases, the design decisions should be refined and the alternative evaluated to confirm whether it should be carried forward to the next stage.

#### *1.3.2.5 Assess Financial Feasibility*

The designer will need to assess whether this project can move forward, given the likely financial impact considerations. Such analysis is outside the scope of this guidebook.

#### *1.3.2.6 Select Project or Alternative*

For Stage 1, the selection will consist of a few alternatives to be carried forward into Stage 2. For Stage 2, the selection will be of the preferred alternative to be carried forward into the final design.

#### *1.3.2.7 Final Design*

Although not specifically covered in this guidebook, the assessment process should continue in an iterative process through various milestones of the final design process. Certain design flags may develop during the final design process that will need to be addressed.

## 1.4 Organization of Guide

This guide is organized as follows:

- Chapters 2 through 4 present the principles of good pedestrian and bicycle design practice, followed by the means to assess the effectiveness of a design.
  - Chapter 2: "Pedestrians," summarizes pedestrian characteristics and safety considerations with relevance to A.I.I.s.

  - Chapter 3: "Bicycles," summarizes bicyclist characteristics and safety considerations, with added consideration for facility selection based on FHWA guidance.
  - Chapter 4: "Assessment," introduces and discusses the two-stage assessment framework for pedestrian and bicycle safety at A.I.I.s in an ICE context.
- Chapters 5 through 9 provide specific design guidance for four A.I.I. forms: Diverging Diamond Interchanges (DDIs), Displaced Left-Turn (DLT) Intersections, Restricted Crossing U-Turn (RCUT) Intersections, and Median U-Turn (MUT) Intersections, along with more general guidance for other designs. These chapters include presentation and discussion of specific pedestrian and bicycle designs and operational methods unique to each design type.
  - Chapter 5: "Generalized Design Treatments," discusses overarching multimodal design concepts that apply to multiple A.I.I. forms.
  - Chapter 6: "Median U-Turn (MUT) Intersections," presents specific guidance for the MUT intersection form.
  - Chapter 7: "Restricted Crossing U-Turn (RCUT) Intersections," presents specific guidance for the RCUT, or Superstreet, intersection form.
  - Chapter 8: "Displaced Left-Turn (DLT) Intersections," presents specific guidance for the DLT or CFI intersection form.
  - Chapter 9: "Diverging Diamond Interchanges (DDIs)" presents specific guidance for the DDI.

## 1.5 References

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CHAPTER 2

# Pedestrians

Pedestrians should be expected at most A.I.I.s., and the design should integrate their needs, starting at an early concept development stage and continuing throughout the design process. Pedestrians are vulnerable road users; their risk of death in a crash increases significantly with higher vehicle speed (*2*). The design of A.I.I.s should provide for people walking, with consideration of pedestrians of all abilities. The Americans with Disabilities Act (*1*) specifies that if pedestrian facilities are provided, they must serve the need of all pedestrians, including those with disabilities. Understanding the needs and characteristics of the full range of pedestrians is a critical component of developing inclusive designs.

## 2.1 Characteristics of Pedestrians

Design parameters and guidance are set forth by FHWA, AASHTO, the U.S. Access Board, and other entities to construct sidewalks and other pedestrian facilities that serve pedestrians (e.g., *1, 3, 4, 5, 6*). Designers should recognize that people have a wide range of physical, cognitive, and sensory abilities, meaning roadway design should serve the variety of pedestrians that might be present and the different characteristics of those pedestrians. Young adults typically walk at a faster pace than older adults do. Children, young teens, people with disabilities, and elderly individuals may have limitations in their ability to predict the speed of oncoming traffic and detect gaps. Designers should identify all likely users and ensure that all designs meet the needs of these users.

### 2.1.1 Walking Speeds

Most pedestrians walk at speeds between 2.5 ft/s and 6.0 ft/s. A design speed of 3.5 ft/s is typical for calculating signal timing and similar design parameters (*3*). In some locations with higher populations of young children, older adults, people with disabilities, and/or large groups of people walking together, walking design speeds of 3.0 ft/s or lower may be more appropriate (*2*, *3*). FHWA notes that speeds can be higher or lower than these ranges, citing that 15% of older pedestrians were more comfortable at a lower speed of 2.2 ft/s (*7*). Depending on local context (e.g., proximity to schools or hospitals), designers may use values that are lower than the 3.0 ft/s noted above.

### 2.1.2 Spatial Needs

For two people walking side by side or passing each other while traveling in opposite directions, the average space taken up is 4.67 feet (*2*). Wheelchair users typically need at least 5 feet of width to pass each other, and 5.4 feet is appropriate for a walking pedestrian to pass a person pushing a double stroller. Greater sidewalk widths are needed as volumes of pedestrians increase, and pedestrian facilities in urban areas tend to require more space than in lower volume areas. Where vertical objects are present (e.g., building faces, bridge parapets, signposts), pedestrians tend to shy away from these objects to provide space between themselves and the object. This shy distance, which is typically 1 foot or greater, reduces the effective width of pedestrian facilities. Shy distance from vertical surfaces is generally not included in the calculation of pedestrian space (*8*), nor is pedestrian space that may be affected by opening doors from cars or buildings.

### 2.1.3 People with Disabilities

Pedestrians with disabilities, including wheelchair users and pedestrians with vision impairments (e.g., those who are blind), are key design users. According to the 2010 Census, 56.7 million people (18%) in the United States and 52% of Americans age 65 and over reported having a disability. With the aging of the population, these proportions are expected to increase, and designs to serve these users should be a key focus. The range of different pedestrian disabilities has practical implications for the design of sidewalk widths, grades, cross slopes, refuge island widths, pushbutton placement, accessible signals, and curb ramps to comply with requirements set forth by the Americans with Disabilities Act (ADA).

The regulations implemented with the ADA of 1990 (*1*) require newly constructed facilities to be "accessible to and usable by" individuals with disabilities [Sections 28 CFR 35.151(a)(1) and (b)(1)]. The Department of Justice published the *2010 ADA Standards for Accessible Design* (*9*) to set minimum requirements for state and local government facilities, public accommodations, and commercial facilities. These regulations addressed only some aspects of projects in the public rights-of-way. The proposed regulations for addressing public rights-of-way, *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way* [proposed Public Rights-of-Way Accessibility Guidelines (PROWAG)] was published in the *Federal Register* in 2011, but, as of this writing, has not been adopted as a final rule. However, the proposed PROWAG is recognized by FHWA (*10*) as the best practice for the design of ADA-compliant pedestrian facilities in public rights-of-way. The guidance of these proposed rules is generally considered minimum needs for access.

A pedestrian access route within the sidewalk must be at least 4 feet wide, firm, stable, slip-resistant, and free of surface discontinuities, with no more than 2% cross slope (the slope perpendicular to the direction of travel). Passing spaces at least 5 feet wide are required every 200 feet. The proposed PROWAG allows sidewalk grade within the right-of-way to be the same as or less than the grade of the adjacent roadway. A maximum running grade of 5% is required for shared-use paths if constructed on a separate alignment from a roadway. Curb ramps must be provided where the sidewalk or shared-use path crosses a curb. The proposed PROWAG provides specifications for perpendicular curb ramps, parallel curb ramps, and blended transitions. Detectable warning surfaces (truncated domes) are required on curb ramps or blended transitions to alert blind pedestrians to the location of the street.

The proposed PROWAG also requires accessible pedestrian signals (APS). The *Manual on Uniform Traffic Control Devices* (MUTCD) provides standards for APS that include audible and vibrotactile indications of the walk interval, pushbutton locator tones, tactile arrows, and automatic volume adjustment (*3*). Guidance is also provided to identify the specific location of APS devices associated with the crosswalks they serve.

The proposed PROWAG contains other information on sign mounting height and legibility, maintenance of accessible features, and maintenance of the pedestrian access route during construction activities.

When designing for people with disabilities, it is important to design not just for the minimum requirements, but with consideration for the needs of all other users of the facility and their relative volumes. For example, while the minimum curb ramp width to meet accessibility requirements is 48 inches in proposed PROWAG, that width cannot accommodate large groups of people walking or accommodate bicyclists operating on a shared-use path. Wider curb ramps may often be necessary or appropriate.

#### *2.1.3.1 People with Mobility Disabilities*

People with mobility disabilities may include those using wheelchairs, scooters, support canes, crutches, walkers, and prostheses. For these users, surfaces need to be smooth, stable, and slip-resistant, and there should be adequate room to maneuver. Curb ramps are required where a pedestrian access route crosses a curb. Maximum running slopes for ramps, street crossings, and the sidewalk or shared-use path area are specified in ADA requirements. Cross slopes steeper than 2% along any point of the pedestrian access route can also be a significant problem for individuals using mobility aids when traveling on the sidewalk or negotiating curb ramps. Grates or cracks wide enough to catch the tip of a cane or the front casters of wheelchairs limit the usefulness of a facility. These features must be carefully considered in the design, construction, and maintenance of crossings, refuge islands, and travel paths through all intersections, including A.I.I.s.

#### *2.1.3.2 People with Vision Disabilities*

People with vision disabilities often travel independently and must walk or use transit during their travels. Many people who are blind or who have low vision use a white cane, dog guide, or other mobility aid; however, many who are legally blind may not use any aid that identifies them as blind. Elderly pedestrians with macular degeneration may not see details in a way that allows them to read signs, recognize faces, or see pedestrian signals, but may nonetheless travel without using any type of mobility aid. Warning surfaces, such as truncated dome detectable warnings, must be detectable underfoot, and with a white cane.

Although a white cane or dog guide may be used to identify streets or obstacles in their paths, individuals who are blind or who have low vision use their hearing and other senses to maintain their orientation and travel efficiently to their destinations. These individuals will not already be oriented to each intersection location or area where they may travel. Just like sighted pedestrians or drivers, they may get directions to a new location and travel there, figuring it out as they go. They may use accessible mapping or transit direction-type programs, if available, to gain information about their route, but details regarding signals or intersection configurations are usually determined by listening to traffic movement.

Varying colors, materials, and textures are sometimes used in the sidewalk environment and, if used consistently, may provide useful information for individuals with vision disabilities. However, decorative changes in texture or pavement across a sidewalk may be mistaken for level changes by individuals with low vision, and the texture change may be confusing for a person who is blind.

Individuals who use a white cane when traveling may use varying techniques in different settings. In outdoor travel on a sidewalk, the white cane is typically used in an arcing, tapping motion close to the sidewalk surface to detect changes in elevation or obstacles in the path.

A small proportion of the population of individuals who are blind or who have low vision uses dog guides. Dog guides operate in response to commands from their handlers, who use voice commands, hand motions, or both. Handlers who are blind typically walk on the right side of the dog, and dog guides often walk near the left edge of the sidewalk. The dog guide stops to indicate drop-offs (e.g., curbs or stairs) and waits for a command from the handler. Dog guides do not use traffic signals or decide about street crossings. They usually stay within the sidewalk area but can be confused by wide plaza areas or skewed crossings.

More information about wayfinding and street crossing techniques is provided in Section 2.3.

#### *2.1.3.3 People with Cognitive Disabilities*

Cognitive disabilities can hinder the ability to perceive, recognize, understand, interpret, and respond to information. The skills of people with cognitive disabilities vary widely, but they may have difficulty navigating intersections with complex configurations, signals, and signs. Designs that accommodate individuals with cognitive disabilities may also benefit adults who do not read English. Signs that use pictures, universal symbols, and colors can convey meaning to a range of individuals, but the symbols and colors should be consistent to improve comprehension.

#### *2.1.3.4 People with Hearing Disabilities*

Hearing loss may limit pedestrians' ability to use cues, such as the sound of approaching vehicles. This condition can be exacerbated where there are limited sight lines or complicated traffic patterns. It is unclear how this complication may affect the ability to recognize and detect traffic in conditions where traffic patterns are atypical. Providing additional visual cues and designing the angle at which a pedestrian crossing intersects traffic close to 90 degrees may help mitigate the absence of expected auditory cues.

### 2.1.4 The Walking Experience

The experience of an A.I.I. for people walking will vary depending on the intersection. In some A.I.I. designs, a pedestrian may not perceive significant differences when crossing compared to doing so at a "traditional" intersection. In more complex intersection designs, the intersection may present subtle differences or more complex challenges to creating a safe and comfortable pedestrian experience, and these challenges should be anticipated and mitigated through design.

For any A.I.I. design, there will be challenges to overcome in design, and opportunities to optimize the safety and operations for pedestrians through the intersections, as discussed in Chapter 1. Sometimes, the pedestrian experience through an A.I.I. can be safer and better operationally than a traditional intersection for some movements.

This guidebook is structured to help the reader recognize the challenges associated with designing for pedestrians in A.I.I.s and how these challenges may be addressed.

The AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (*2*) assesses the decision to walk and the associated experience according to these key factors:

- **Distance and densities.** The length of a trip greatly influences the decision to walk. Most walking trips are 1 mile or less, and community structures with higher densities of destinations and mixed land uses encourage walking trips. The design of A.I.I.s should include pedestrian design features in nearly any land use context. For A.I.I.s in areas with destinations near together and distributed on more than one quadrant of the intersection, the likelihood of people walking within the A.I.I. could be common and should be anticipated.
- **Route directness.** Depending on the A.I.I., the pedestrian route through the intersection may not be as direct as in traditional intersections. Pedestrians value the directness of a walking route and are discouraged when forced to travel circuitous paths that take them out of their way. Where A.I.I.s require pedestrian routing that is indirect or nonintuitive, the designer should minimize the distance that pedestrians must divert from a direct path between points.

- **Personal safety and security.** Many elements that the AASHTO *Pedestrian Guide* (*1*) notes as detrimental to a pedestrian's sense of personal safety and security may be present at A.I.I.s, as with any intersection. Such elements include fast-turning motorists, long crossing distances, and long block lengths. Some of these factors can be mitigated in A.I.I.s through attentive design, including constructing raised median refuges and implementing prohibitions against motorist turns across the crosswalk during the Walk interval. Other treatments that can enhance personal safety and security in A.I.I.s include pedestrian-scale lighting, railings, wider walkways, and increased separation or using physical barriers to motor vehicle traffic. Designs that improve personal safety and security can promote walking and bicycling activity throughout the day.
- **Personal comfort and attractiveness.** Pedestrians are naturally more engaged with their surroundings than motorists are because pedestrians are moving more slowly through the roadway environment. Within an A.I.I., the presence of shade, artistic or visually interesting design treatments, and separation from motor vehicle traffic can all enhance the comfort and appeal of walking.

Besides the aspects identified by AASHTO, travel time is an important factor in pedestrian activity. Travel time is the time to traverse the intersection, accounting for the length of the pedestrian route and walking speed, and delays incurred along the route. These delays may be created by multistage crossings, long cycle lengths at signalized locations, insufficient traffic gaps, or failure of motorists to yield at uncontrolled crossings. Pedestrian travel time through intersections and between destinations should account for the time in motion and the delay when stopped.

### 2.1.5 Safety

Pedestrian safety can generally be viewed considering three tasks that must be completed by a pedestrian: traversing, wayfinding, and crossing as shown in Exhibit 2-1. These are described in the following sections. All three tasks can cause safety concerns, and all three can be mitigated through proper design techniques and using countermeasures, as needed.

One of the key factors in pedestrian safety is vehicular travel speed, with higher speeds linked to a higher risk of injury or death to pedestrians if a collision occurs (*2*). Research has further shown that motorist yielding behavior at uncontrolled crossings declines with higher speeds

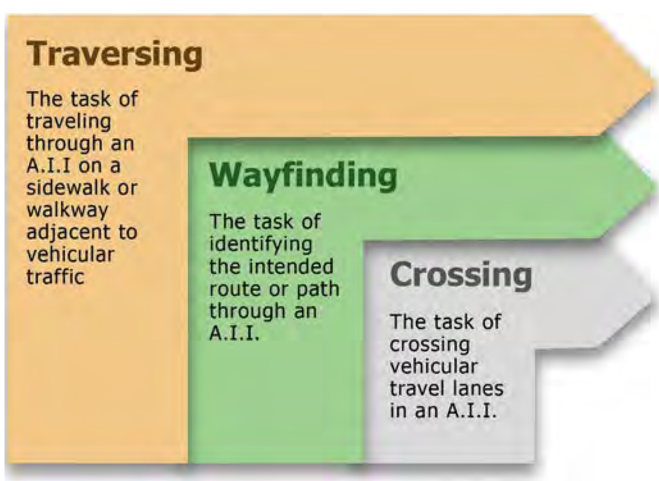


***Exhibit 2-1. Three components of pedestrian travel at A.I.I.s.***

and multiple lanes of traffic (Exhibit 2-2) (*11*, *12*). The overall design of the A.I.I. should consider alignments to maximize the comfort of nonmotorized users by creating a geometry that

- Eliminates multiple-threat conditions;
- Minimizes the need for uncontrolled movements across crosswalks and bicyclist crossings, particularly in high-speed and/or high-volume conditions;
- Reduces motorist speeds at uncontrolled crossings; and
- Provides lateral space between travel lanes and nonmotorized facilities by establishing buffer zones and/or widening sidewalks and sidepaths.

Pedestrian safety is particularly important in nighttime conditions when visibility is limited. In 2017, the National Highway Traffic Safety Administration (NHTSA) reported that 74% of all pedestrian fatalities happened at night (*13*). Proper lighting of the overall A.I.I., with supplemental lighting at any crossing point, is needed to enhance pedestrian visibility to drivers.

An important design factor for street crossings is providing sufficient sight distance for pedestrians and motorists to view each other clearly on the approaches to any conflict points. Both parties should be able to perceive and react to a potential conflict, and motorists should be able to come to a full stop before conflicting with a pedestrian. This sight distance, which is needed at both uncontrolled and controlled crossings and relates to multiple-threat conditions, is discussed in Chapter 5. The design should provide adequate approach clear space before crossings

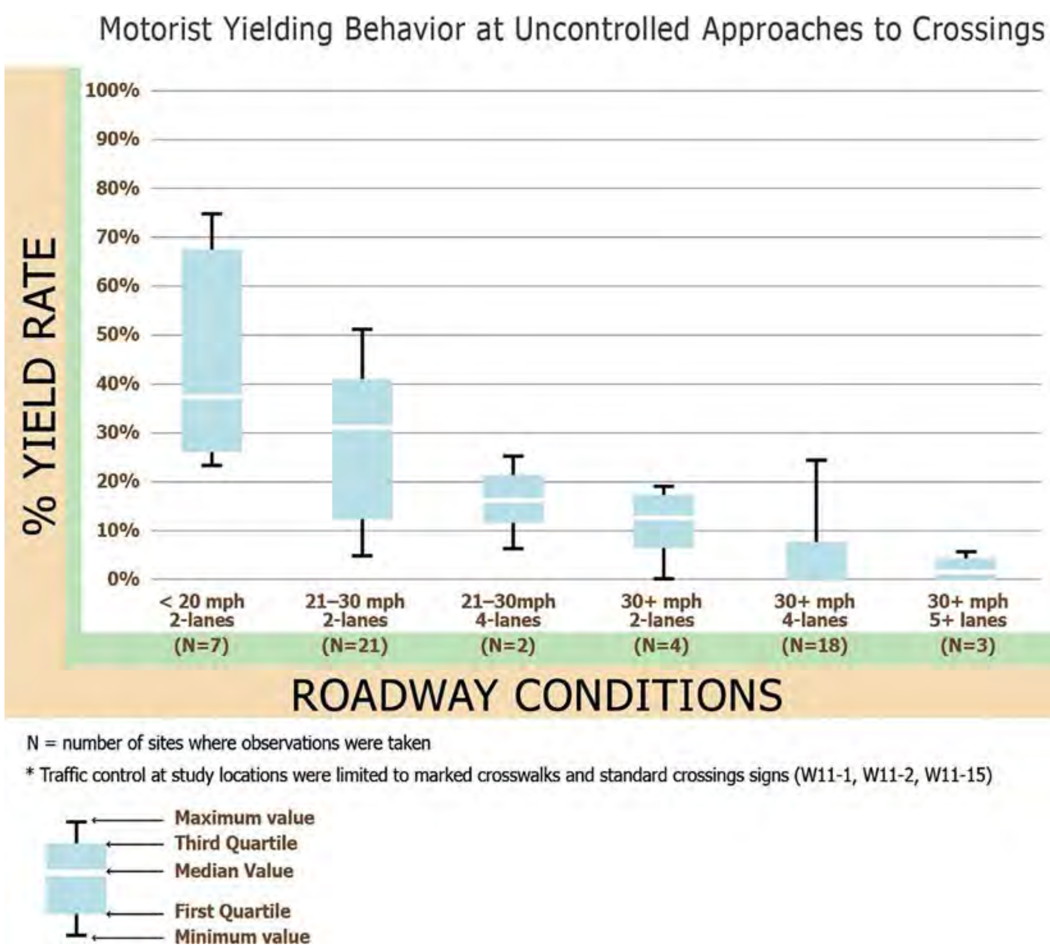


***Exhibit 2-2. Motorist yielding behavior at uncontrolled crossings. Source: (11, 12).***

by eliminating tall and opaque roadside elements that could limit visibility between motorists and vulnerable users approaching the crossing.

At uncontrolled crossings, the ability to identify appropriate gaps in traffic is critical for pedestrians. At controlled crossings, sight distance is critical when there are potential conflicts, such as permissive right-turns-on-red and concurrent pedestrian and motorist signal phases that could lead to turning conflicts with pedestrians.

## 2.2 Traversing

When designing for pedestrians within an intersection, the designer should seek configurations that minimize out-of-direction travel and the number of crossings to be traversed in balance with the many other objectives the intersection form seeks to address. Large, complex intersections are often perceived by pedestrians as barriers to travel, and routes that include significant out-of-direction travel can further exacerbate this perception. Exhibit 2-3 shows the out-of-direction travel encountered when traversing an RCUT intersection. Each location where pedestrians must cross a motor vehicle path presents a potential risk, and these crossings should be minimized and appropriately designed to manage that risk. It may be necessary, often, to balance pedestrian route length with the number of crossings to maintain a tolerable pedestrian environment within the intersection. Additionally, pedestrian comfort and perceptions of safety are affected by their proximity to traffic, so adequate street buffers should be incorporated into the design to increase the pedestrian distance from moving vehicles. Chapter 4 includes more details on these design details and their evaluation.

## 2.3 Wayfinding

Wayfinding refers to the process by which a pedestrian navigates an intersection. Exhibit 2-4 shows wayfinding at a DDI. At A.I.I.s, vehicular, pedestrian, and bicycle paths that differ from simple intersections may make wayfinding more challenging. Wayfinding can be more complicated for blind pedestrians than for sighted pedestrians due to the inability to detect visual cues available to sighted pedestrians.

*NCHRP Research Report 834* provides detailed information derived from research at roundabouts and channelized turn lanes regarding wayfinding and crossing problems and solutions

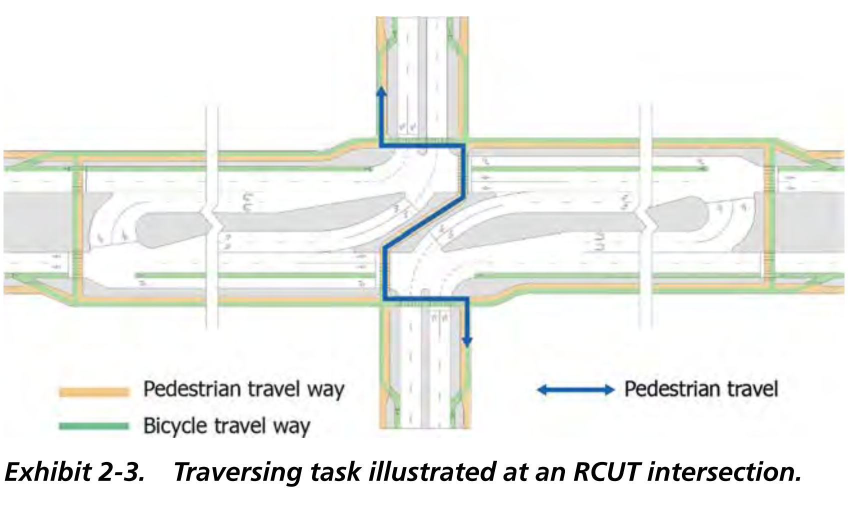


***Exhibit 2-3. Traversing task illustrated at an RCUT intersection.***

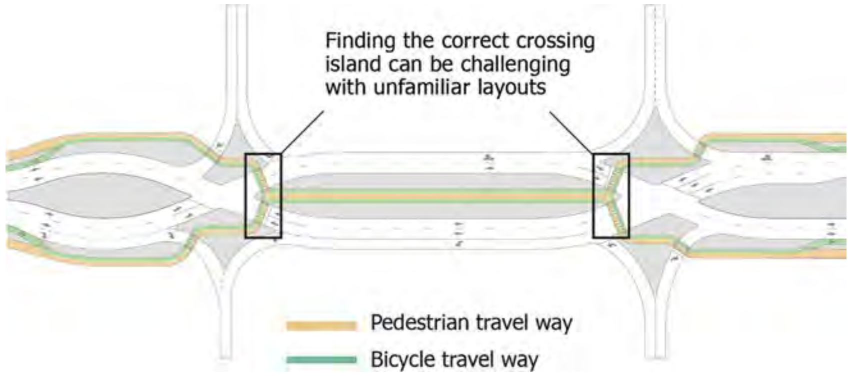


***Exhibit 2-4. Wayfinding task illustrated at a DDI.***

for pedestrians with vision disabilities (*14*). Many of the same issues may be present at A.I.I.s, and Sections 2.3 through 2.4 of this report are derived from the information in *NCHRP Research Report 834*.

Given their experience and familiarity with conventional intersections, pedestrians are accustomed to walking in a generally direct path between contiguous quadrants of an intersection. In some A.I.I.s, however, the pedestrian route with the fewest conflicts or shortest travel time may not be the most obvious, and a pedestrian expecting a straight path between intersection quadrants may need to travel out-of-direction for some part of the trip. Out-of-direction travel for pedestrians should be minimized in any design. Where it cannot be eliminated, the designer may need to incorporate guidance to show pedestrians how to reach their destination.

For very large A.I.I.s, it may be useful to follow the principles of the wayfinding process that help people spatially orient themselves: orientation, route decision, route monitoring, and destination recognition (*15*). Traditional wayfinding signage facilitates this process by providing sign assemblies for routing decisions, routing confirmation, and turns needed for specific destinations (*3*, *5*).

Additional design considerations to ease pedestrian travel through a complex walking environment may include

- Providing high-visibility crosswalks, including preservation of the visibility of the crosswalk and other pavement markings through routine maintenance;
- Locating pedestrian pushbuttons in accessible locations near the crossing and placed on the side of the pole where pedestrians will approach the pushbutton;
- Where staged crossings are needed, installing pedestrian pushbuttons at intermediate dwelling locations to avoid trapping pedestrians on median islands or other mid crossing locations;
- Providing accessible signals for people with vision disabilities to help with orientation to preferred crossing locations;
- Providing lighting along the preferred walking route;
- Providing wayfinding kiosks to illustrate the preferred routes for pedestrians using both visual and tactile methods on the kiosk display; and
- Providing pavement markings for pedestrians to indicate from which direction traffic is coming (see Chapter 9, Section 9.5).

### 2.3.1 Determining the Appropriate Crossing Location

Pedestrians who are blind and approaching an intersecting street intending to cross and continue in their direction of travel often assume that they are within the width of the crosswalk as they approach and that the crosswalk will continue across the street in the same direction they have been traveling. They may also assume that vehicles idling on the street they want to cross are stopped at a stop line parallel to the direction of the crosswalk.

The typical techniques used by a blind pedestrian intending to continue in their direction of travel is to stop when they reach a curb or a location that seems to be a curb ramp, check features with their cane, and listen to traffic. Pedestrians then cross from that location if they believe motorists have stopped or are yielding to them. This set of techniques may not be effective at finding a crosswalk at many A.I.I.s.

If there is a landscaped, unwalkable, or otherwise detectable edge as a traveler approaches the intersection, a blind pedestrian may follow (i.e., trail) along that edge, looking for the intersecting sidewalk or curb ramp. If there is not a detectable edge, some individuals may follow the curb while using their canes, looking for a sloped area that may be a curb ramp, or for a detectable warning surface. Some dog guide users may seek a detectable warning surface with their feet if they are uncertain about the location of a crosswalk. However, some individuals will cross from the point at which they contact a curb, not wanting to risk becoming disoriented while looking for a curb ramp.

### 2.3.2 Aligning to Cross

Blind pedestrians typically use two primary strategies to align when preparing to cross at a typical intersection. To establish a heading to the desired location on the opposite side of the street, travelers often assume they will be continuing to travel in the same direction as they were traveling when they approached the intersection. The first strategy is to use auditory and tactile cues to maintain that line of travel. The second strategy is to align with the sound of traffic proceeding straight ahead on the street parallel to the travel direction (*16*, *17*, *18*) and/or to square off (i.e., directly face the loudest point) of traffic moving perpendicular to their path.

When traffic is flowing on the street adjacent to them as they cross, it is then assumed to be flowing in the same direction as the crosswalk (i.e., parallel), helping with both initial alignment and maintaining alignment during crossing. This is an effective strategy at intersections with traditional geometry, because the traffic *is* normally moving parallel to the crosswalk. However, in some A.I.I.s, the crosswalk may not lie straight ahead in alignment with the sidewalk as one approaches an intersection. Depending on the location of the crosswalk and the geometry of the intersection:

- Traffic direction may not give adequate auditory cues to the orientation of the crosswalk.
- Traffic movement may not coincide with a safe pedestrian crossing opportunity.
- Traffic may not be traveling perpendicular to the crosswalk.
- Traffic may be moving on both sides of the crosswalk nearby.
- Traffic may be flowing in an unexpected counterflow direction adjacent to the crosswalk.

These conditions may confuse a person with vision disabilities attempting to cross the roadway.

Absent traffic traveling parallel to their crossing direction, individuals who are blind may attempt to align with (or square off with) the traffic traveling across the crosswalk perpendicular to their travel path. The success of this strategy depends on the angle and location of the crosswalk in relation to the traffic movement. Pedestrians who are blind may also judge alignment based on the street gutter and align themselves so they are perpendicular to the gutter or the curb line on each side of the ramp.

To offset the potential routing challenges a person with vision disabilities may encounter moving through an A.I.I., it is important to provide curb ramp designs that help a person orient to the desired crossing and to install APS where signalization is provided.

Curb ramps should slope and align in the direction of travel to the associated crosswalk to serve as a wayfinding aid for pedestrians who are blind. Curb ramps should serve a single direction of pedestrian travel (i.e., directional curb ramps), rather than serving two diverging crosswalks via a diagonal curb ramp. Diagonal curb ramps require people in wheelchairs to enter the street at an angle and then turn in their desired direction (*6*). They also do not direct people with vision disabilities into the correct crossing.

Detectable warning surfaces, used to indicate where a pedestrian is crossing from the sidewalk into the roadway, are not intended as an alignment cue, and neither pattern nor the edge of the detectable warning results in accurate alignment for crossing (*19*). Therefore, although they may affect alignment, neither the slope of curb ramps nor how truncated dome detectable warnings are installed are usually considered reliable sources of information for aligning to cross. Despite this unreliability, many blind pedestrians attempt to use a combination of the slope of the curb ramp, the gutter of the street, and the detectable warning surface as additional alignment information. While this is a strategy that may work for some blind pedestrians absent other cues, it is not recommended as a design strategy for A.I.I.s.

### 2.3.3 Maintaining Correct Heading while Crossing

The act of maintaining correct heading while crossing is a wayfinding task distinct from the act of determining when to cross and complete the crossing. The primary strategy used by pedestrians who are blind to maintain their heading and travel straight across crosswalks at signalized and stop-controlled intersections is to travel parallel to straight-ahead traffic on the street beside them as they cross (*20*, *21*). This strategy is not useful at A.I.I. crossings where traffic may not be moving straight ahead, parallel to the crosswalk. Where there are channelized lanes, this strategy may work for the main part of the intersection, but not at the channelized lane crossing. At shorter crossings, the need for additional information while crossing is mitigated by the shorter distance. As long as individuals are properly aligned to begin the crossing, they will usually complete the crossing within the crosswalk if there are only one or two lanes. The likelihood of veering out of the crosswalk increases with crosswalk length.

An accessible pedestrian signal or other treatment with an audible message, if present, may serve as a far-side audible beacon to help with maintaining heading.

## 2.4 Crossing

The crossing task consists of determining when to enter a crosswalk and then completing the crossing—an action distinct from wayfinding tasks of maintaining alignment while crossing. Exhibit 2-5 shows crossing at a DLT intersection. A crossing opportunity generally exists when either a sufficient gap exists between conflicting vehicles or a driver yields. In addition, these opportunities can be enhanced with traffic control devices that assist in assigning right-of-way (e.g., pedestrian signals). Most A.I.I.s feature a combination of signalized crossings (typically at the main intersection) and uncontrolled crossings (typically across channelized lanes, but sometimes across the major legs). Crossing type, crossing length, and vehicle speeds are key factors in the safety of a crossing and become key variables in the assessment framework discussed in Chapter 4 of this guidebook.

### 2.4.1 Street Crossings for Pedestrians Who Are Blind

Like wayfinding, this task can be more challenging for pedestrians with limited vision than for pedestrians with full vision. At A.I.I.s, unexpected vehicular movements can present unique

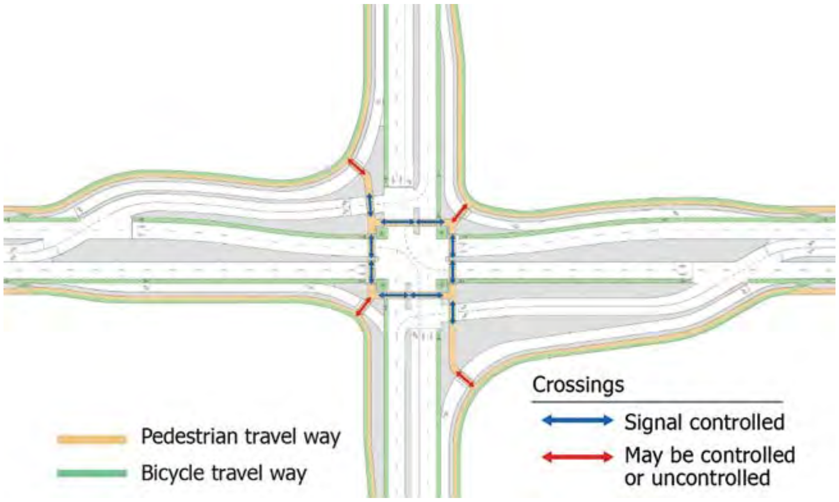


***Exhibit 2-5. Crossing task illustrated at DLT intersection.***

challenges to pedestrians. The potential for vehicles to be approaching from an atypical direction can be confusing. In the United States, pedestrians are taught from an early age to look left, look right, look left, and then cross. There is the possibility in an A.I.I. that traffic may not come from a "typical" direction, which may cause confusion (particularly for those with cognitive disabilities) or cause a person to miss detecting close approaching vehicles. Some DDIs, for example, have used "LOOK RIGHT" pavement markings (particularly at unsignalized crossings) to inform pedestrians about traffic movements and where to look for approaching traffic. The same information needs to be communicated to pedestrians who are blind, which may require the use of audible devices with custom speech messages.

At signalized crossings of typical orthogonal intersections, pedestrians who are blind or have low vision typically listen to the movement of traffic, along with APS, if present, to determine when to cross. Stopping traffic on the cross street, combined with the surge of traffic on the street parallel to the crosswalk, can provide a relatively strong confirmation of APS information and cues to the signal changes.

At unsignalized crossings, the pedestrian who is blind has two types of crossing opportunities: (1) when there is a gap in traffic such that no approaching vehicle can reach the crosswalk before the crossing is completed, or (2) when vehicles have yielded (*19*). The yield crossing can be in the form of a voluntary yield maneuver by drivers or may involve crossing in front of the vehicle(s) that have stopped or are stopping just upstream of the crosswalk for other reasons (e.g., queuing). When crossings are at high-speed locations, drivers are less likely to yield to a pedestrian preparing to cross. For those who are totally blind, these decisions must be made using sound cues alone. Individuals with low vision may be able to visually observe vehicles stopping or visually detect a gap in traffic within certain distances or locations in relation to the crosswalk.

## 2.5 Design Principles for Pedestrian Facilities

This section summarizes the key design principles for designing for pedestrians at an A.I.I. These principles should be considered in balance with the needs for other modes, recognizing that tradeoffs will likely be needed for a given context and constraint. There will be cases where A.I.I.s are proposed for very constrained areas, and these constraints may be used to justify reductions or elimination of elements for pedestrian safety and/or comfort unnecessarily. Three primary categories of design principles for pedestrian facilities are discussed below:

- Pedestrian Routing and Delay
- Minimizing Conflicts with Motor Vehicles
- Minimizing Conflicts with Bicycles

Efforts should be made to include as many positive pedestrian features as possible in the given context and constraints. Sometimes, a different intersection form may provide a better balance of these tradeoffs.

### 2.5.1 Pedestrian Routing and Delay

The design principles associated with best practices for pedestrian routing and minimizing delay are as follows:

- Provide a highly visible and coherent route;
- Consider pedestrian desire lines and reducing out-of-direction travel;
- Minimize grade changes (unless grade separation is provided);
- Minimize the use of multistage crossings unless a multistage crossing can reduce delay or eliminate crossings of high-volume, free-flow ramps; and
- Minimize pedestrian exposure to high-speed and/or high-volume traffic movements.

Exhibit 2-6 shows "pedestrian routing and delay" principles at an RCUT intersection.

### 2.5.2 Minimizing Conflicts with Motor Vehicles

Design principles associated with best practices for minimizing conflicts between pedestrians and motorists are as follows:

- Maximize visibility between pedestrians and motorists, by providing
  - Pedestrian crossings in conspicuous locations where there are clear sightlines between motorists and pedestrians.
  - Pedestrian crossings as perpendicular to conflicting motorists as possible.
  - Adequate lighting at the crossing locations.
- Reduce motor vehicle speeds at conflict areas with uncontrolled or concurrent motor vehicle movements by
  - Limiting motor vehicle speeds to 20 mph or less where a pedestrian and motorist path cross.
  - Minimizing or avoiding the use of high-speed merging lanes and free-flow traffic movements.

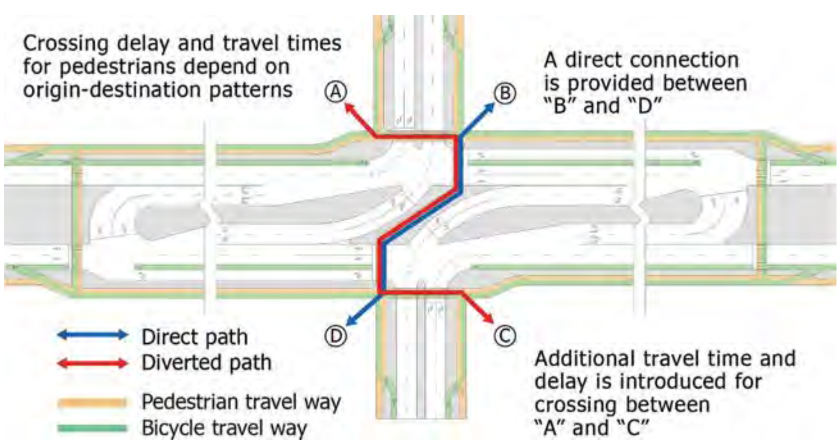


*Exhibit 2-6. Pedestrian routing and delay principles.*

- Minimizing corner radii to slow turning speeds.
- Using traffic calming measures such as raised crossings.

- Minimize the severity of conflicts where they cannot be eliminated by
  - Separating movements in time using traffic controls.
  - Separating movements in space using geometry.
  - Minimizing exposure to conflicts with motorists by providing short crossing distances.
  - Minimizing the speed of vehicles at conflict points.
- Provide adequate signal timing for pedestrians to clear crossings before permitting conflicting movements to proceed (i.e., by providing pedestrian lead, lag, or exclusive phases when appropriate).

Exhibit 2-7 shows "minimize conflicts with motor vehicles" principles at a DDI with controlled turns from the off-ramp.

### 2.5.3 Minimizing Conflicts with Bicyclists

Design principles associated with best practices for minimizing conflicts between bicyclists and pedestrians are as follows:

- Maximize visibility between bicyclists and pedestrians.
- Provide separated bike lanes at locations with higher volumes of bicyclists or pedestrians where bicyclists are likely to operate on a sidewalk due to traffic speeds over 30 mph or traffic volumes over 6,000 vehicles/day on the roadway.
- Where separated bike lanes are provided, continue to separate bicyclists and pedestrians at crossings.
- Ensure shared-use paths are wide enough to service anticipated volumes while minimizing conflicts (understanding that, even in low-volume locations, people will walk or bicycle side by side when traveling in groups).
- Provide wide curb ramps that match the full width of shared-use paths.

Exhibit 2-8 shows "minimize conflicts with bicyclists" principles at a DDI.

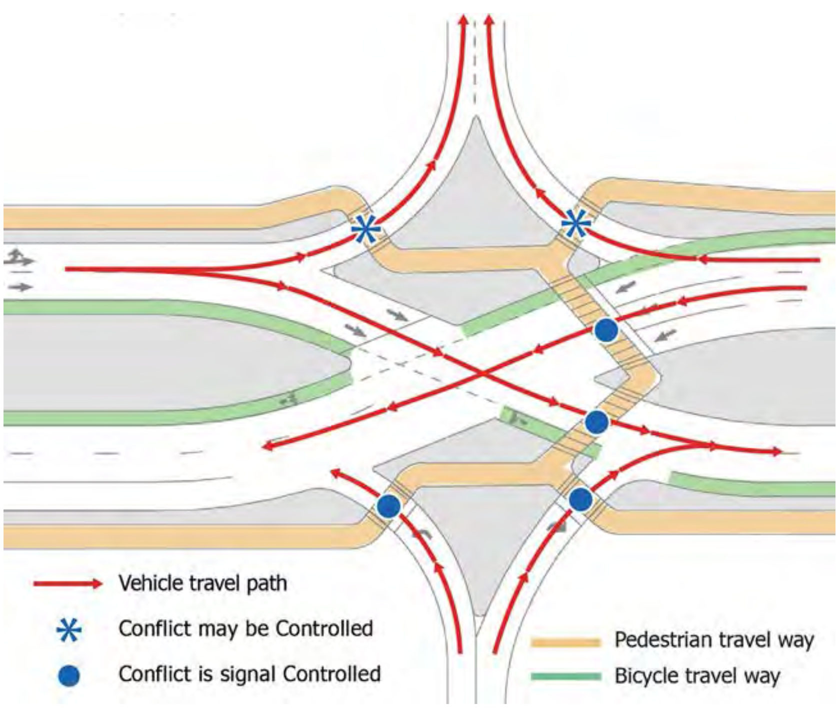


***Exhibit 2-7. Minimize conflicts with motor vehicles principles.***

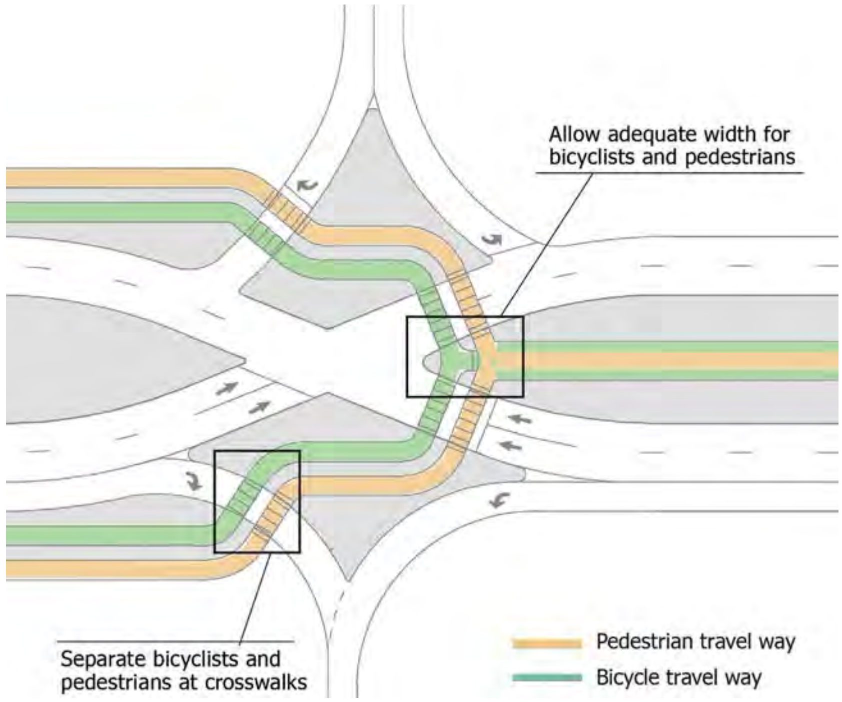


***Exhibit 2-8. Minimize conflicts with bicyclists' principles.***

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CHAPTER 3

# Bicycles

Bicycles are used for commuting, accessing transit, traveling to the store and to visit friends, recreation, and exercise. Although highly confident bicyclists may be comfortable riding with motor vehicles in large or complex intersections, including A.I.I.s, many bicyclists will view these intersections as barriers to mobility if such intersections have not been designed to facilitate bicycle travel. The potentially large intersection footprint, the complexity of vehicle (and bicycle) movements, and potentially high vehicular traffic speeds and volumes prevalent in these intersections can present significant challenges to people cycling. The design of A.I.I.s should consider the needs of bicyclists traversing the intersection, as well as wayfinding and crossing concerns—especially when bicyclists use a separate path. Design decisions for bikeway types and crossing treatments should prioritize safety while considering the demographics and abilities of people likely to ride within the A.I.I.

A.I.I.s should be designed to be as nonthreatening as possible to vulnerable road users. Bicycle facility design techniques in these settings should provide adequate bikeway width and separation from motor vehicle traffic while minimizing exposure to conflicts and high-speed vehicles. Depending on the context, full separation may not be necessary or feasible, but the selection of bicycle facility type should be considered in the early stages of an A.I.I. design. Facility selection is explored in Section 3.3.5.

## 3.1 Characteristics of Bicyclists

Given their exposure, bicyclists are at risk of severe injury in even minor crashes with motor vehicles. This vulnerability has proven to affect perceptions of traffic danger, which greatly influence whether people bicycle, where they bicycle, and how they operate their bicycles.

As bicycling becomes more popular, communities are seeking to encourage more people to choose bicycles as a mode of transportation. Perceptions of traffic danger influence bicyclist tolerance for traffic stress, as well as comfort when riding with or near motor vehicle traffic. Most people prefer to ride bicycles in space dedicated to that purpose, separated from and with as few interactions with motor vehicles as possible.

Bicyclists also differ in their confidence levels and riding abilities. People who ride bicycles can be categorized into one of three groups based on their confidence (*1*); these categories are illustrated in Exhibit 3-1. The categories are useful for anticipating the design needs of the expected bikeway user within an A.I.I. and are as follows.

- **Highly Confident Bicyclists.** The smallest proportion of bicyclists, these riders have a high tolerance for traffic stress and prefer direct routes, even if it requires mixing with motor vehicle traffic. Although they also enjoy separated bike facilities, they may avoid bikeways they perceive to be less safe, too circuitous, or too congested with other bicyclists and/or pedestrians.

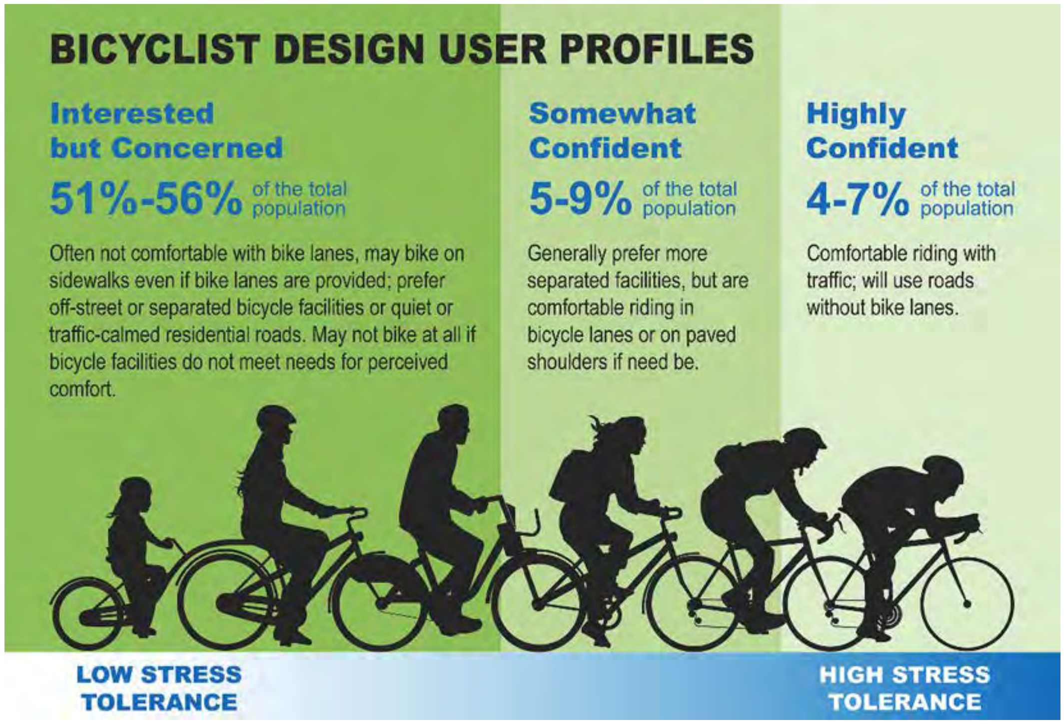



***Exhibit 3-1. Bicyclist design user profiles. Source: FHWA* Bikeway Selection Guide, *Figure 6 (6).***

- **Somewhat Confident Bicyclists.** Somewhat Confident Bicyclists make up a slightly larger percentage of the bicycling population than Highly Confident Bicyclists. They actually tend to bicycle more frequently than Highly Confident Bicyclists, but are more selective about the types of bicycle facilities they will use. Their traffic stress tolerance is lower than that of Highly Confident Bicyclists, and they generally prefer low-volume residential streets and striped or separated bike lanes when bicycling on major streets. However, they will tolerate higher levels of traffic stress for short distances when necessary for key connections to avoid out-of-direction travel.
- **Interested but Concerned Bicyclists.** Most people who ride bicycles or who want to ride bicycles fall into this category. They have the lowest tolerance for traffic stress and tend to ride only in locations with networks of separated bikeways or very low-volume streets with safe roadway crossings. To maximize the potential for bicycling as a viable transportation option, bicycle facilities need to meet the needs of the Interested but Concerned Bicyclist category.

When bicyclists have been considered in the design of A.I.I.s, most designs have generally defaulted to configurations used only by those who are highly tolerant of traffic stress, or the Highly Confident Bicyclist. These designs leave the bicyclist to share travel lanes with motorists or to navigate the intersection in a striped, on-street bike lane.

In most contexts, ranging from very rural to very urban, A.I.I.s have the potential to see bicyclists from a wide cross section of the community, including children, older adults, and families. Many of these riders will fall within the Somewhat Confident and Interested but Concerned categories, and they will not be willing to share roadway space with motorists or endure high-stress crossings. This can result in bicycling on sidewalks or avoiding bicycling through the A.I.I. altogether if comfortable bicycle facilities are not provided.

## 3.2 Types of Bicycle Facilities

Bicycle facilities can be differentiated based on their separation from motor vehicle traffic and/or the presence of a vertical physical barrier. Bikeways that provide dedicated space for bicyclists but do not include vertical barriers include

- On-street bicycle lanes, and
- In rural areas, shoulders designed to accommodate bicyclists.

Conversely, bikeways that provide horizontal separation, vertical barriers, or both between bicyclists and motorists include

- Separated bicycle lanes, also known as protected bicycle lanes or cycle tracks; and
- Shared-use paths, also known as sidepaths when within the street right-of-way.

In some cases, bicyclists may ride in a travel lane with motor vehicles; however, this is generally appropriate only in low-speed, low-volume conditions. Bicycle treatments at a specific A.I.I. may largely be a function of which bikeway types exist on the streets connecting to it. However, even with on-street bike lanes, transitions can be designed on the approaches to A.I.I.s to allow bicyclists to move to more comfortable positions separated from motor vehicle traffic (see Chapter 5). Exhibit 3-2 provides images of various facility types.

Given that implementation of A.I.I.s requires reconstruction or new construction, it is recommended that the highest quality bikeway be considered to maximize the comfort and safety of bicyclists operating through the A.I.I.

### 3.2.1 On-Street Bicycle Lanes

On-street bike lanes provide dedicated space for bicycling and are differentiated from motor vehicle space by pavement markings and signing. Striped bike lanes may include a single stripe to designate the bike lane, or they may include a striped buffer space to separate bicyclists from motorists further. Striped bike lanes typically follow the routing of motor vehicles and are normally located to the right of motor vehicle travel lanes.


***Exhibit 3-2. Bicycle facility types, from left to right: shared-lane, on-street bike lane, buffered bike lane, two-way separated bicycle lane, and shared-use path.***

The AASHTO *Guide for the Development of Bicycle Facilities* provides guidance on the sizing of bike lanes (*3*). Conventional striped bike lanes should be at least 5 feet wide, exclusive of the gutter space. The preferred width is at least 6 feet to better accommodate the bicyclist operating width and buffers from curbs and moving traffic. Bike lanes may need to be wider when there is a vertical barrier at the edge of the bike lane that is high enough for the bicycle handlebars to hit, such as at some DDIs. However, bike lanes 8 feet wide or more may be confused with on-street parking if such lanes are not properly marked and/or signed.

Buffered bike lanes are generally preferable when bike lane space exceeds 7 feet in width. Separated bike lanes can also be provided when lane width exceeds 7 feet (see below). Buffered bike lanes have two components: the bike lane space, typically at least 5 feet exclusive of the gutter; and a painted buffer with diagonal or chevron hatching, typically at least 2 feet in width, to separate the bike lane from adjacent travel lanes horizontally (*3*). The values provided above represent design minimums and are not recommended widths. In general, more lateral clearance, including buffer width, is preferable.

In high-speed, high-volume conditions, striped bike lanes are unlikely to see use by anyone but those bicyclists with the highest traffic stress tolerance (Exhibit 3-3). Further guidance on bikeway selection is presented in Section 3.3.

### 3.2.2 Separated Bicycle Lanes

Like striped on-street bike lanes, separated bike lanes (also known as protected bike lanes or cycle tracks) establish a dedicated space for people to ride bicycles. However, separated bike lanes increase the safety and comfort of people riding a bicycle by physically separating their operating space from motor vehicle and pedestrian uses with vertical design elements. Vertical separation is provided with either a vertical object or a differentiation in elevation. Often, additional horizontal width is provided to improve separation from adjacent motorized traffic and to improve bicyclist comfort and safety. To emphasize the separation of a bikeway from pedestrian activity, it is preferable to provide a detectable edge for people with vision disabilities. The provision of a visual delineation in surface type or material has been used, although these visual treatments are insufficient for pedestrians with vision disabilities. For more information on the detailed design of separated bike lanes, see FHWA's *Separated Bike Lane Planning and Design Guide* (*4*) and the Massachusetts Department of Transportation's

***Exhibit 3-3. Example of on-street bicycle lanes at A.I.I.s in a high-speed, high-volume environment unlikely to see much use by bicyclists due to safety concerns.***

*Separated Bike Lane Planning and Design Guide* (*5*), or the AASHTO *Guide for the Development of Bicycle Facilities* (*3*).

Separated bike lanes (Exhibit 3-4) provide increased comfort in locations with higher speed, higher volume motor vehicle traffic. Bicyclists of all types prefer separated bike lanes and shared-use paths or sidepaths (see Section 3.2.3) in these higher stress environments.

#### *3.2.2.1 One-Way Versus Two-Way Separated Bike Lanes*

While separated bike lanes may be one-way or two-way, a one-way configuration is preferable in most situations, because it establishes bicyclist travel patterns that are more consistent with motorist expectations. Matching motorist expectations in this way can create safer crossings at intersections and driveways. Two-way separated bike lanes generally require more complex transitions to directional bikeways at their endpoints, as well as more complex signal phasing to reduce or eliminate bicycle conflicts with turning motorists. Further detail on potential applications of one-way versus two-way separated bike lanes can be found in the FHWA *Bikeway Selection Guide* (*2*).

#### *3.2.2.2 Separated Bike Lane Widths*

Recommended widths for one-way separated bike lanes depend on the expected volumes of users. The preferred minimum width is 6.5 feet (exclusive of gutter widths) to provide space for faster bicyclists to pass those riding more slowly, with an absolute minimum of 5 feet (*4*). Where bicycle activity is expected to be high, the bike lane width should exceed 6.5 feet to allow for passing within the bike lane or side-by-side riding (*4*). For information about separated bike lane widths, see the FHWA *Separated Bike Lane Planning and Design Guide* (*4*), the Massachusetts Department of Transportation (MassDOT) *Separated Bike Lane Planning and Design Guide* (*5*), and the AASHTO *Guide for the Development of Bicycle Facilities* (*3*).

#### *3.2.2.3 Separated Bike Lane Elevation and Materials*

A wide range of design treatments may be used to create separated bike lanes. Separated bike lanes may be implemented at sidewalk-level with some detectable division between the bikeway

***Exhibit 3-4. Example of separated bicycle lanes.***

and pedestrian space on the sidewalk. Separated bike lanes may also be placed at street-level at the same elevation as motor vehicle lanes, or at an intermediate level above street-level and below sidewalk-level.

The options for separation materials also vary. The greatest protection is usually offered by concrete curb separation; this separation may be provided by placing the bike lane at sidewalk-level or by constructing a curbed concrete island between travel lanes and the bike lane for intermediate- or street-level configurations. This is more common in new construction or reconstruction projects.

For many retrofit projects and some reconstruction projects, lower-cost separation materials may be used for street-level separated bike lanes. These devices, including flexible delineators and rubber wheel stops, do not provide the same quality of comfort to bicyclists as concrete curb separation, because it is easier for motorists to drive over these devices and encroach into the bike lane. These materials are more appropriate in lower speed environments. In other cases, high-cost concrete barriers may be appropriate based on motorist speeds or in locations where there is limited space to increase the width of the buffer between the travel lanes and bike lanes.

### 3.2.3 Shared-Use Paths or Sidepaths

Shared-use paths are paved facilities separated from motor vehicles and are designed for activity by both bicyclists and pedestrians. When located along a roadway within the street right-of-way, shared-use paths are known as sidepaths. These facilities are typically at least 10 feet wide, allow for travel in both directions, and are appealing to all types of bicyclists. Shared-use paths and sidepaths can increase the safety and comfort of people riding bicycles by using vertical and horizontal design elements to separate physically their operating space from that of motor vehicles. Paths with high volumes of bicyclists and pedestrians can have degraded comfort and safety as conflicts between users increase because of the two-way operation and shared operating space. The designer should consider the volume of users expected on a shared-use path, particularly the number of bicyclists and the potential for conflicts between users when determining the appropriateness of shared-use path facility and when determining an appropriate width. (See Chapter 4 for an explanation of the Shared-Use Path Level of Service tool that can be used to determine an appropriate path width.) In locations where use by bicyclists and pedestrians is expected to be high, additional width should be added to the shared-use path. Shy distance should also be added to the ultimate width of the shared-use path (see Chapter 5 for further discussion). Exhibit 3-5 provides an example of a shared-use path at a DDI.

## 3.3 Selecting a Bikeway Type and Width

Every effort should be made to include a bikeway that provides bicyclists with a dedicated and safe space for their operation. As described in Section 3.2, separated bike lanes and shared-use paths are more suitable for providing dedicated bicycling space where motor vehicle traffic conditions are higher speed, higher volume, or both. Even on lower speed or lower volume streets, the intersection configuration may benefit from transitioning to a separated bicycle facility. Choosing the most appropriate bikeway type should be based primarily on the prevailing speeds and volumes of motor vehicles expected in the A.I.I. and a comparison of the benefits associated with each bikeway type.

***Exhibit 3-5. Example of shared-use path at a DDI with pavement markings to delineate two-way operation on each side of the roadway.***

In addition to selecting the bikeway type, the design parameters for the bikeway must be determined, such as width and separation type. These parameters will be based on various factors, including right-of-way and expected bicyclist and pedestrian volumes.

### 3.3.1 Expected Motor Vehicle Speeds and Volumes

Often, A.I.I.s are implemented where motor vehicle throughput is meant to be optimized, which tends to correlate with locations where high volumes of motor vehicles are expected. The determination of an appropriate bicycle facility should be based on the planned traffic context as recommended by FHWA (*2*).

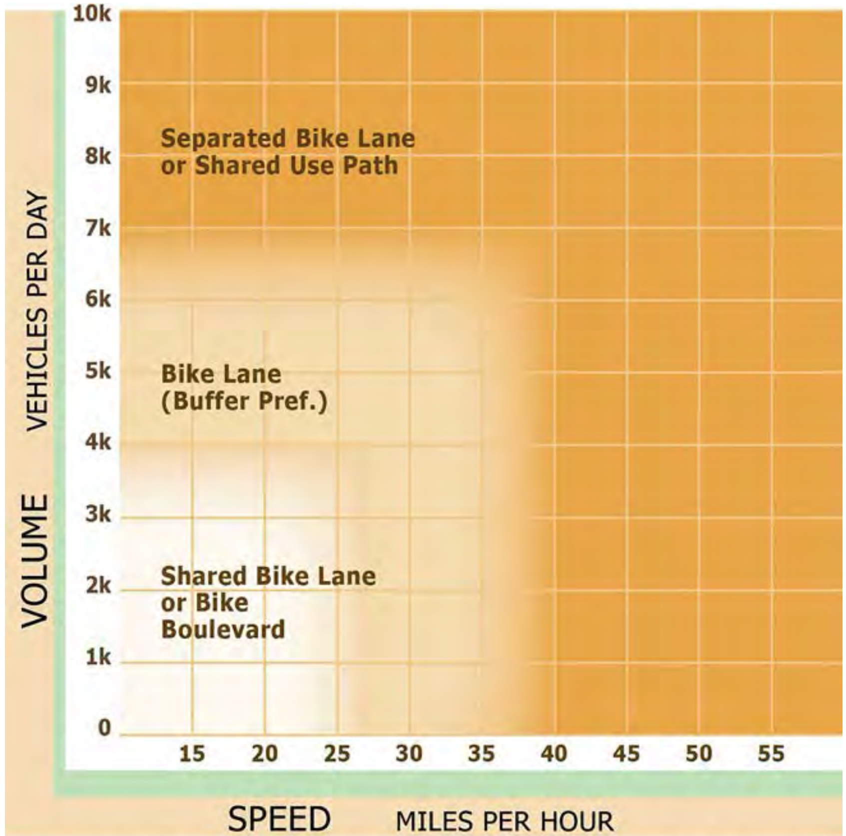
For facilities in urban, urban core, suburban, and rural town contexts, the typical bicyclist is in the Interested but Concerned category. In these cases, FHWA provides guidance on selecting the most appropriate bikeway type based on adjacent motor vehicle speeds and volumes (*2*). Exhibit 3-6 provides a selection chart for facilities in the urban, urban core, suburban, and rural town contexts. The FHWA *Bikeway Selection Guide* provides additional guidance for using the chart. Often, the conditions found within an A.I.I. will exceed 30 mph or 6,000 vehicles per day; therefore, selecting a shared-use path or separated bike lane will often be the preferred choice.

If the decision is made to select a bikeway type that is less appropriate for the conditions (e.g., implementing a buffered bike lane in place of a shared-use path), the designer should expect that fewer bicyclists will ride in the facility. Accordingly, the intersection may see lower-than-expected bicycle ridership, or there may be more instances of people riding bicycles on the sidewalks.

In rural areas, FHWA provides guidance for selecting a shoulder-width to accommodate bicycles based on the adjacent motor vehicle speeds and volume (*2*). This table is given in Exhibit 3-7, which assumes a more confident cyclist will be the design user. However, if bicycle activity is expected to be common in rural areas (for example, in locations with bicycle tourism), a shared-use path or separated bike lane may be more appropriate.

### 3.3.2 Available Right-of-Way

The amount of right-of-way that an A.I.I. needs can be larger or smaller than that for a conventional intersection for the same traffic volume, depending on the form of A.I.I. Often, the

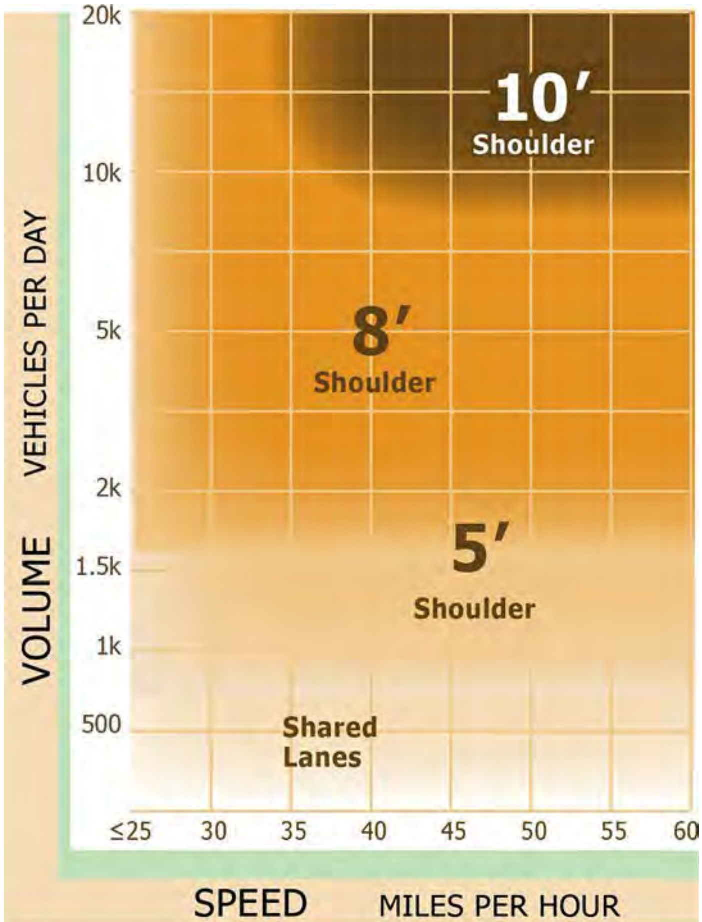



1. Chart assumes opreating speeds are similar to posted speeds. If they differ, use operating speed rather than posted speed.
2. Advisory bike lanes may be an option where traffic volume is <3K ADT.
3. See page 32 for a discussion of alternatives if the preferred bikeway type is not feasible.

***Exhibit 3-6. Bicycle facility selection for urban areas.***
***Source: FHWA* Bikeway Selection Guide*, Figure 9 (2).***

A.I.I. may take a shape that is more compatible with existing right-of-way constraints; this can allow the provision of a higher quality bicycle facility. A.I.I.s are also sometimes constructed in greenfield locations where adequate right-of-way is available for an optimal bikeway design. However, most A.I.I. projects have been retrofits for existing conventional intersections. One reason A.I.I.s are becoming increasingly popular in retrofit situations with right-of-way constraints is that little-to-no additional right-of-way may be needed to redesign the intersection. However, if right-of-way acquisition is necessary to accommodate the required geometry for motor vehicles, the acquisition of right-of-way to accommodate other users should be included. If an A.I.I. requires less right-of-way than the existing conditions, every effort should be made to use that space for safe separated bicycle facilities.

Preferred and minimum dimensions for the bicycle facility options were discussed in Section 3.2. Where right-of-way is constrained, tradeoffs may be required to achieve the preferred bikeway design. Options to adjust the intersection may include narrowing or reducing the number of travel lanes, narrowing center islands or channelization areas, reallocating landscaping space, reducing or eliminating shoulder widths, and other treatments to provide the preferred bikeway. There may be conditions where providing shared-use paths, which heighten bicyclist comfort at the potential expense of pedestrian comfort, could conserve more right-of-way than on-street or separated bike lanes. Similarly, there may be conditions where the bikeway




1. Chart assumes the project involves reconstruction or retrofit in constrained conditions. For new construction, follow recommended shoulder widths in the AASHTO Green Book.
2. A separated shared use pathway is a suitable alternative to providing paved shoulders.
3. Chart assumes opreating speeds are similar to posted speeds. If they differ, use operating speed rather than posted speed.
4. If the percentage of heavy vehicles is greater than 5%, consider providing a wider shoulder or a separated pathway.

***Exhibit 3-7. Bicycle facility selection for rural areas.***
***Source: FHWA*** **Bikeway Selection Guide*****, Figure 10 (2).***

dimensions could be narrowed to minimum dimensions. Narrowing bikeways or downgrading the quality of the bikeway should be among the last options considered in favor of preserving the preferred bikeway type. Changes to the bikeway design should be considered only after travel lanes and other areas have been narrowed to minimum practical values, recognizing that minimum widths for all elements are not an ideal outcome.

### 3.3.3 Expected Bicyclist Volumes

Where lower pedestrian and bicycle activity is anticipated, it may be possible to use a shared-use path instead of separated bicycle and pedestrian facilities. In these cases, the FHWA Shared-Use Path Level of Service (SUPLOS) tool (see Chapter 4) should be used to determine if a shared-use path is an appropriate facility. The SUPLOS tool can help assess whether a shared-use path provides adequate width or if users would be better served by providing sidewalks for pedestrians and separated bike lanes for bicyclists. If the SUPLOS score is projected to be at or below C, separating bicyclist and pedestrian activity should be considered. Providing separate accommodations for bicyclists and pedestrians reduces the likelihood of crashes between the two user groups and minimizes the potential for frustrating interactions between users in a confined space.

### 3.3.4 Sight Distance

An important design factor for street crossings is the provision of sight distance for bicyclists and motorists to view each other clearly on the approaches to any conflict points. Both parties should have the ability to perceive and react to a potential conflict, and motorists should be able to come to a full stop before conflicting with a bicyclist. The deceleration rate to come to this full stop should be no more than 5 feet/sec$^2$, to minimize the risk of a vehicle-to-vehicle rear-end collision. That deceleration rate is consistent with AASHTO Green Book recommendations for drivers decelerating in approach to an uncontrolled intersection and is significantly less than the rate used for signal timing applications. This sight distance, which is needed at both uncontrolled and controlled crossings and relates to multiple-threat conditions, is discussed in Chapter 5. The design should provide adequate approach clear space before crossings by eliminating tall and opaque roadside elements that could limit visibility between motorists and vulnerable users approaching the crossing.

### 3.3.5 Facility Selection Summary

Exhibit 3-8 summarizes the bicycle facility selection guidance based on FHWA (*2*). This table is useful as designers consider tradeoffs between different facility types. The assessment framework in Chapter 4 provides detailed guidance on how to select and evaluate bikeway facilities.

## 3.4 Design Principles for Bicycle Facilities

The design of bicycle facilities requires consideration of factors that make bikeways safe and pleasant to use. Riding a bicycle is traditionally a human-powered activity (although using electronically assisted bikes, or e-bikes, is on the rise), so consideration should be given to reducing route lengths and uphill grades that require additional effort. In the interest of safety for all users, designs should also seek to minimize the risk of crashes between bicyclists and motorists, as well as between bicyclists and pedestrians. Achieving these aims is guided by the principles in Sections 3.3.1 through 3.3.3. Bicyclist comfort is not as tangible or readily quantifiable as delay or conflict points, but selecting the appropriate bikeway facility and designing it to serve the three listed purposes will promote a comfortable facility that encourages use.

Design principles for bicycle facilities fall into three categories:

- Bicyclist Routing and Delay
- Minimizing Conflicts with Motor Vehicles
- Minimizing Conflicts with Pedestrians

Unless the design of an A.I.I. includes grade separation that fully separates motor vehicle movements from those of bicyclists and pedestrians (i.e., an overpass or underpass), the interaction between motorists and these vulnerable road users will occur. The design of the A.I.I. should consider likely conflict scenarios and configure the intersection or signal phasing to manage conflicts between these users where possible. A design that minimizes or physically separates conflict points between motorists and bicyclists is also likely to result in greater attentiveness by all users at each crossing, resulting in a safer multimodal interaction. The design

**Exhibit 3-8. Summary of bicycle facility types.**

| Bikeway Type | Design Alternative | Benefits | Considerations |
|---|---|---|---|
| Shared-Use Path or Sidepath | Recommended 10' Minimum Width | Provides a high level of comfort for bicyclists when pedestrian volumes are low to moderate. | The design should include a minimum 2' street buffer or vertical railing/barrier to separate path from travel lanes.<br>Crossing treatments may be combined with pedestrian crossings. |
| | Preferred 12'-16' Width | Can allow for greater separation between bicyclists and pedestrians.<br>Wider width accommodates higher volumes of bicyclists and pedestrians. | The design should include a minimum 2' street buffer or vertical railing/barrier to separate lanes.<br>May require additional right-of-way.<br>Additional width should be added to accommodate shy distances if railings or walls are used.<br>Crossing treatments may be combined with pedestrian crossings. |
| Separated Bike Lanes (also called Protected Bike Lanes or Cycle Tracks) | Sidewalk-level Separated Bike Lane | Separates bicyclists both vertically and horizontally from motorists. Also provides horizontal separation from pedestrians.<br>Functions similarly to a shared-use path in terms of separation from motorists. Also provides horizontal separation from pedestrians. | The bike lane width depends on expected demand. The preferred width is at least 6.5 feet, the minimum width is 5 feet.<br>Requires ADA-compliant tactile separation from sidewalks to avoid pedestrian encroachment.<br>Provides similar levels of comfort as shared-use paths.<br>May require special design treatments at crossings. Enhanced treatments such as green pavement are recommended. *Note: green paint is an interim approval (IA-14) from FHWA.* |
| | Intermediate-level Separated Bike Lane | Separates bicyclists both vertically and horizontally from motorists and pedestrians. | The bike lane width depends on expected demand. The preferred width is at least 6.5 feet; the minimum width is 5 feet.<br>Construction may be more challenging than sidewalk-level or street-level separated bike lanes.<br>Provides similar levels of comfort as shared-use paths.<br>May require special design treatments at crossings. Enhanced treatments such as green pavement are recommended. *Note: green paint is an interim approval (IA-14) from FHWA.* |

*(continued on next page)*

**Exhibit 3-8.** ***(Continued).***

| Bikeway Type | Design Alternative | Benefits | Considerations |
|---|---|---|---|
| | Street-level separated bike lane with Concrete Curb Separation | Concrete curb separation is more effective than other street-level separation devices for preventing encroachment by motorists. | Concrete curb separation should be at least 2-ft wide where adjacent to travel lanes.<br>The bike lane width depends on expected demand. The preferred width is at least 6.5 feet; the minimum width is 5 feet (exclusive of the gutter).<br>Crossing treatments may be similar to conventional bike lanes. Enhanced treatments such as green pavement are recommended. *Note: green paint is an interim approval (IA-14) from FHWA.* |
| | Street-level Separated Bike Lane with Other Types of Separation (e.g., Flexible Delineators) | Visually delineates bicyclist space. Offers more bicycling space than conventional bike lanes. | Separation with flexible delineators, wheel stops, and other nonconcrete devices is less effective for protecting occupants of the bike lane.<br>The bike lane width depends on expected demand. The preferred width is at least 6.5 feet; the minimum width is 5 feet (exclusive of the gutter).<br>Crossing treatments may be similar to conventional bike lanes. Enhanced treatments, such as green pavement, are recommended. *Note: green paint is an interim approval (IA-14) from FHWA.* |
| Striped Bike Lanes | Buffered Bike Lanes | Provides dedicated bicycling space with additional width to horizontally separate bicyclists from motorists. | Does not provide adequate comfort for bicyclists in high-speed and/or high-volume roadway conditions.<br>4- to 6-foot preferred minimum bike lane width with minimum 2- to 3-foot buffer.<br>Lack of vertical separation devices increases the likelihood of encroachment by motorists. |
| | Conventional Bike Lanes (i.e., single stripe designation) | Provides dedicated bicycling space. | Does not provide adequate comfort for bicyclists in high-speed and/or high-volume roadway conditions.<br>5-foot minimum bike lane width.<br>Lack of vertical or horizontal separation increases the likelihood of encroachment by motorists.<br>In high-speed, high-volume conditions, unlikely to be used by any but the Highly Confident Bicyclist. |

should also apply techniques to reduce crash severity by reducing motorist speeds, improving sight distance, and implementing other safety treatments. A design that minimizes or physically separates conflict points between motorists and bicyclists is also likely to result in greater attentiveness by all users at each crossing, resulting in a safer multimodal interaction.

### 3.4.1 Bicyclist Routing and Delay

The design principles associated with best practices for bicyclist routing and minimizing delay are as follows:

- Provide a highly visible and coherent route.
- If on-street bike facilities are provided, bicyclists should be able to proceed through the intersection in a relatively straight line. To this end, provide lane line extensions to guide bicyclists through wide intersections. If a straight line cannot be achieved, designs should avoid abrupt turns for bicyclists.
- Consider bicycle desire lines and reduce out-of-direction travel to accommodate both through and turning movements.
- Minimize grade changes (unless grade separation is provided).
- Minimize the use of multistage crossings unless a multistage crossing can reduce delay or eliminate crossings of high-volume, free-flow ramps.
- Minimize bicyclist exposure to high-speed and/or free-flowing traffic movements.

Exhibit 3-9 shows "bicycle routing and delay" principles at a MUT intersection.

### 3.4.2 Minimizing Conflicts with Motor Vehicles

The design principles associated with best practices for minimizing conflicts between bicyclists and motorists are as follows:

- Maximize visibility between bicyclists and motorists.
  - Provide bicycle crossings that are as perpendicular to conflicting motorists as possible.
  - Provide bicycle crossings in conspicuous locations where there are clear sightlines and adequate sight distance between motorists and bicyclists.
  - Provide adequate lighting at the crossing locations.
- Maintain separated bicycle facilities or transition bicyclists to off-street facilities near high-speed and/or high-volume conflict areas.

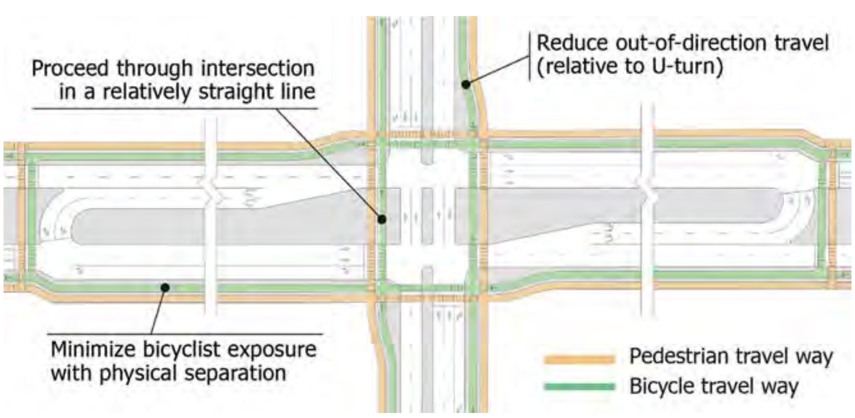



***Exhibit 3-9. Bicycle routing and delay principles.***

- Reduce motor vehicle speeds in conflict areas.
  – Limit speeds to 20 mph or less where bicyclist and motorist paths cross.
  – Minimize or avoid the use of conflicts with high-speed merging lanes and/or high-volume traffic movements.
  – Minimize corner radii to slow turning speeds.
  – Use traffic calming measures such as raised crossings.
- Minimize the severity of conflicts where they cannot be eliminated.
  – Separate movements in time using traffic controls as well as with geometric separation when feasible.
  – Minimize exposure to conflicts with motorists by providing short crossing distances and physically separated bikeways.
  – Avoid designs that require bicyclists to merge across multiple lanes of traffic.
  – Minimize speed differential at conflict points.
- Provide adequate signal timing for bicyclists to clear intersections before permitting conflicting movements to proceed.

Exhibit 3-10 shows "minimizing conflicts with motor vehicles" principles at a DLT intersection. Note: not all conflict points are shown.

### 3.4.3 Minimizing Conflicts with Pedestrians

The design principles associated with best practices for minimizing conflicts between bicyclists and pedestrians are as follows:

- Maximize visibility between bicyclists and pedestrians.
- Where separated bike lanes are provided, continue to separate bicyclists and pedestrians at crossings.
- In shared-use paths, ensure there is adequate width for safe passing by bicyclists and pedestrians.
- Provide curb ramps that match the full width of shared-use paths.

Exhibit 3-11 shows "minimizing conflicts with pedestrians" principles at a MUT intersection.

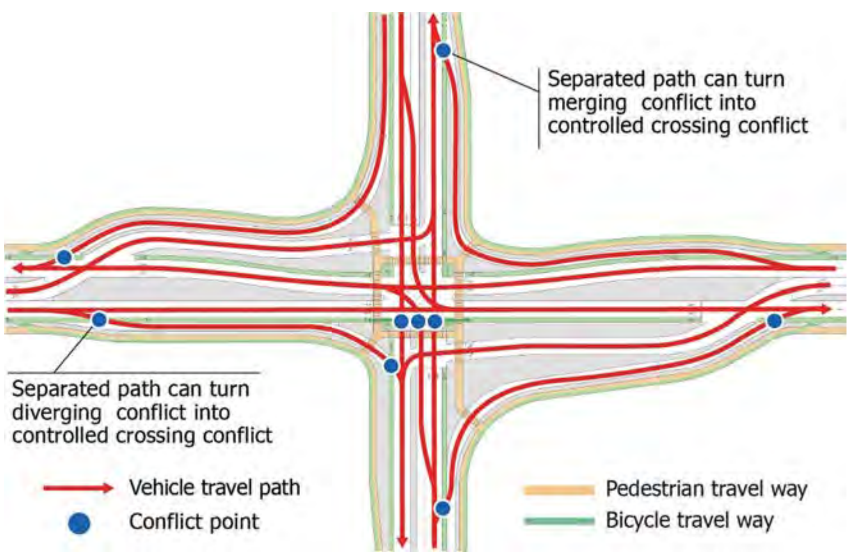



***Exhibit 3-10. Minimizing conflicts with motor vehicles principles.***

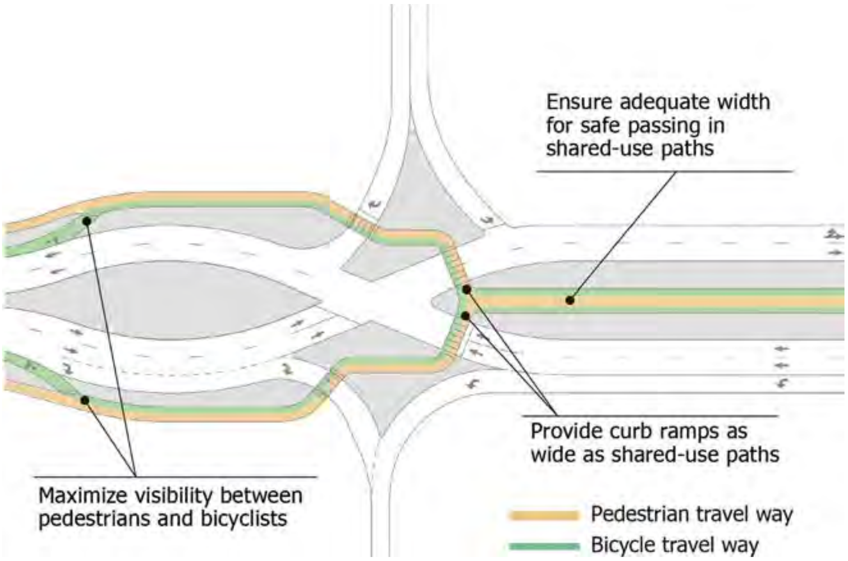



***Exhibit 3-11. Minimizing conflicts with pedestrians principles.***

## 3.5 References

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3. AASHTO. 2012. *Guide for the Development of Bicycle Facilities, Fourth Edition.* AASHTO, Washington, DC.
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CHAPTER 4

# Assessment

The assessment of A.I.I. alternatives for pedestrians and bicyclists is an integral part of the Intersection Control Evaluation (ICE) process and performance-based design. As noted in Chapter 1, the ICE process is carried out using two stages of evaluation, which are mirrored in this assessment approach. Even absent an ICE framework, the concepts in this chapter apply to the project development process in general. This chapter presents quantitative and qualitative techniques to establish initial design decisions and to evaluate the performance of alternatives.

This chapter presents three major categories of assessment tools:

- Facility design elements, used during Stage 1 to identify basic pedestrian and bicyclist facility types and routing;
- Quantitative evaluation techniques, used during both Stages 1 and 2, to assess to quality of service and level of comfort; and
- Design flags, used during Stage 2, to assess safety, accessibility, comfort, and operational aspects for each mode.

The core of the assessment is the Design Flag method in Section 4.4. The evaluation criteria for determining which alternatives are selected for advancement to the next stage vary based on context and agency requirements, as well as other factors and are beyond the scope of this document.

Exhibit 4-1 summarizes the assessment framework for pedestrian and bicyclist safety at A.I.I.s

## 4.1 Facility Design Selection – ICE Stage 1

At Stage 1, the overall footprint and feasibility of an intersection or interchange configuration are established for each alternative. Pedestrian and bicycle facilities need to be considered during this stage because they can directly affect the footprint and right-of-way needs for an alternative.

The basic questions at this stage focus on the pedestrian and bicycle facilities needed and how each origin-destination movement will be served. In many respects, these are the same types of decisions being made for each origin-destination movement for motor vehicles. Also, a configuration can have poor viability for pedestrians, bicyclists, or both, even though it may be viable for motor vehicles. As a result, the assessments for pedestrians and bicyclists for each Stage 1 alternative are a vital part of the evaluation.

Key questions for making initial decisions in Stage 1 for pedestrian and bicycle facilities are given in Exhibit 4-2. It may be desirable to have different types of facilities on the major and the minor streets to serve different functional purposes or to address different speed and volume characteristics.

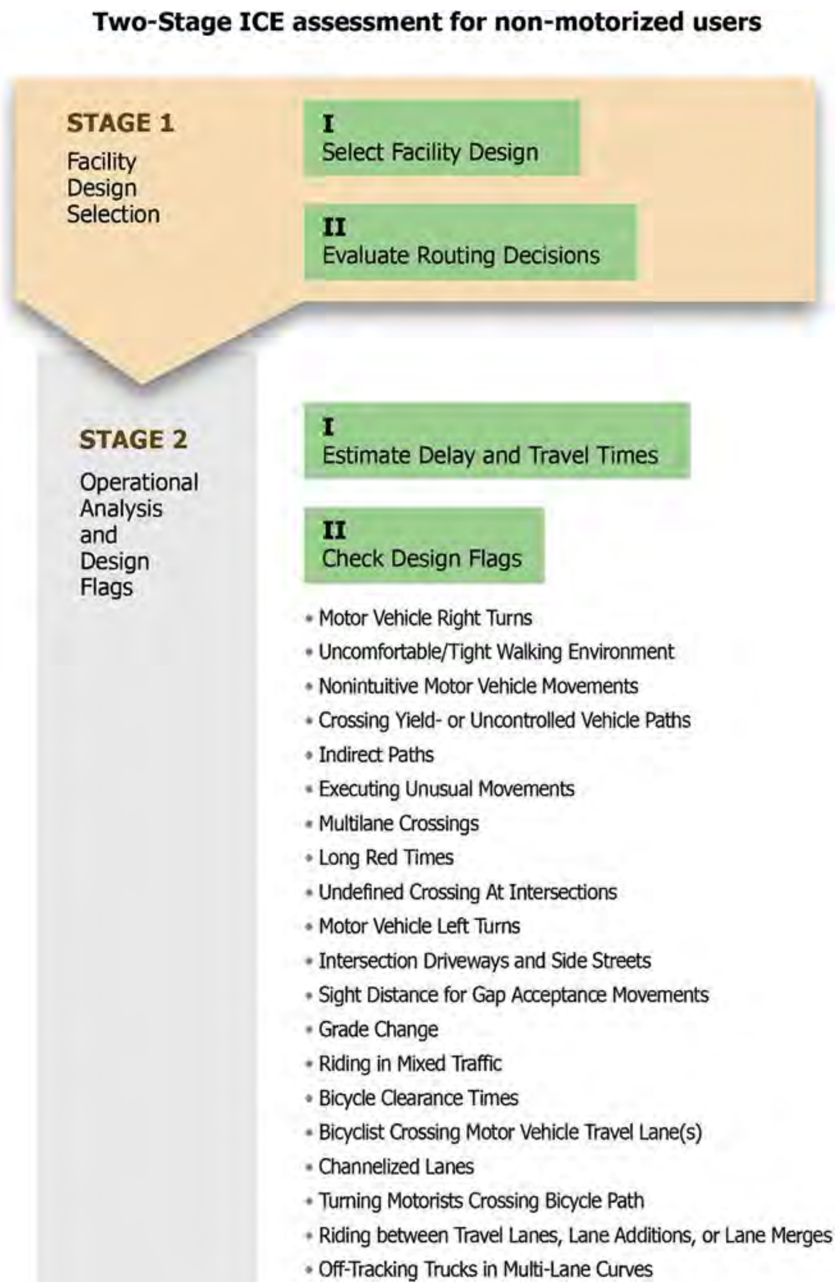


***Exhibit 4-1. Overview of the assessment framework for pedestrian and bicyclist safety at A.I.I.s.***

**Exhibit 4-2. Stage 1 design questions.**

| Decision | Questions to Ask |
|---|---|
| Facility type | 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 bicycle lanes, or shared-use path) will be provided on each intersecting street? |
| Routing decisions | How will each origin-destination route for pedestrians be routed through the intersection (e.g., around the perimeter, through the interior, etc.)? |
| | 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, etc.)? |
| | How much space and what design treatments are needed to enable this *bicyclist* routing? |

It is critical in the design process to decide on the pedestrian and bicycle facility type early; the decision can directly affect overall right-of-way needs and many subsequent design decisions. For pedestrians, sidewalks should be sized depending on local context and functional classification (see Chapter 2). For bicyclists, the guidance in Chapter 3 should be considered to determine whether a separated bike lane or shared-use path is needed in the design. Failure to incorporate these design elements into early concept designs may make it difficult to provide for a safe walking and riding environment in later stages of design.

## 4.2 Quantitative Performance Measures – ICE Stages 1 and 2

For motor vehicles, a planning-level quantification of performance measures can be performed using a spreadsheet tool similar to FHWA's CAP-X tool (*1*), the Florida Department of Transportation's adaptation of CAP-X (*2*), or the Virginia Department of Transportation's VJuST tool (*3*), which screen alternatives based on automobile critical movement analysis and resulting volume-to-capacity (v/c) ratio.

For pedestrians and bicyclists, various quantitative performance measures are available to assess pedestrian and bicyclist quality of service and level of comfort. This section summarizes these measures.

### 4.2.1 Pedestrian Level of Service (PLOS)

The Pedestrian Level of Service (PLOS) tool in the *HCM* (*4*), quantifies the comfort experienced by pedestrians when traversing street links and intersections and includes factors associated with many of the parameters described in Section 2.1.4.

PLOS categorizes quality of service for pedestrians on an A to F scale, where PLOS A is excellent or very comfortable for pedestrians, and F is very poor, indicating a very uncomfortable experience for pedestrians. Exhibit 4-3 tabulates the effect that various PLOS inputs have on the PLOS score for street segments and signalized intersections, where a higher score worsens the PLOS rating of the link or intersection.

The PLOS link score reflects the pedestrian's perceived comfort when walking along a street link. The PLOS score for a link is improved (made more comfortable) by wider sidewalks and greater separation distance from adjacent motor vehicle traffic. The presence of a barrier at least 3 feet tall within the street buffer or on-street parking that is normally occupied improves the PLOS score. The PLOS model cannot measure pedestrian safety or security, nor has it been calibrated to a mix of signalized and unsignalized crossings that may be present at some A.I.I.s. The PLOS model has other shortcomings, such as yielding scores that are more desirable when pedestrian signals are not provided in favor of vehicular traffic signals. Designers should understand the effect of various inputs in the PLOS analysis and make informed decisions about factors that not only affect the score but also the expected comfort.

Motor vehicle LOS is based on motorist delay, and facilities are typically designed to provide LOS C or D; however, because PLOS measures perceived comfort, it is not appropriate to compare or apply similar target values of LOS for motorists and pedestrians. PLOS values of A or B are desirable to provide a comfortable experience.

Many of these design variables relate to conditions in an A.I.I. Wide sidewalks and street buffers are encouraged for A.I.I. locations, given the high speeds and motor vehicle volumes that some A.I.I.s accommodate and which degrade PLOS. In an A.I.I., effective walkway widths should be at least 10 feet or greater so as to accommodate the expected pedestrian demand. It is unlikely that on-street parking will be part of the A.I.I. design; therefore, it is recommended that a vertical barrier or greater separation between the motor vehicle travel lanes and sidewalk be considered to improve the quality of service for pedestrians.

**Exhibit 4-3. Influence of design factors on PLOS. Source: Adapted from *HCM*, Sixth Edition (*4*).**

| System Element | Design Element | Influence on PLOS |
|---|---|---|
| Urban Street Segment | Width of outside through lane, shoulder, bike lane, parking lane | Greater width → Better PLOS score |
| | On-street parking occupancy | Greater parking occupancy → Better PLOS score |
| | Street buffer width | Wider buffer → Better PLOS score |
| | Presence of continuous 3-ft minimum-height barrier within the street buffer | Presence of continuous barrier → Better PLOS score |
| | Sidewalk width | Wider sidewalk → Better PLOS score |
| | Adjacent motor vehicle flow per travel lane | Higher motor vehicle flow → Poorer PLOS score |
| | Adjacent motor vehicle speed | Higher motor vehicle speed → Poorer PLOS score |
| Roadway Crossing | Diversion of the pedestrian path (to reach a signalized crossing) | Greater diversion distance → Poorer PLOS score |
| | Travel time delay (due to signal control or gap acceptance) | Greater delay → Poorer PLOS score |

A factor in calculating PLOS involves the delay experienced by pedestrians. When a delay is perceived as excessive, pedestrians are more likely to take risks in crossing a conflicting traffic stream. The threshold for what is deemed excessive is similar for signalized and unsignalized crossings. Waiting in uncomfortable locations, like narrow median refuges or narrow sidewalks adjacent to travel lanes, could contribute to a pedestrian's willingness to engage in risk-taking behavior.

At signalized crossings where pedestrians expect to wait no more than 10 seconds, they are more likely to comply with pedestrian signal indications. However, when the signal-based pedestrian delay exceeds 30 seconds, the incidence of noncompliance grows, and pedestrians are more likely to disregard signal indications and look for gaps to cross against the signal (*4*).

Unsignalized intersections may be evaluated by determining pedestrian crossing delay as pedestrians wait for gaps in traffic or for motorists to yield and allow them to cross. Pedestrians crossing at unsignalized locations have a slightly higher tolerance for delay than those crossing at signalized locations, with risk-taking behavior more likely as delays exceed 30 seconds. As delay reaches 45 seconds or more, pedestrians are more likely to accept smaller gaps and attempt to cross within a gap insufficient for a safe crossing (*4*).

### 4.2.2 Bicycle Level of Service (BLOS)

Bicycle Level of Service (BLOS) analysis is described in the *HCM* (*4*). The BLOS method produces a comfort rating for street segments and intersection crossings that reflects numerous factors, including curb lane widths, bike lane widths, traffic volumes and speeds, pavement surface conditions, the presence of heavy vehicles, and on-street parking. BLOS A represents the most comfortable conditions. The BLOS model does not measure bicyclist safety or security and is not designed to measure the comfort of physically separated bicycle facilities. Exhibit 4-4 shows the influence of design factors on BLOS.

Motor vehicle LOS is based on motorist delay, and facilities are typically designed to provide LOS C or D; however, because BLOS measures perceived comfort, it is not appropriate to compare or apply similar target values of LOS for motorists and bicyclists; BLOS values of A or B are desirable to ensure a comfortable experience. BLOS was calibrated based on more confident adult bicyclists and so may overestimate the level of comfort perceived by many riders in the Somewhat Confident and Interested but Concerned groups.

### 4.2.3 Shared-Use Path Level of Service

FHWA provides a Shared-Use Path Level of Service (SUPLOS) method to measure path user comfort based on the estimated number of passing maneuvers likely to occur along a shared-use path and potential for conflict (*5*). Communities use SUPLOS in several ways:

- Setting benchmarks for SUPLOS on shared-use paths of varying classifications;
- Assessing overall network performance of existing conditions; and
- Assessing proposed designs to determine optimal shared-use path width and the need for separating path users. (SUPLOS values below C suggest that separating users should be considered.)

SUPLOS was developed through a large research sample of shared-use paths in multiple locations around the country and represents many shared-use path conditions. The inputs for scoring are

- Shared-use path width;
- User volumes and speeds in different modes (actual, estimated, or projected); and
- Presence of a centerline stripe.

**Exhibit 4-4. Influence of design factors on BLOS. Source: *HCM*, Sixth Edition, Chapters 18 and 19 (*4*).**

| System Element | Design Element | Influence on BLOS |
|---|---|---|
| Network Link/ Segment | Width of outside through lane, shoulder, bike lane, parking lane | Greater width → Better BLOS score |
| | On-street parking occupancy | Greater parking occupancy → Poorer BLOS score |
| | Adjacent motor vehicle flow per travel lane | Higher motor vehicle flow → Poorer BLOS score |
| | Adjacent motor vehicle speed | Higher motor vehicle speed → Poorer BLOS score |
| | Adjacent heavy vehicle percentage | Higher heavy vehicle percentage → Poorer BLOS score |
| | Pavement quality | Better pavement quality → Better BLOS score |
| | Number of intersecting side streets and driveway approaches (access points) | More intersecting access points → Poorer BLOS score |
| Signalized Intersection | Curb-to-curb width of the street being crossed | Greater crossing width → Poorer BLOS score |
| | Total combined left-turn, through, and right-turn vehicular demand flow rates per total travel lanes | Greater vehicular demand → Poorer BLOS score |
| | Width of outside through lane, shoulder, bike lane, parking lane | Greater width → Better BLOS score |
| | On-street parking occupancy | Greater parking occupancy → Poorer BLOS score |

Generally, the scoring accounts for the "friction" between users of different modes—pedestrians, bicyclists, runners, in-line skaters, and child bicyclists—as they pass one another using the trail. This friction is influenced by (1) volume and (2) width for users to move around one another.

Within the context of an A.I.I., the SUPLOS tool can be used to identify (1) whether a shared-use path (sidepath) will safely accommodate the expected volumes of pedestrians and bicyclists and (2) if these users should be separated by constructing a combination of sidewalks and separated bike lanes. If SUPLOS is projected to be C or lower, a wider shared-use path should be evaluated or the provision of distinct facilities for each of these user groups should be considered.

### 4.2.4 Bicycle Level of Traffic Stress (LTS)

Level of Traffic Stress (LTS) addresses deficiencies in the Bicycle LOS method (*6*). Unlike BLOS, which is calibrated to the confident bicyclist, LTS is based on the experiences of a wider range of bicyclists, including those less confident riding with or near motor vehicle traffic.

The LTS method considers bicyclists' varying confidence levels and integrates a suite of design parameters (such as bike lane width, motor vehicle speeds and volumes, and the likelihood of bike lane blockage) to develop a numerical rating for the comfort of a street segment. Scores range in integer values from 1 to 4, with more stressful conditions on the higher end of the range (LTS 3 or LTS 4). These scores loosely correspond to the three types of bicyclists, with all groups preferring LTS 1 bikeways and only the more stress-tolerant riders willing to use LTS 3 or LTS 4 facilities.

Bicycle facilities that are wider, separate bicyclists from high-speed traffic, and have signalized treatments at crossings and intersections will typically receive lower LTS scores (indicating higher comfort), attracting a wider variety of users, including those who are less confident. In high-speed environments like many A.I.I.s built to date, it will be difficult to achieve low-stress bicycle facilities that are comfortable for all users without building shared-use paths (sidepaths) or high-quality separated bike lanes.

### 4.2.5 Other Quantitative Performance Measures

Performance measures were examined under NCHRP Project 07-25 as either direct assessments of the performance of pedestrian and bicyclist facilities or as quantifiable surrogates. These are documented in the NCHRP Project 07-25 final report and are as follows:

- Fastest path vehicle speed assessment,
- Sight distance calculations,
- Safety and conflict assessment, and
- Accessibility assessment.

## 4.3 Operational Analysis – ICE Stage 2

In ICE Stage 1, the geometry of the intersection for each alternative has been relatively generic, with basic initial decisions about needed travel lanes for motor vehicles and types and routing of pedestrian and bicycle facilities. In ICE Stage 2, more details are developed in each of the remaining alternatives, and the operational needs for each user group are used to determine the initial geometry.

At most traditional intersections, the crossing options for pedestrians and bicyclists are generally limited to one or two possible configurations; however, some A.I.I.s can have several possible crossing configurations. An operational analysis of the travel time and delay experienced by pedestrians and bicyclists, conducted in parallel with a similar analysis for motorists, will help to assess the most efficient routing for each mode. As routings become less efficient, it becomes increasingly likely that some pedestrians and bicyclists will cross in undesignated locations they perceive to be more efficient. These undesignated locations present a potential safety risk, because the design features in these undesignated locations may not be optimal for crossing, and motorists may not be expecting pedestrians and bicyclists in those locations. Also, these undesignated locations do not have the features to be accessible to all people.

The operational analysis for each alternative should be appropriate for the context and complexity of the location. It should consider the effect of cycle length, phase sequence, and phase durations on each key pedestrian and bicyclist movement. Delays incurred by pedestrians and bicyclists should be considered concurrently with those incurred by motor vehicles and should be consistent with the context of the location. Analyses, sometimes, may be feasible with analytical methods in the *HCM* (*4*). Sometimes, a simulation may be a better tool for assessing travel time and delay for each mode, particularly in cases of higher pedestrian and bicyclist volumes or more complex routings. Further discussion of these operational aspects is presented in Chapter 5 and the specific chapters for each A.I.I.

## 4.4 Design Flag Assessment

As a surrogate for quantitative performance measures, performance measures—also known as *design flags*—can help identify potential safety, accessibility, operational, or comfort issues for pedestrians and bicyclists. A design flag does not necessarily represent a fatal flaw for an alternative; rather, it presents a design issue that should be addressed in the iterative development and evaluation of the alternative. Some design flags depend on signalization decisions. Before a full signal design, an analysis should be conducted with the best information available.

These design flags are not unique to A.I.I.s, as they may also apply to traditional intersections and interchanges. This guidebook encourages the use of design flags in evaluating and designing pedestrian and bicycle facilities for each alternative, whether traditional or A.I.I. The treatment guidance in this guidebook is intended to assist with both traditional intersections and A.I.I.s.

Design flags generally apply to conflict points within the intersection rather than to segments, as discussed for the level-of-service and level-of-stress measures. Outputs related to safety or accessibility are generally higher priority items that need to be addressed in design refinements in Stage 2. Outputs related to delay and travel time and outputs related to the level of comfort are generally of lesser priority relative to safety and accessibility, suggesting items of concern but not necessarily fatal flaws in the design. Both of these levels of priority can be used to differentiate alternatives during the ICE process, and the relative balance of these levels of priority can be customized to the context of the location.

Exhibit 4-5 summarizes the flags identified for pedestrians and bicyclists for various traversing, wayfinding, and crossing movements. The design flags apply to either the pedestrian movement, the bicyclist movement, or both.

The flags have been derived from research including literature reviews, focus groups with users of these facilities, online surveys, expert panels, and practitioner experience. Each of the flag descriptions includes specific references to literature. The NCHRP Project 07-25 final report explains the focus group, survey, and panel input that informed the design flag development.

The evaluation includes two types of design flags:

- **Red Flags**, for design elements directly related to a <u>safety concern</u> for pedestrians or bicyclists, and
- **Yellow Flags,** for design elements negatively affecting <u>user comfort</u> (i.e., increasing user stress) or the quality of the walking or cycling experience.

The design flags are assessed for the four pedestrian crossing movements between adjacent quadrants and the 12 bicycle turning movements (left-turn, through, and right-turn for each approach). Exhibit 4-6 shows the four possible pedestrian paths part of the assessment, evaluated as two-directional movements between quadrants A, B, C, and D.

Exhibit 4-7 shows the 12 bicycle turning movements feasible at most intersections. Bicycles traveling as pedestrians (e.g., walking bikes on sidewalks or children using the sidewalk network) should use the pedestrian assessment. U-turns are not considered in the bicycle assessment, because these are rare for bicyclists. Movements to or from approaches where bicyclists are prohibited (such as ramps to or from controlled-access facilities) are ignored.

If a particular pedestrian path or bicycle movement is not feasible in a design, it is assumed that the corresponding pedestrian and bicycle demands are redirected to the next shortest alternate paths. Flags for that alternate path are applied to the movement under analysis. For example, if in Exhibit 4-6 pedestrian movement A-B is not allowed, those pedestrians encounter design flags for crossings B-C, C-D, and D-A.

**Exhibit 4-5. Summary of design flags pedestrian and bicycle assessment.**

| Sec. | Design Flag | Bikes | Peds. | Flag Type | Flag Description |
|---|---|---|---|---|---|
| 4.4.1 | Motor Vehicle Right-Turns | | X | Y/R | Permissive motor vehicles right-turns across pedestrian paths |
| 4.4.2 | Uncomfortable/Tight Walking Environment | | X | Y | Pedestrian facilities of narrow width |
| 4.4.3 | Nonintuitive Motor Vehicle Movements | | X | Y/R | Motor vehicle movements arriving from an unexpected direction |
| 4.4.4 | Crossing Yield- or Uncontrolled Vehicle Paths | X | X | Y/R | Yield or uncontrolled pedestrian crossings |
| 4.4.5 | Indirect Paths | X | X | Y/R | Paths resulting in out-of-direction travel |
| 4.4.6 | Executing Unusual Movements | X | X | Y | Movements that are unexpected given local context |
| 4.4.7 | Multilane Crossings | X | X | Y/R | Crossing distances of significant length across multiple lanes |
| 4.4.8 | Long Red Times | X | X | Y/R | Excessive stopped delay at signalized crossings |
| 4.4.9 | Undefined Crossings at Intersections | X | X | Y | Unmarked paths through intersections |
| 4.4.10 | Motor Vehicle Left-Turns | X | X | Y/R | Permissive and protected left-turns across pedestrian and bicycle paths |
| 4.4.11 | Intersection Driveways and Side Streets | X | X | Y/R | Driveways or streets within intersection area of influence |
| 4.4.12 | Sight Distance for Gap Acceptance Movements | X | X | R | Providing adequate sight distance to conflict points |
| 4.4.13 | Grade Change | X | X | Y/R | Vertical curves adjacent to intersections |
| 4.4.14 | Riding in Mixed Traffic | X | | Y/R | On-street bicycle facilities on high-speed/volume roads |
| 4.4.15 | Bicycle Clearance Times | X | | Y/R | Bicycles require longer clearance times than vehicles at signals |
| 4.4.16 | Lane Change Across Motor Vehicle Travel Lane(s) | X | | Y/R | Lane changes by bicycles across motor vehicle lanes |
| 4.4.17 | Channelized Lanes | X | | Y/R | Bicyclist Traveling in Channelized Lane Adjacent to Motor Vehicles |
| 4.4.18 | Turning Motorists Crossing Bicycle Path | X | | Y/R | Lane changes by motor vehicles across bicycle facility |
| 4.4.19 | Riding between Travel Lanes, Lane Additions, or Lane Merges | X | | Y/R | Bicycle lanes with motor vehicle lanes on both sides |
| 4.4.20 | Off-Tracking Trucks in Multilane Curves | X | | Y/R | The tendency of trucks to swing into bicycle lanes while turning |

Note: Sec. = Section in this Guide; Peds. = Pedestrians; X = Applicable to this mode; Y = Yellow; R = Red

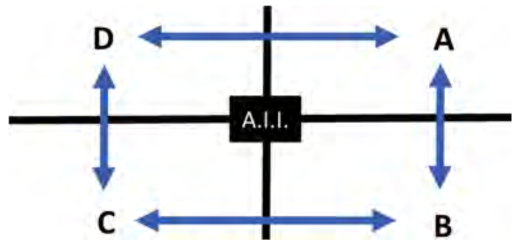


***Exhibit 4-6. Illustration of pedestrian design flag assessment.***

For designs in which there is more than one way to complete a particular movement (e.g., a shared-use path adjacent to an on-street bicycle lane), the analysis should select one of these options and remain consistent over the evaluation of all flags.

For each flag, one or more mitigation interventions apply and are described as part of the design techniques later in this guidebook. To assist in comparing alternatives, use the following procedure:

1. For each alternative, sum the number of yellow pedestrian flags. Repeat this step for red pedestrian flags.
2. For each alternative, divide the number of yellow pedestrian flags by the total possible number of yellow flags and multiply by 100 to determine the Percent Yellow. Repeat this step for red flags to determine the Percent Red.
3. For each alternative, sum the number of yellow bicycle flags. Repeat this step for red bicycle flags.
4. For each alternative, divide the number of yellow bicycle flags by the total possible number of yellow flags and multiply by 100 to determine the Percent Yellow. Repeat this step for red flags to determine the Percent Red.

The design flag assessment presents 20 flags evaluated for pedestrians, for bicyclists, or both. For pedestrians, 13 out of the 20 flags apply, for a total of 52 potential flags (13 flags multiplied by 4 pedestrian flows). For bicycles, 17 out of the 20 flags apply, for a total of 204 potential flags (17 flags multiplied by 12 bicycle movements). An example assessment for four design alternatives (A through D) is given in Exhibit 4-8, showing that Alternative C results in the fewest design flags for both pedestrians and bicycles. However, any alternative can be moved forward if design flags are addressed and mitigated using the guidance in Chapter 5 and the rest of this guidebook.

Exhibit 4-8 summarizes all flags, including their applicability (pedestrian vs. bicyclist) and potential flag severity (yellow vs. red flag). The exhibit further contains a brief description of

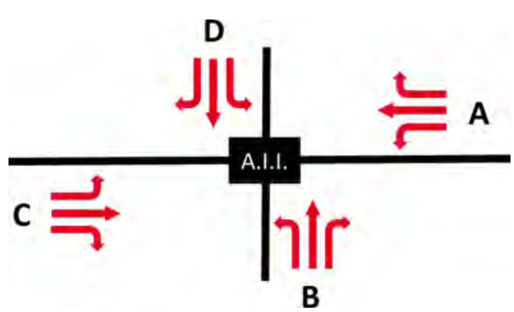


***Exhibit 4-7. Illustration of bicycle design flag assessment.***

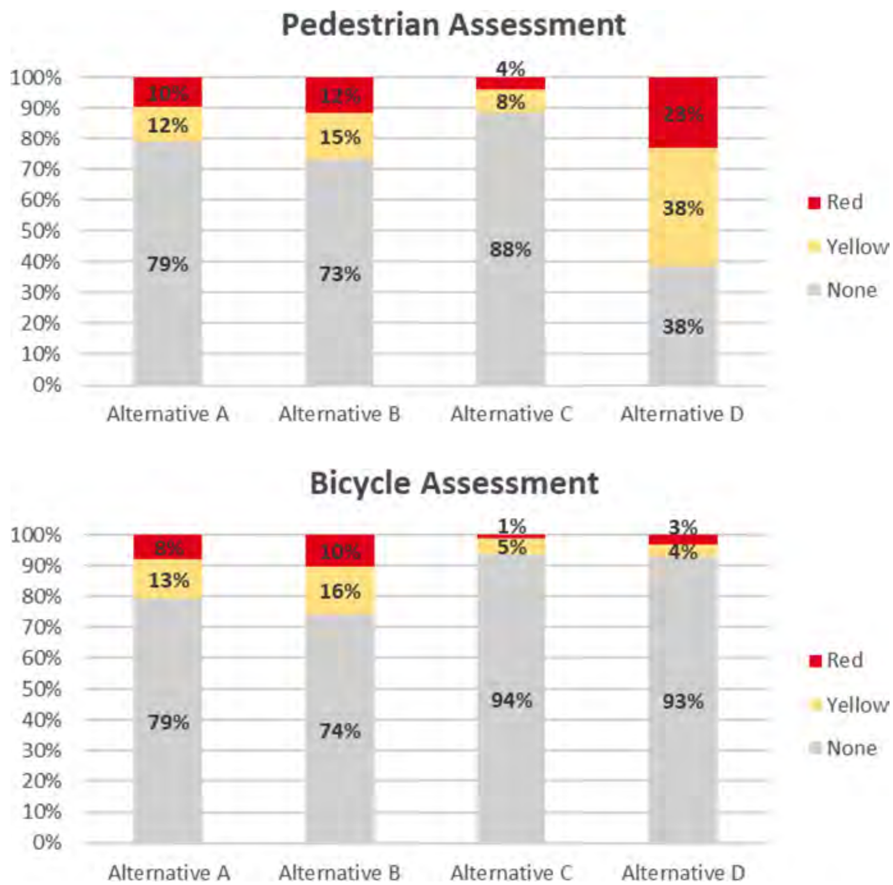


***Exhibit 4-8. Summary of design flags for pedestrian and bicycle assessment.***

each flag. The following sections present each design flag in detail. The provided volumes for thresholds (in vehicles per hour) refer to the peak hour.

### 4.4.1 Motor Vehicle Right-Turns

Right-turning vehicles directly conflict with pedestrians crossing at intersections. Pedestrians often find that their path of travel is impeded by drivers inching forward to see traffic moving left to right, in preparation to making either a right-turn-on-red movement or a right-turn during a permissive green phase. With a right-turn-on-red movement, the driver sees a red signal; during a permissive right-turn, the driver sees a green ball. In both cases, the pedestrian has either a Walk or Flashing Don't Walk indication. The driver inching forward, and even the anticipation of drivers making this movement, degrades the level of comfort for pedestrians who otherwise have a controlled crossing phase at an intersection.

Motor vehicle right-turn conflicts are amplified at channelized turn lanes due to an increase in vehicle speed commonly facilitated by the larger radii of channelized turn lanes. With increasing vehicle speeds, drivers are less likely to yield to pedestrians (see Chapter 2). Channelized turn movements can also inhibit the ability of blind pedestrians to proceed into the crosswalk based on audible cues. Exhibit 4-9 illustrates the right-turn conflict for an intersection without channelized lanes.

Note: This flag applies only to pedestrians; turning conflicts with bicycles are evaluated in Section 4.4.18.

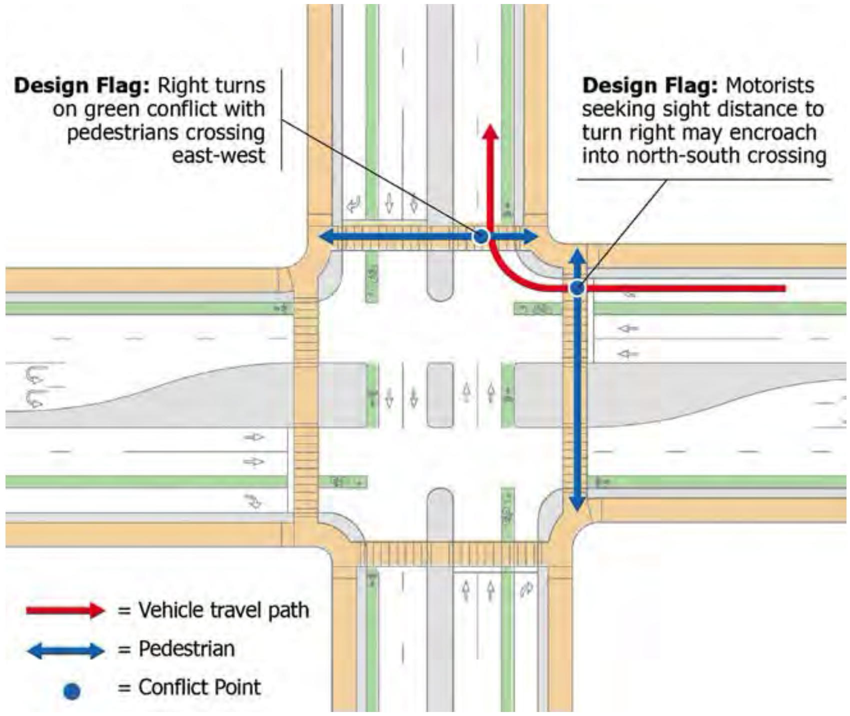


***Exhibit 4-9. Design Flag 1 – Motor vehicle right-turns.***

This motor vehicle right-turn design flag can be categorized as either yellow or red, depending on two dimensions: (1) vehicle right-turn speed, and (2) vehicle right-turn volume. Thresholds for these measures of effectiveness are provided in Exhibit 4-10. The vehicle right-turn speed can be estimated using the speed-radius relationship found in the AASHTO Green Book or measured in the field, while vehicle volumes are available from traffic forecasts or local counts. This flag is only applied to pedestrian paths.

The "Motor Vehicle Right-Turns" flag applies to both right-turns-on-red (vehicles conflicting with perpendicular pedestrian crossing) and right-turns-on-green (vehicles conflicting with parallel pedestrian crossing). A special case of this flag is right-turns in channelized right-turn lanes, which may have higher vehicle speeds.

Vehicle speed directly relates to pedestrian safety. Tefft found the average risk of severe injury for a pedestrian struck by a vehicle traveling 16 mph is 10%, while the risk when struck by a vehicle traveling 23 mph increases to 25% (*7*). Similarly, an increase in the number of vehicles turning across a pedestrian's path increases the likelihood of the pedestrian to encounter a vehicle while crossing. Turning speeds less than or equal to 20 mph and vehicle volumes less than or

**Exhibit 4-10. Design Flag 1 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold* | Red-Flag Threshold* |
|---|---|---|---|---|
| Motor Vehicle Right-Turns | Pedestrian | Vehicle Turning Speed & Vehicle Volume | <=20 mph **AND** <= 50 veh/h | >20 mph **OR** >50 veh/h |

Note: mph = miles per hour; veh/h = vehicles per hour
** If the vehicle movement is stop-controlled or signalized (with no right-turns-on-red), or speeds are below 10 mph (e.g., through a raised crosswalk) this flag is eliminated.*

***Exhibit 4-11. Design Flag 1 example. Vehicles permitted to turn right across marked crosswalks.***

equal to 50 veh/h are therefore given a yellow flag, while a turning speed or volume beyond these thresholds increases the safety risk for the pedestrian and results in a red flag.

Exhibit 4-11 shows a traditional four-legged intersection with both exclusive right-turn lanes and shared through-right lanes. At all four legs, right-turning vehicles cross marked pedestrian crosswalks. Each pedestrian movement would be identified with the appropriate flag color depending on the vehicle turning speed and volume. Given the radius of curvature, vehicle right-turn speeds are likely to be higher for the western crossing than the eastern crossing, for example.

In Exhibit 4-12 an intersection with channelized turn lanes can also be flagged for motorist right-turns. Vehicle speeds at channelized turn lanes are a function of the design of the

***Exhibit 4-12. Design Flag 1 example. Intersection with channelized right-turn lanes.***

channelization island (see Chapter 5). Vehicle speeds can be controlled with raised pedestrian crossings, as shown in the top left, bottom right, and bottom left quadrants of this intersection.

### 4.4.2 Uncomfortable/Tight Walking Environment

As most sidewalks are used for two-way pedestrian traffic, sufficient width for passing opposing or slower-moving pedestrians must be provided. Pedestrians avoid walking immediately next to other modes of traffic or buildings that reduce the usable width of the sidewalk.

The uncomfortable/tight walking environment flag (Exhibit 4-13) only uses the yellow flag, as shown in Exhibit 4-14. A yellow flag is warranted if less than 5 feet of width is provided for sidewalks with vehicle traffic on one side. For sidewalks with traffic on two or more sides (e.g., traffic moves on three sides when pedestrians or bicyclists are positioned on a channelization island), a width of fewer than 10 feet would result in a yellow flag. This flag is only applied to pedestrian paths. Sidewalk widths are also subject to ADA requirements, which have to be considered.

The flag primarily applies to pedestrians, assuming bicyclists travel on-street or on separate facilities. For multiuse path applications, the flag may also be applied to bicyclists. In these

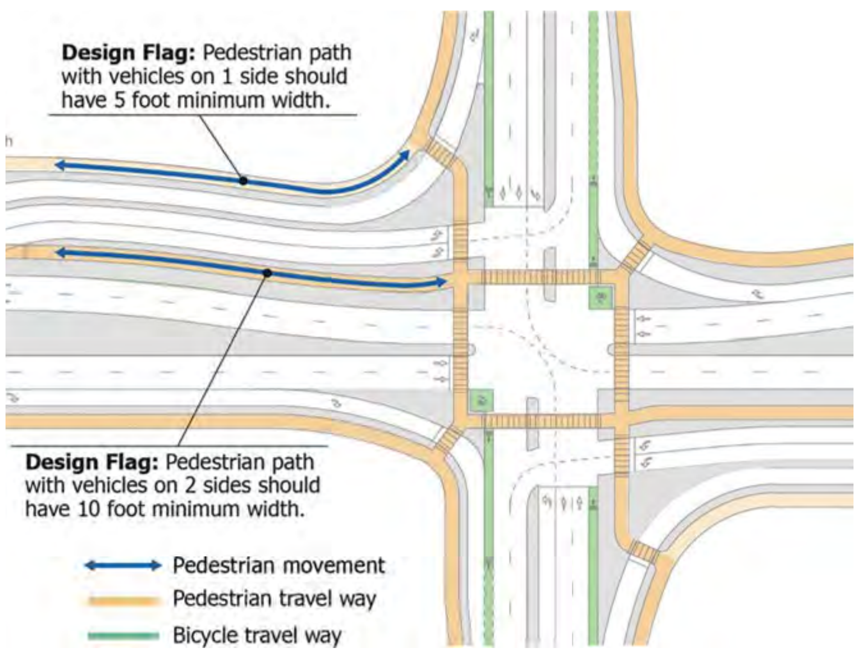


***Exhibit 4-13. Design Flag 2 – Uncomfortable/tight walking environment.***

**Exhibit 4-14. Design Flag 2 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Uncomfortable/ Tight walking environment | Pedestrian | Effective walkway width | < 5 ft if traffic present on one side; <10 ft if traffic present on two sides | N/A |

***Exhibit 4-15. Design Flag 2 example. Narrow median width.***

applications, it is important to consider any shy distance requirements from the edge of the travel lanes, or vertical obstructions. In both cases, the “effective width” is reduced by 2 feet each, recognizing that bicyclists cannot ride immediately next to these obstructions. Chapter 3 discusses bicycle dimensions and shy distances.

This flag applies to walkways that travel parallel to traffic and those with traffic traveling perpendicular to traffic, or at other angles. This flag applies to walkways that travel parallel to traffic and those with traffic traveling perpendicular to the walkway, or at other angles. The flag commonly applies to walkways through channelization islands or within medians.

Exhibit 4-15 shows a Z-crossing from a bus stop on the western side of the median-divided arterial to a local street on the right side. Offset barriers create a walkway through the median. The design should be evaluated for walkway width in the median; at least 10 feet is needed given traffic being present on both sides. If sidewalks were provided on the outside of the travel lanes, a 5-foot minimum walkway would be the standard for the flag evaluation of those walkways.

## 4.4.3 Nonintuitive Motor Vehicle Movements

The nonintuitive motor vehicle movement flag is shown in Exhibit 4-16. When a pedestrian or bicyclist initiates a street crossing, the normal expectation (in countries where driving is on the right side of the roadway) is that conflicting motor vehicle traffic initially comes from the left. A common exception to this is the case of a one-way street. At some A.I.I.s, oncoming traffic may initially approach from the right. The most likely scenario where this would happen in an A.I.I. would be at a DLT where there is no right-turn bypass adjacent to the displaced left-turn movement.

Also, it is common that, when two consecutive crossings are near one another, the oncoming traffic at the second crossing will be from the opposite direction of the first crossing. However,

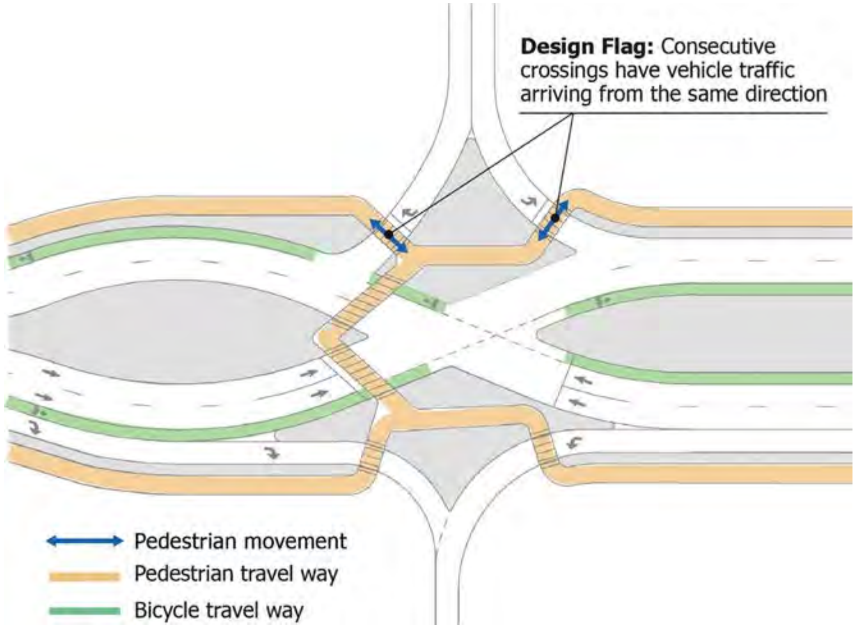


*Exhibit 4-16. Design Flag 3 – Nonintuitive motor vehicle movements.*

at channelized turn lanes and in some A.I.I. configurations, this may not always be the case. For example, in DDIs with sidewalks on the outside, oncoming traffic comes from the same direction in back-to-back crossings. This can confuse a pedestrian or bicyclist, which can create a significant safety risk.

Nonintuitive motor vehicle movements flags can be yellow or red, depending on the acceleration profile of the vehicle at the conflict point. As shown in Exhibit 4-17, if the vehicle is decelerating, as is typical near the first half of a curve, a yellow flag would be assigned. If the conflict point between the pedestrian and the nonintuitive vehicle movement occurs while the vehicle is accelerating or in a free-flow condition, a red flag would be assigned. Red flags occur most frequently at interchange entrance ramps where the vehicle-pedestrian crossing is located downstream of a curve's midpoint. This flag is only applied to pedestrian paths.

At the eastern junction of the interchange in Exhibit 4-18, pedestrians traveling eastbound on the southern crosswalk at the interchange would encounter vehicles arriving from the right. The typical expectation in right-side driving countries would be to first encounter vehicles arriving from the left. At the northern crossing, it appears the crossing location is such that vehicles traveling east-to-north and west-to-north would both be accelerating when crossing the pedestrian path. Therefore, the northern crossing would be assigned a red flag. The southern crossing is stop-controlled and therefore no flag is assigned as the vehicle is not accelerating, decelerating, or in a free-flow condition.

**Exhibit 4-17. Design Flag 3 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Nonintuitive Motor Vehicle Movements | Pedestrian | Vehicle acceleration profile | Vehicle decelerating | Vehicle accelerating or free-flowing |

***Exhibit 4-18. Design Flag 3 example. Pedestrian crossing with vehicles from the right as opposed to left.***

### 4.4.4 Crossing Yield-Controlled or Uncontrolled Vehicle Paths

The flag for crossing yield-controlled or uncontrolled vehicle paths is shown in Exhibit 4-19. Focus group discussions indicated yield-controlled and uncontrolled crossings of vehicle and pedestrian paths lead to uncomfortable and potentially unsafe interactions. Even if marked, drivers may not be looking for pedestrians at the crossing and may fail to yield to them. Such crossings are typical at channelized turn lanes found at a DLT, DDI, or RCUT. Additionally, yield-controlled or uncontrolled vehicle crossings may be present at the entrance ramp junctions of DDIs.

This design flag can be categorized as either yellow or red, depending on two dimensions: (1) vehicle turn speed, and (2) vehicle turn volume. Thresholds for these measures of effectiveness are provided in Exhibit 4-20. The vehicle turn speed can be estimated using the

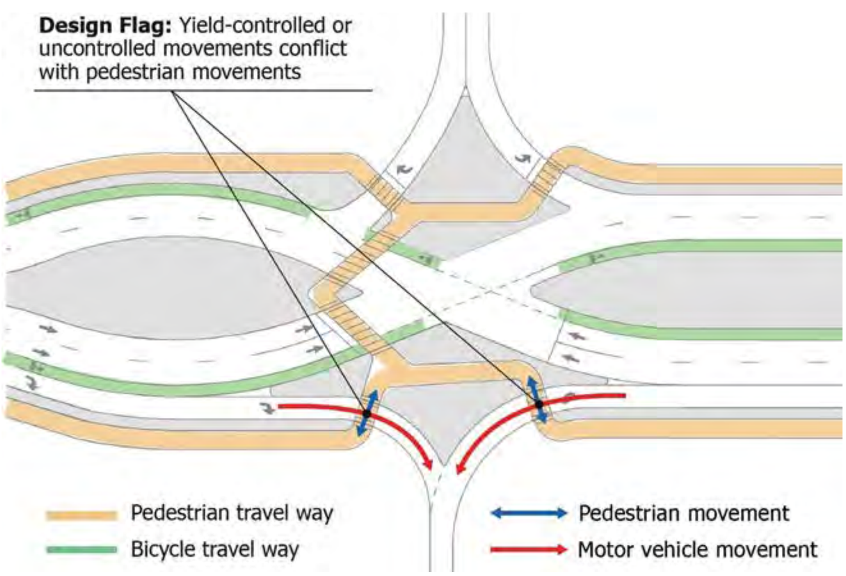


***Exhibit 4-19. Design Flag 4 – Crossing yield-controlled or uncontrolled vehicle paths.***

**Exhibit 4-20. Design Flag 4 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Crossing yield-controlled or uncontrolled vehicle paths | Pedestrian and Bicycle | Vehicle Speed & Vehicle Volume | <=20 mph **AND** <= 50 veh/h | >20 mph **OR** >50 veh/h |

Note: mph = miles per hour; veh/h = vehicles per hour

***Exhibit 4-21. Design Flag 4 example. Yield-controlled channelized turn lanes.***

speed-radius relationship found in the AASHTO Green Book or measured in the field, while vehicle volumes are available from traffic forecasts or local counts. This flag applies to both pedestrian and bicycle paths.

The likelihood of vehicle-pedestrian or vehicle-bicycle interaction increases with an increase in vehicle volumes, while the likelihood of severe crashes increases with vehicle speed (*7*). Therefore, vehicle volumes greater than 50 vehicles per hour *or* vehicle speeds greater than 20 miles per hour indicate a red flag.

Exhibit 4-21 has two yield-controlled turns, one each in the northwestern and southeastern quadrants. A visual comparison of the channelized curves suggests the southeastern radius may be larger, resulting in higher vehicle speeds.

## 4.4.5 Indirect Paths

The indirect paths design flag is shown in Exhibit 4-22. Indirect, or out-of-direction, paths lead to a moderate level of discomfort for pedestrians and bicyclists navigating an intersection. These indirect paths are notable at traditional intersections with a closed crosswalk and at RCUT and DLT designs where circuitous pedestrian and bicyclist paths may be present. An intersection with a relatively high number of crossings for a particular origin-destination pattern not facilitated by the design can be burdensome to pedestrians and bicyclists and detracts from the quality of service. Paths that are inefficient and burdensome may nudge pedestrians or bicyclists into risk-taking behavior in pursuit of a seemingly more convenient path not provided.

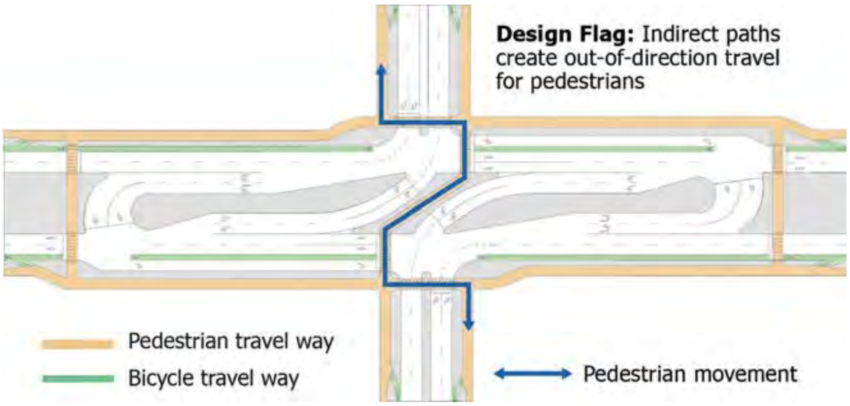


***Exhibit 4-22. Design Flag 5 – Indirect paths.***

The level of comfort in this assessment category is not strictly a function of the number of crossings (e.g., provision of midblock refuge to create a two-stage crossing), but rather from multiple crossings that do not lead directly to the desired destination. One such example is an intersection with the crossing of an approach leg restricted, forcing pedestrians to walk around and cross in multiple locations.

The indirect paths flag can be classified as yellow or red, depending on the out-of-direction travel distance of the user (Exhibit 4-23). Thresholds are based on the delay experienced by the user, assuming a pedestrian walking speed of 3 feet per second and a bicycle speed of 15 feet per second. At a delay of 30 seconds, users are likely to execute risky behaviors to avoid further delay, while at 45 seconds, there is a high likelihood of risk-taking behavior (5). Multiplying the speed by the delay values produces the yellow and red distance thresholds. This flag can be applied to pedestrian paths or bicycle movements.

Some indirect travel paths may result in additional signal delay. This occurs when the provided path encounters signalized crossings that the direct path otherwise would not encounter. If the signal timing does not explicitly provide progression for pedestrians and/or bicycles along the path, an additional stopped delay is likely. The indirect path flag does not account for stopped delay; it should be analyzed using the Long Red Time flag (#8).

Intersections with more than four legs often result in indirect paths, as shown in Exhibit 4-24. A pedestrian traveling south along the eastern sidewalk of the northwestern leg would need to travel across the northwestern leg before continuing south, shown in blue. The desire line is shown in red. To find the total indirect length, subtract the distance of the red path from the total distance of the blue path to arrive at the portion of the path that is indirect.

Exhibit 4-25 shows a four-leg intersection in which one leg is not marked for crossing. The intended path of a pedestrian arriving at the northwest quadrant and desiring to travel to the southwest quadrant is to first travel east, then south, then return west. To find the indirect path distance, the distance to cross directly from the northwest quadrant to the southwest quadrant should be subtracted from the distance to travel east, then south, then west.

**Exhibit 4-23. Design Flag 5 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Indirect Paths | Pedestrian & Bicycle | Out-of-direction travel distance | 90 ft (ped)<br>450 ft (bike) | 135 ft (ped)<br>675 ft (bike) |

Note: ft = feet

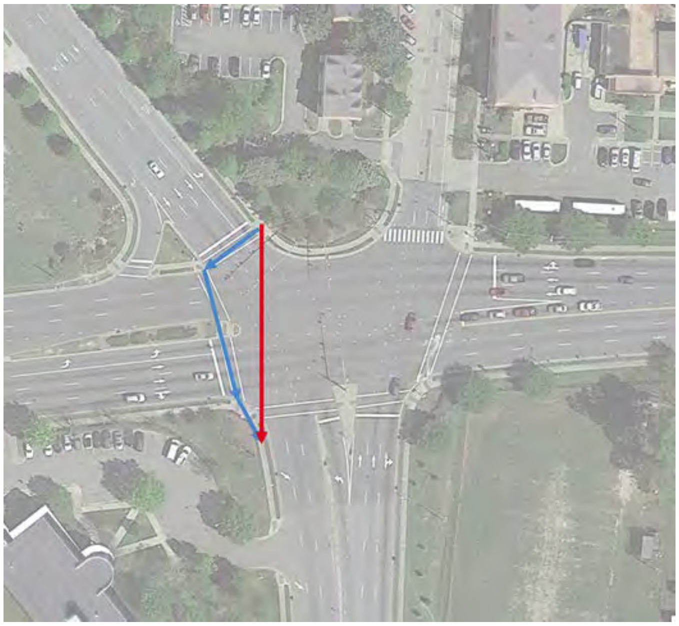

***Exhibit 4-24. Design Flag 5 example. Out-of-direction travel for southbound crossing.***

***Exhibit 4-25 Design Flag 5 example. Out-of-direction travel for southbound crossing.***

### 4.4.6 Executing Unusual Movements

The executing unusual movements design flag is shown in Exhibit 4-26. Design consistency helps roadway users by setting expectations for how to move around a network and through an intersection. Just as drivers have expectations for various movements at an intersection, pedestrians and bicyclists have similar expectations about typical crossing patterns at intersections. This flag captures the confusion users may experience upon arriving at an intersection and being unsure of how to continue on the desired path. This flag is most commonly seen at DDIs with inside paths, RCUTs with Z-crossing designs, and DLTs with channelized turns and multiple crossing stages. The first two are examples of paths that may require users to travel along an indirect path. [Note: depending on the distance of indirect travel, an indirect path flag (flag #5) may also be assigned]. The DLT with channelized turns and multiple crossing stages may be unusual due to the significant number of stages needed to cross a single leg of the intersection. Users may not expect to encounter multiple islands and refuge areas.

This design flag can only be yellow and is based on local expectations as shown in Exhibit 4-27. The general familiarity of movement by the public may best be gathered through public meetings and a thorough understanding of local practices. The first-of-its-kind design in an area may be flagged for an unusual movement, but if, over time, the design is replicated, the movement may no longer be unusual to the user.

This flag is not intended to be used for expected, or common, movements that are unpopular or undesirable by the public. Typically, the lack of desirability would indicate another flag might be present (e.g., indirect path, motor vehicle right-turns, riding in mixed traffic, etc.). This flag can be applied to pedestrian paths or bicycle movements.

In Exhibit 4-28, the southwest/northeast street is a one-way, two-lane road that transitions to a one-way, one-lane road southwest of the intersection. A southwest bound bicycle originating in a shared bicycle-motor vehicle lane is presented with a marked bike lane to the left that

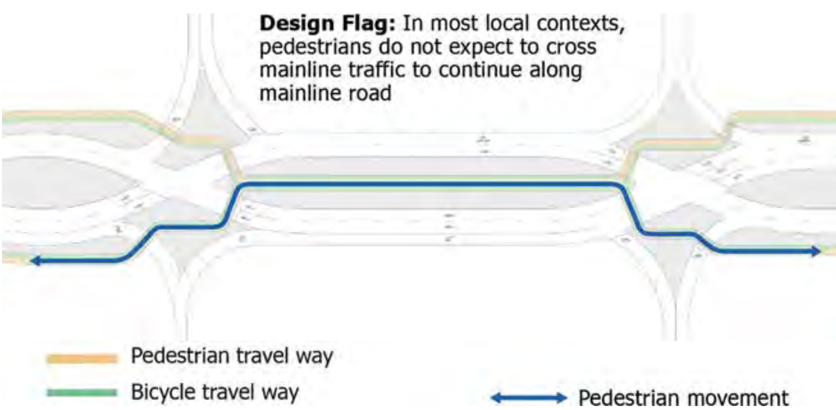


***Exhibit 4-26. Design Flag 6 – Executing unusual movements.***

**Exhibit 4-27. Design Flag 6 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Executing Unusual Movements | Pedestrian & Bicycle | Local Expectation | The path does not match the expectation | N/A |

***Exhibit 4-28. Design Flag 6 example. Bike lane developing between lanes.***

proceeds across the intersection into a two-way cycle track. In most locations, the presentation of an exclusive bicycle lane developing between two vehicular lanes and proceeding at an angle through an intersection would be considered an unusual movement.

### 4.4.7 Multilane Crossings

The multilane crossings design flag is shown in Exhibit 4-29. Long crossings, particularly with multiple lanes from both directions, are a source of stress and potentially risk at intersections. Pedestrians in focus groups noted a comfort-based preference for shorter crossings with median

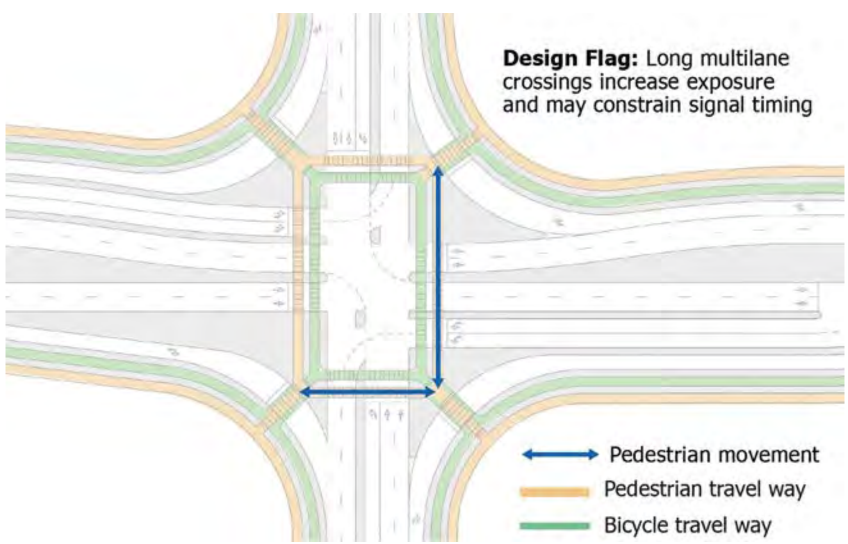


***Exhibit 4-29. Design Flag 7 – Unassisted multilane crossings.***

**Exhibit 4-30. Design Flag 7 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Multilane crossing | Pedestrian & Bicycle | Number of lanes without refuge | 2 – 3 lanes (ped)<br>4 – 5 lanes (bike) | >3 lanes (ped)<br>>5 lanes (bike) |

***Exhibit 4-31. Design Flag 7 example. Pedestrian and bicycle crossings conflicting with 2 and 3 vehicle lanes.***

refuges, for crossing one direction of travel at a time, and for having raised separation between opposing directions of traffic. Similar considerations apply for bicyclists.

This flag can be classified as either yellow or red, depending on the number of vehicle travel lanes crossed without refuge as shown in Exhibit 4-30. This flag can be applied to pedestrian paths or bicycle movements.

The number of lanes is irrespective of the direction of travel. Bicycle lanes and parking lanes are not counted in this assessment. For example, the following would all be classified as a yellow flag:

- A pedestrian crossing three lanes of traffic in the same direction
- A pedestrian crossing two lanes of traffic in one direction and one lane of traffic in the opposing direction
- A pedestrian crossing two or more lanes of opposing traffic plus a two-way-left-turn-lane.

Pedestrian paths along each of the four legs in Exhibit 4-31 would qualify for a yellow flag. The eastern, southern, and western paths all cross three vehicle travel lanes while the northern path crosses two lanes. Bicycle lanes and parking lanes do not count toward the flag threshold. For bicycles, no movement crosses four vehicle lanes, so there would be no bicycle flags for this intersection.

## 4.4.8 Long Red Times

The long red times design flag is shown in Exhibit 4-32. Both pedestrians and bicyclists can experience extended delays due to long cycle lengths and the number of phases over which

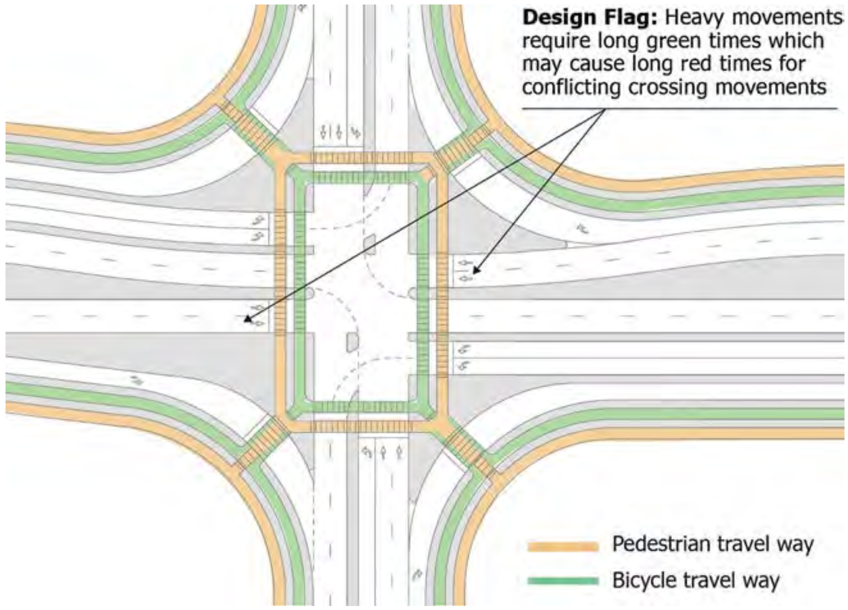


***Exhibit 4-32. Design Flag 8 – Long red times.***

a particular origin-destination movement must be completed. These delays should be minimized to the extent possible. Excessive delays can result in reduced compliance through an increase in risk-taking behavior. Crossings which must be completed in multiple stages, or over multiple phases or multiple cycles (such as through a bicycle box to execute a left-turn or a pedestrian needing to cross two legs of an intersection to execute a diagonal route) commonly result in long delays due to the cumulative effect of the red times.

This flag can be classified as either yellow or red, depending on stopped delay (Exhibit 4-33). At a delay of 30 seconds, users are likely to execute risky behaviors to avoid further delay, while at 45 seconds, there is a high likelihood (*4*). This flag can be applied to pedestrian paths or bicycle movements. For pedestrians, the flag is assessed for each quadrant-to-quadrant crossing. If a connection is not provided, the resulting delay is cumulative across the shortest feasible route. For multistage crossings, the delay is also evaluated across all stages of the crossing.

For bikes, the delay is assessed for each turning movement. For bicycle movements that are redirected (e.g., through a MUT or RCUT U-turn) the total cumulative delay is considered.

If a bicycle movement requires the use of two phases, such as with a bicycle box to execute a left-turn, the total delay experienced over both phases should be considered. However, engineering judgment should be used to determine how the phase order would affect the delay experienced for the second phase.

Out-of-direction travel time is not considered in the delay measure, because it is separately accounted for in flag #5.

**Exhibit 4-33. Design Flag 8 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Long Red Times | Pedestrian & Bicycle | Delay | 30 seconds | 45 seconds |

**Exhibit 4-34. Percent red time reference table.**

| # Critical Phases | % Red Time of Cycle Length | |
|---|---|---|
| | Crossing with Major Vehicle Movement | Crossing with Minor Vehicle Movement |
| 2 | 30% | 70% |
| 3 | 50% | 75% |
| 4 | 60% | 85% |

A planning-level estimation of delay can be made using the equation below. This method assumes random arrival at the intersection. Therefore, the delay calculation may not be appropriate for movements that require multiple phases (e.g., the second phase of a bicycle box-enabled left-turn movement):

$$Delay = \frac{r^2}{2C}$$

Where:

$r$ = movement red time (seconds)
$C$ = cycle length (seconds)

When the movement red time is not known, the estimates in Exhibit 4-34 can be used to find the percent of the time a movement is red relative to the cycle length. This percent should be multiplied by the cycle length to determine the value of red time in seconds. Movements that proceed with the major vehicle movement (e.g., major street through) typically have less red time than movements that proceed with minor vehicle movements (e.g., cross street through, left-turns)

A pedestrian crossing eastbound or westbound with the minor street in Exhibit 4-35 may experience long red times. Minor streets typically have shorter green times relative to major streets, and exclusive left-turn lanes on each leg indicate the possibility of protected or protected-permissive left-turn phases, which increases the cycle length.

***Exhibit 4-35. Design Flag 8 example. Large intersection with possible long red times.***

### 4.4.9 Undefined Crossings at Intersections

The undefined crossings at intersections design flag is shown in Exhibit 4-36. For all intersection forms, unmarked or undesignated space at an intersection can lower the level of comfort when walking or biking. Absent clear pavement demarcation, right-turning drivers are more likely to encroach on pedestrian and bicyclist crossings, creating conflicts. Additionally, right-turning or left-turning vehicles may not expect pedestrians or bicycles at the downstream crossing point. For example, in Exhibit 4-36, westbound-to-northbound right-turning vehicles may not expect pedestrians and bicycles to be traveling along the northern leg despite those users likely having the right-of-way.

This flag can be classified only as a yellow flag as shown in Exhibit 4-37. If there is no marking through the intersection for the movement, the yellow flag should be applied. This includes bicycle lane markings that are present on both sides of the intersection but do not extend through the intersection. This flag can be applied to pedestrian paths or bicycle movements. Right-turn and left-turn bicycle movements are exempt from this flag.

Exhibit 4-38 shows a situation with pedestrian crossings along all four legs; this situation would not receive a flag for any of the pedestrian path evaluations. However, the eastbound through and westbound through bicycle movements have exclusive lanes for which markings do not extend through the intersection. Therefore, the eastbound through and westbound through movements would receive a yellow flag. Because the northbound and southbound through movements do not have exclusive bicycle lanes nor a shared-use path, this flag does not apply.

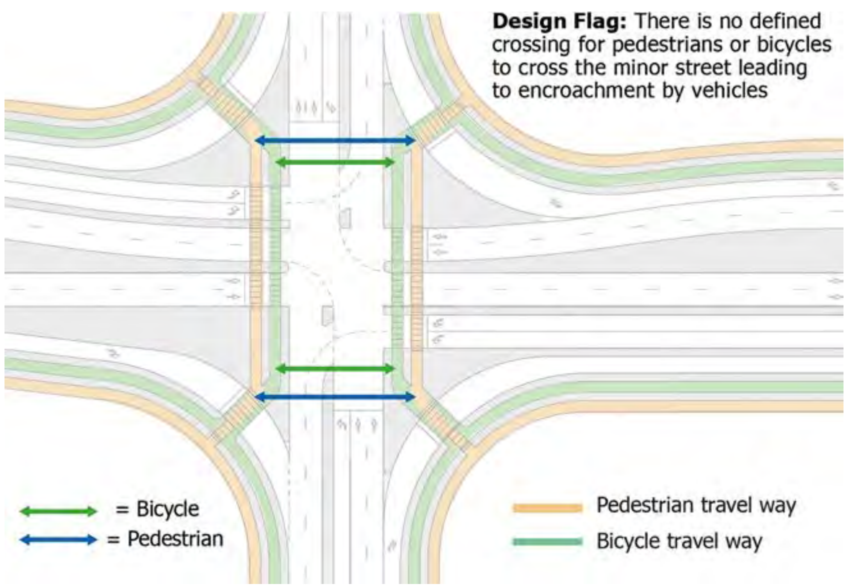


*Exhibit 4-36. Design Flag 9 – Undefined crossings at intersections.*

**Exhibit 4-37. Design Flag 9 – Yellow-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Undefined Crossings at Intersections | Pedestrian & Bicycle | Path Markings | Unmarked crossing | N/A |

***Exhibit 4-38. Design Flag 9 example. Westbound bicycle lane without markings in the intersection.***

***Exhibit 4-39. Design Flag 9 example. Undefined vehicle right-turn space.***

In Exhibit 4-39, crosswalks exist at all legs and from the curb through a channelized vehicle right-turn. However, the resulting large undefined space adjacent to the vehicle right-turns has no clear pedestrian demarcation and does not use a raised channelization island. This results in a yellow flag for pedestrians crossing through that space.

### 4.4.10 Motor Vehicle Left-Turns

The motor vehicle left-turns design flag is shown in Exhibit 4-40. Both permissive and protected motor vehicle left-turns can affect the safety and comfort of pedestrians and bicyclists. While pedestrians are crossing or bicyclists are making a through movement, permissive left-turning drivers are often focused on finding a gap in oncoming motor vehicle traffic and may not be watching out for nonmotorized road users. Similarly, one study found that leading protected left-turns lead to more pedestrian-vehicle conflicts (*8*). This may be because, on seeing a red indication on the opposing street, the pedestrian expectation may be to receive a walk indication. Pedestrians may not realize the conflicting leading protected left-turn has been given the green indication but the walk interval has not yet started.

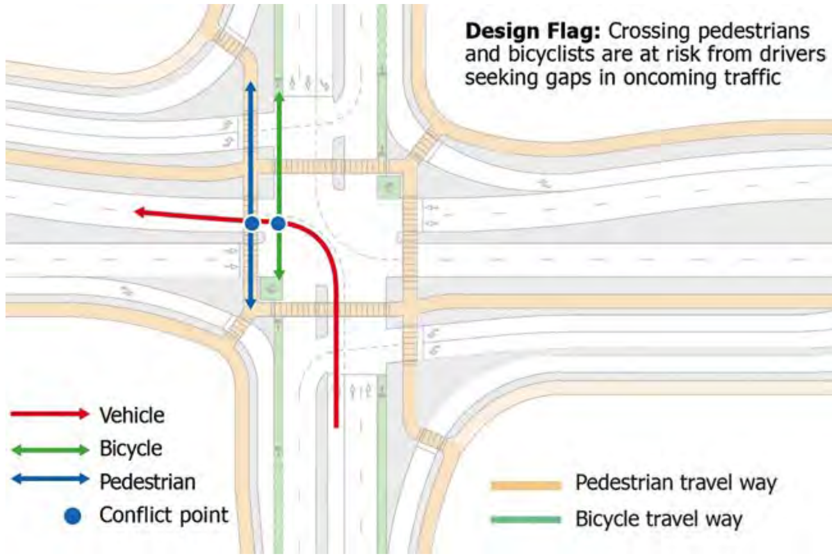


***Exhibit 4-40. Design Flag 10 – Motor vehicle left-turns.***

This design flag can be categorized as either yellow or red, depending on two dimensions: (1) vehicle turn speed, and (2) vehicle turn volume. Thresholds for these measures of effectiveness are provided in Exhibit 4-41. The vehicle turn speed can be estimated using the speed-radius relationship found in the AASHTO Green Book or measured in the field, while vehicle volumes are available from traffic forecasts or local counts. This flag can be applied to pedestrian paths or bicycle movements.

Exhibit 4-42 shows the conflict between a heavy pedestrian movement and a left-turning vehicle. Although the vehicle is turning from a one-way road and, therefore, the driver need not look for gaps in oncoming vehicles, the heavy pedestrian volume may reduce the capacity of the

**Exhibit 4-41. Design Flag 10 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Motor Vehicle Left-Turns | Pedestrian & Bicycle | Vehicle Turning Speed & Vehicle Volume | <=20 mph **AND** <= 50 veh/h | >20 mph **OR** >50 veh/h |

Note: mph = miles per hour; veh/h = vehicles per hour

***Exhibit 4-42. Design Flag 10 example. Conflict between left-turning vehicle and pedestrians.***

***Exhibit 4-43. Design Flag 10 example. Permissive left-turns.***

left-turning movement and thus increase vehicle delay and the likelihood of a driver accepting an inappropriately small gap in the pedestrian flow.

Exhibit 4-43 shows a more traditional permissive left-turn conflict with two-directional traffic. Once a left-turning driver sees a gap in the oncoming vehicles, he or she will accelerate to complete the left-turn movement and may not see the pedestrian or cyclist until either it is too late to stop or he or she is forced to stop in the path of conflicting motor vehicles.

### 4.4.11 Intersecting Driveways and Side Streets

The intersecting driveways and side streets design flag is shown in Exhibit 4-44. Driveways and sidestreets near intersections can result in an increased cognitive load and distractions for all users. Users at the intersection and the driveway and sidestreet may be focused on monitoring multiple traffic streams for noncompliant behavior at the expense of monitoring the users in the immediate vicinity. Driveways and side streets that intersect with two-way bicycle lanes or cycle tracks (either at street or sidewalk level) are of particular concern. Drivers attempting to turn right out of a driveway or sidestreet and merge with traffic traveling left to right may not expect or look for bicycles traveling right to left (because the driver's attention is to their left to screen for gaps in vehicular traffic).

This flag can be classified as either yellow or red depending on three factors as shown in Exhibit 4-45: (1) the mode of travel, (2) the number of directions of travel, and (3) the number of driveways or side streets in the area of influence. The area of influence is the greater of 250 feet in both directions from the center of the main intersection (for a total of 500 feet) or the entire frontage area along the path through the intersection. For example, a DLT with a median pedestrian walkway that extends 800 feet from the main intersection before returning pedestrians to the outside sidewalk would have an area of influence of 800 feet for that path. This flag can be applied to pedestrian paths or bicycle movements.

Given the increased concern of vehicle/bicycle interaction at two-way bicycle facilities, any access points present within the area of influence should be classified as a red flag. For pedestrian facilities and one-way bicycle facilities, one or two access points should be classified as a yellow flag, while more than two should be classified as a red flag.

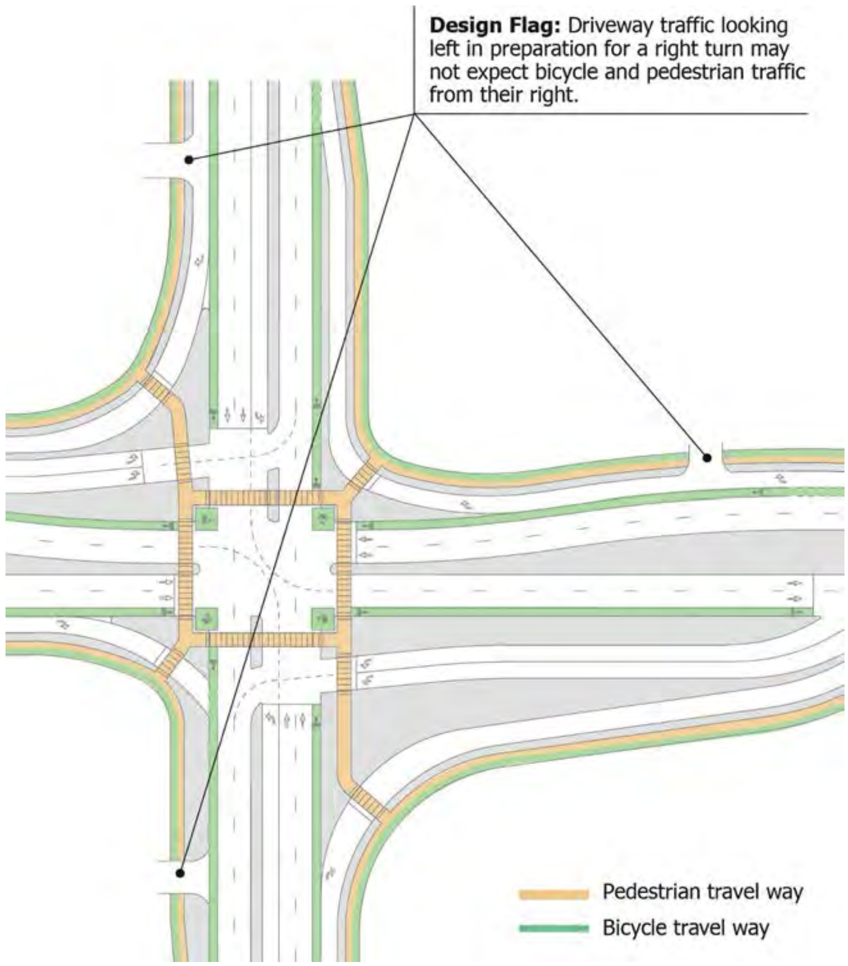


***Exhibit 4-44. Design Flag 11 – Intersecting driveways and side streets.***

In Exhibit 4-46, bicycles traveling northbound and pedestrians traveling north- or southbound on the eastern side of the intersection encounter four driveways (shown as red Xs) within the 500-foot total area of influence shown. This would classify as a red flag for those paths and movements. A right-turning east to north bicycle encounters five access points classifying the movement as a red flag.

Exhibit 4-47 shows a two-way multiuse path on the east side of the intersection resulting in potential conflicts with right- and left-turning vehicles – particularly for pedestrians and bicycles approaching from the north (given that drivers tend to look south for gaps).

**Exhibit 4-45. Design Flag 11 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Intersecting Driveways and Side Streets | Pedestrian & Bicycle | # of Access points in Area of Influence | 1-2 (peds) 1-2 (one-way bikes) | >2 (peds) >2 (one-way bikes) >0 (two-way bikes) |

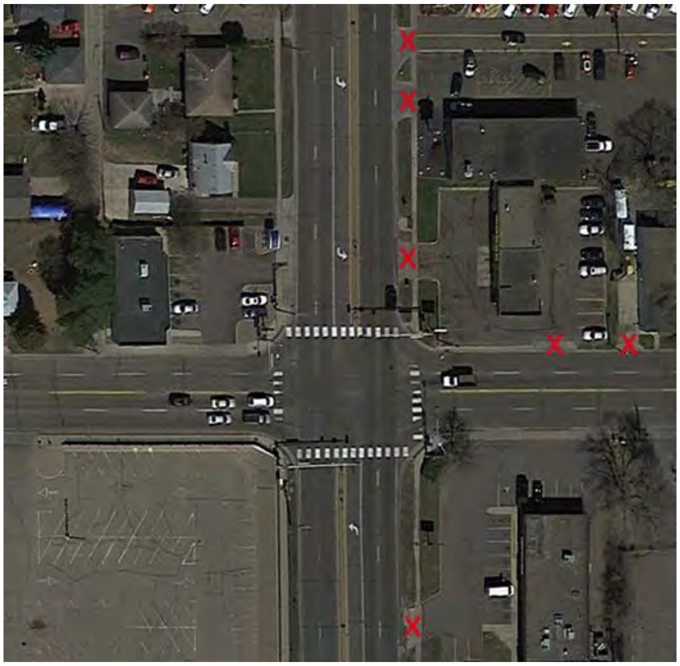

***Exhibit 4-46. Design Flag 11 example. Significant number of driveways and side streets adjacent to the intersection.***

***Exhibit 4-47. Design Flag 11 example. Multiuse path crossing.***

### 4.4.12 Sight Distance for Gap Acceptance Movements

The design flag describing sight distance for gap acceptance movements is shown in Exhibit 4-48. Throughout the design, sight distance must be provided. Sight distance includes these components:

- **Stopping sight distance:** the distance for drivers to react to objects in the roadway, including pedestrians and bicyclists in conflict areas.
- **Intersection sight distance:** the distance for drivers to see oncoming drivers and bicycles and pedestrians, and vice versa. The concept of **pedestrian crossing sight distance** was introduced in *NCHRP Report 834* (*9*) and should be provided to ensure that pedestrians can see far enough to judge gaps necessary for crossing adequately.
- **Decision sight distance:** the distance when in motion for drivers to make decisions, such as lane selection.
- **View angles:** when looking to the left or right, a driver's view angle should not exceed 15 degrees beyond a line perpendicular to the alignment of the vehicle. Oncoming vehicles, bicyclists, and pedestrians located beyond this angle may be in a driver's blind spot and thus not visible.

This flag should be classified as red if the required sight distance is not provided, as shown in Exhibit 4-49. Sight distance requirements by vehicle speeds can be found in the AASHTO Green Book and *NCHRP Report 834* for pedestrians. This flag can be applied to pedestrian paths or bicycle movements.

Exhibit 4-50 and Exhibit 4-51 show the plan and profile images of a T-intersection. Due to vertical and horizontal curves, a vehicle traveling south along the mainline may not have

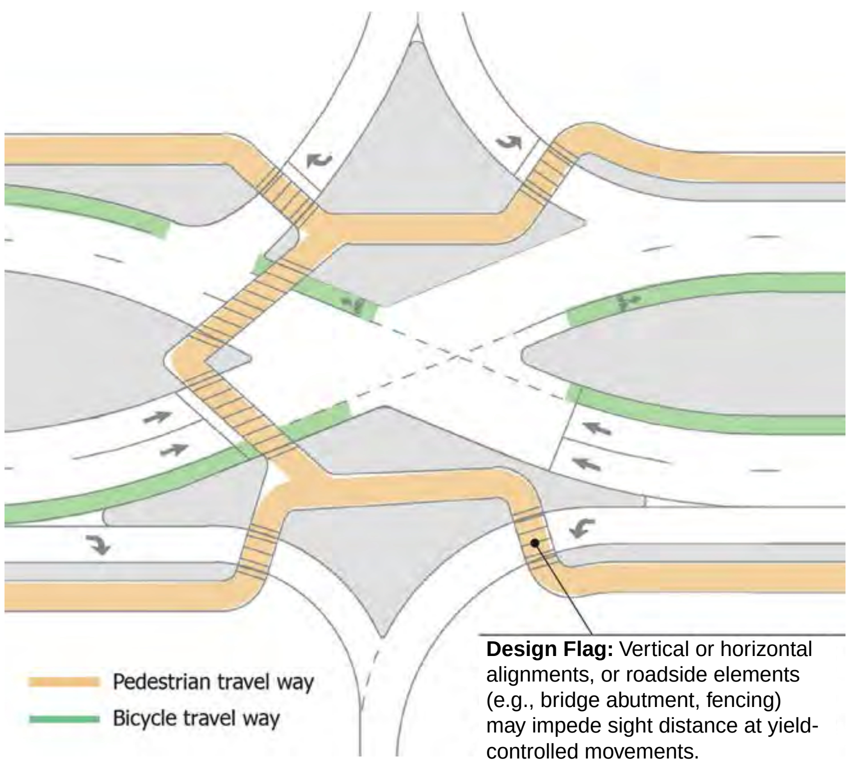


***Exhibit 4-48. Design Flag 12 – Sight distance for gap acceptance movements.***

**Exhibit 4-49. Design Flag 12 – Red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Sight distance for gap acceptance movements | Pedestrian & Bicycle | Sight Distance | N/A | Less than required for vehicle speed |

***Exhibit 4-50. Design Flag 12 example. Plan view of the intersection with significant vertical and horizontal curves limiting sight distance.***


***Exhibit 4-51. Design Flag 12 example. Profile view of the intersection with significant vertical and horizontal curves limiting sight distance.***

appropriate sight distance for pedestrians standing on the northeast quadrant preparing to cross the mainline to the west.

### 4.4.13 Grade Change

The grade change design flag is shown in Exhibit 4-52. Grade changes within or immediately next to an intersection can create challenges for pedestrians and bicycles. For bicycles, positive grades require more power to increase or maintain speeds. If a bicycle is stopped, such as at a red signal indication or while yielding at a permissive movement, initiating movement uphill without lateral deviation in the path can be especially challenging. Pedestrians, particularly those with mobility challenges or those carrying or pushing other objects (e.g., strollers and groceries) can face problems with both positive and negative grades. On an uphill, pedestrians may move more slowly, thus increasing the time necessary to clear the intersection. On a downhill, pedestrians with lower joint problems may slow down to reduce the impact on ankle, knee, and hip joints. Pedestrians using or pushing objects with wheels may struggle to maintain control as gravity's effect increases the travel speed.

This flag can be classified as either yellow or red, depending on the steepest grade experienced along the path or movement. The thresholds are shown in Exhibit 4-53. Grades with a positive or negative slope of 3 to 5 degrees would be classified as a yellow flag, while grades with a positive or negative slope exceeding 5 degrees would be classified as a red flag. The slope of curb ramps should not be considered in determining the steepest grade but should still conform to ADA requirements. This flag can be applied to pedestrian paths or bicycle movements.

Exhibit 4-54 shows a steep uphill grade headed northbound immediately next to the intersection. Northbound bicyclists who must stop for a red indication have only the width of the intersection to gain speed before beginning the descent. Those traveling eastbound may need to slow or stop completely to yield to oncoming traffic. Vehicles traveling down an incline may be less likely to yield to pedestrians.


***Exhibit 4-52. Design Flag 13 – Grade change.***

**Exhibit 4-53. Design Flag 13 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Grade Change | Pedestrian & Bicycle | % grade | +3% to +5% **OR** -3% to -5% | <–5% **OR** >+5% |


***Exhibit 4-54. Design Flag 13 example. Significant uphill grade adjacent to intersection.***

### 4.4.14 Riding in Mixed Traffic

The riding in mixed traffic design flag is illustrated in Exhibit 4-55. As noted in Chapter 3, riding in mixed traffic next to motorized vehicles with high speeds, high volumes, or both have been documented as both a safety issue and a comfort issue for bicyclists. A heavy volume of motor vehicles or vehicles traveling at a higher speed can create a high level of stress for bicyclists and an increased likelihood of severe injury or death if a bicyclist-motorist collision occurs.

This flag can be classified as yellow or red, depending on two dimensions: (1) vehicle speed and (2) vehicle volume per day as shown in Exhibit 4-56. Thresholds are based on FHWA's *Bikeway Selection Guide* (*10*) and were shown in Chapter 3 of this guidebook. The yellow threshold corresponds to the recommended conditions for use of an on-street bike lane, preferably with a buffer, while the red threshold corresponds to the recommended conditions for a separated bike lane or shared-use path. Shared-lane designs are subject to both the yellow and red thresholds, while bike lanes are subject only to the red threshold.

Vehicle speed can be determined by field data collection or, absent such data, by using the design speed. Engineering judgment should be applied to determine if the expected vehicle speed might be higher or lower than the design speed, given the intersection environment. Vehicle volume can be found from traffic forecasts or local counts. This flag can only be applied to bicycle movements.

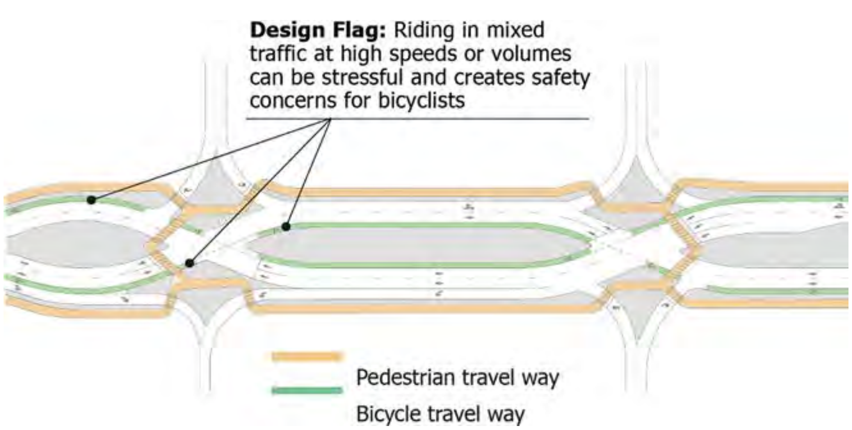


***Exhibit 4-55. Design Flag 14 – Riding in mixed traffic.***

**Exhibit 4-56. Design Flag 14 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Riding in Mixed Traffic | Bicycle | Vehicle Speed & Vehicle Volume | 25-35 mph **OR** 3,000 – 7,000 vpd | >35 mph **OR** >7,000 vpd |

Note: mph = miles per hour; vpd = vehicles per day

***Exhibit 4-57. Design Flag 14 example. On-street bicycle lanes adjacent to heavy volume roadway.***

Exhibit 4-57 shows an intersection with a posted 25 mph speed limit on the east-west street and a 35 mph speed limit on the north-south street. On both streets, there is a dedicated bike lane with no buffer. Because the design uses a bike lane, only the red threshold should be evaluated. Both roadways are at or under the 35 mph posted speed, although local data may reveal actual vehicle speeds to be higher than 35 mph. If so, the red flag would be applied. If actual vehicle speeds are at or under 35 mph, the total daily vehicle volume on each road should be analyzed.

### 4.4.15 Bicycle Clearance Time

The bicycle clearance time design flag is illustrated in Exhibit 4-58. Clearance time is determined specifically for motorists and pedestrians in the calculations of yellow and red intervals for motorists and flashing Don't Walk time for pedestrians. Neither clearance time calculation is likely appropriate for bicycles, given their travel speed relative to pedestrians or motor vehicles. Bicyclists using signals for motor vehicles must use personal judgment to determine if there is enough time to clear the intersection. Absent bicycle-specific signals, there are typically two options to assist bicyclists in this decision:

- If a pedestrian signal is present with a countdown indicator, bicyclists may get a better idea of when the signal indication is about to change. It is still up to the bicyclists to determine how much time they need to cross and to decide whether to attempt a crossing. The decision to

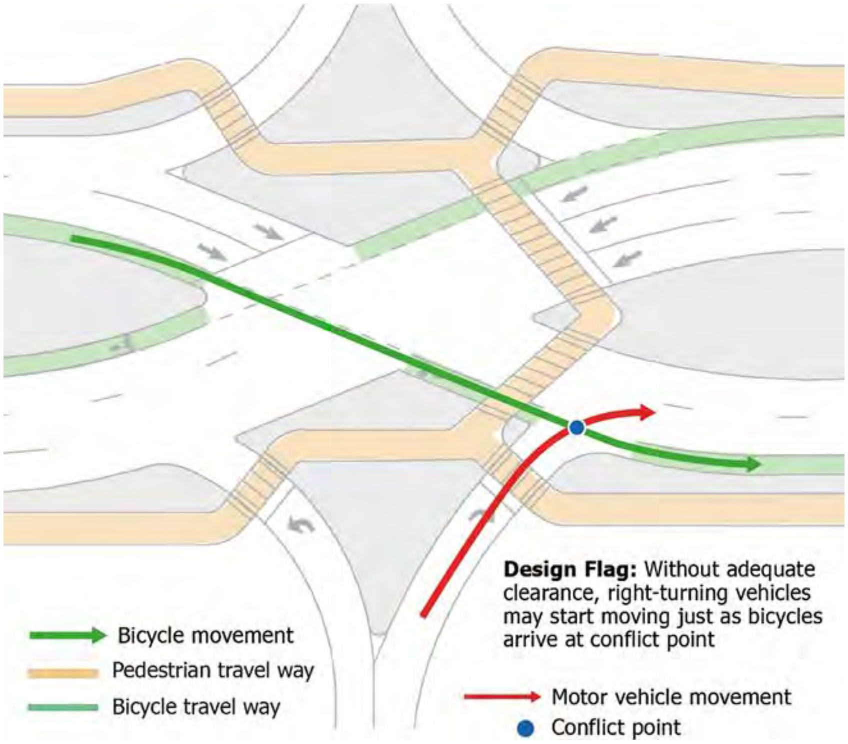


***Exhibit 4-58. Design Flag 15 – Bicycle clearance time.***

cross may occasionally lead to a bicyclist being in the intersection when a conflicting movement receives a green indication.

- At many signals, a cyclist can only rely on the yellow indications for motorists. This yellow clearance interval is designed for motorists and is generally 3 to 6 seconds, per the MUTCD (*11*). This clearance time is rarely enough time for cyclists to clear the intersection. The problem worsens with larger speed differentials between motorists and bicyclists, as well as with larger intersections.

In A.I.I.s, clearance time can often become a bigger issue for cyclists with multiple medians (DLT), wide medians (RCUT, MUT), and gaps between movements (DDI). The issue is compounded in most DDIs and some DLTs when signal heads are placed before the full clearance of the intersection. In those situations, bicyclists have no indication if the signal phase has changed once they have ridden past the signal heads.

This flag can be classified as either yellow or red and is a function of the length of the roadway section over which clearance times are calculated, as shown in Exhibit 4-59. The average bicycle travel speed is approximately 10 to 14 mph. Compared to a vehicle traveling at 35 to 50 mph,

**Exhibit 4-59. Design Flag 15 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Bicycle Clearance Times | Bicycle | Vehicle Speed and Clearance Zone Length (feet) | <=35 mph and 36–72 ft **OR** > 35 mph and 24–60 ft | <=35 mph and >=72 ft **OR** > 35 mph and >=60 ft |

Note: mph = miles per hour; ft = feet

***Exhibit 4-60. Design Flag 15 example. Bicycle clearance time.***

a bicycle, therefore, requires 3 to 5 times the clearance times calculated for motorized traffic. This flag can only be applied to bicycle movements. The thresholds in Exhibit 4-59 assume a bicycle travel speed of 12 mph.

Exhibit 4-60 shows a north-south on-street bike lane crossing a four-lane urban arterial. At a sidestreet travel speed of 35 mph, this 48-foot crossing distance is classified as a yellow flag. At 35 mph, the estimated vehicle clearance time (resulting in the calculated all-red time) is 0.9 seconds, compared to 2.7 seconds required for a bicycle to clear the arterial. The resulting difference of 1.8 seconds is equal to the potential time a bicyclist may still be within the intersection after the vehicle mainline has gotten a green signal indication. Given a typical vehicle start-up lost time of 2 seconds, this is classified as a yellow flag. However, had the intersection been wider, the added exposure in the roadway after east-west vehicular green would have resulted in a red flag.

### 4.4.16 Lane Change Across Motor Vehicle Travel Lane(s)

The design flag for lane change across motor vehicle travel lane(s) is shown in Exhibit 4-61. For bicyclists, movements that require lane changes over motor vehicle travel lanes, while bicyclists are moving with traffic, are both a safety and comfort concern. To complete this maneuver, bicyclists have to look over their shoulders to assess gaps available for lane changes while riding. At high vehicle speeds and volumes, this maneuver can be stressful and even dangerous to complete, as bicyclists have to maintain their trajectory while scanning for gaps. Specific examples noted in focus group research include the following:

- Approaching the U-turn movement at an MUT or RCUT;
- Approaching the displaced left-turn movement at a DLT; and
- Approaching a left-turn lane at most traditional intersections.

Perpendicular crossings of motor vehicle lanes (from a stopped bicycle position) should be evaluated using design flag #4.


***Exhibit 4-61. Design Flag 16 – Lane change across motor vehicle travel lane(s).***

**Exhibit 4-62. Design Flag 16 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Lane change across the motor vehicle travel lane | Bicycle | Vehicle Speed & Vehicle Volume | 25–35 mph **OR** 3,000–7,000 vpd | >35 mph **OR** >7,000 vpd |

Note: mph = miles per hour; vpd = vehicles per day

***Exhibit 4-63. Design Flag 16 example. Southbound bicycle path departing bike lane and crossing vehicle lane to turn left downstream.***

This flag can be classified as yellow or red, depending on two dimensions: (1) vehicle speed and (2) vehicle volume per day as shown in Exhibit 4-62. Thresholds are based on FHWA's *Bikeway Selection Guide* (*10*). Any uncontrolled movement requiring a bicycle to cross a motor vehicle travel lane, regardless of the bicycle facility type, is subject to both the yellow and red thresholds.

Vehicle speed can be determined by field data collection or, absent such data, by using the design speed. Engineering judgment should be applied to determine if the expected vehicle speed might be higher or lower than the design speed, given the intersection environment. Vehicle volume can be found from traffic forecasts or local counts. This flag can only be applied to bicycle movements.

Exhibit 4-63 shows a southbound bicycle lane crossing a T-intersection and proceeding downstream to a larger intersection with left- and right-turn bays. Bicycles traveling southbound desiring to make a left-turn at the downstream intersection must cross the southbound vehicle lane to move into the left-turn bay. The actual vehicle travel speed and the daily roadway volume would be needed to determine which flag, if either, applies to this design.

### 4.4.17 Channelized Lanes

The channelized lanes design flag is illustrated in Exhibit 4-64. For bicyclists, situations where bicyclists travel in a channelized lane with motorized traffic are both a safety and a comfort concern. The flag applies to single-lane channelized lanes (narrow shared space between curbs) and multilane facilities. The latter situation may also be covered by design flag #19 and should not be double-counted. Specific examples noted in focus group research include the following:

- Traversing a channelized left-turn lane at a DLT; and
- Traversing a channelized right-turn bypass lane.

This flag can be classified as yellow or red depending on two dimensions: (1) vehicle speed and (2) length of the channelized lane (see Exhibit 4-65). The speed thresholds are based on FHWA's *Bikeway Selection Guide* (*10*), while the length thresholds are based on the exposure time of 3 seconds at an assumed bicycle travel speed of 12 mph (17.6 ft/s). The yellow and red flags are applicable regardless of the bicycle facility type.

Vehicle speed can be determined by field data collection or, absent such data, by using the design speed. Engineering judgment should be applied to determine if the expected vehicle

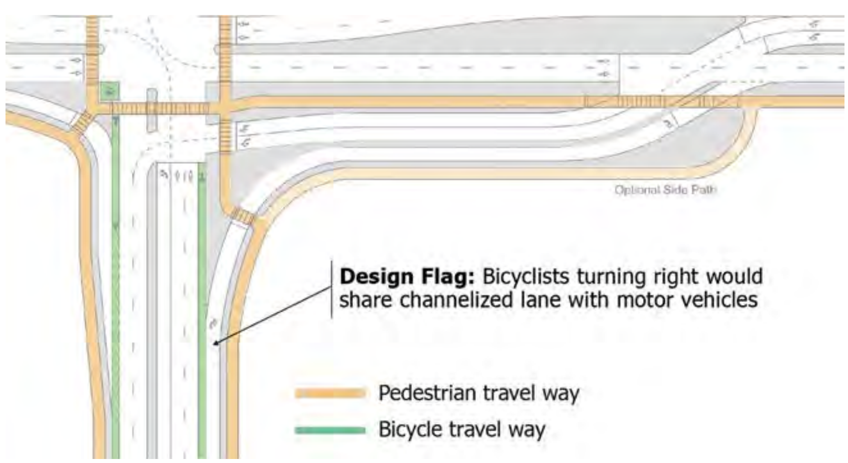


***Exhibit 4-64. Design Flag 17 – Bicyclists traveling in channelized lane adjacent to motor vehicles.***

**Exhibit 4-65. Design Flag 17 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Channelized Lanes | Bicycle | Vehicle Speed & Channelization Length | 25-35 mph **AND** <= 50 ft | >35 mph **OR** >50 ft |

Note: mph = miles per hour; ft = feet

***Exhibit 4-66. Design Flag 17 example. Bicycle exposure in channelized turns.***

speed might be higher or lower than the design speed given the intersection environment. The channelization length should be measured from the design concepts, aerial surveys, or field measurements. This flag can only be applied to bicycle movements.

In Exhibit 4-66, the single-lane roundabout features channelized lanes, which can be a challenging riding environment. This is especially true in the eastbound direction, where a significant upgrade results in slow-moving cyclists. Here, the agency widened the sidewalk to a multiuse path to allow cyclists to use it as a "bypass lane" and avoid the channelized section. For the southbound right-turns, channelization remains a potential design flag, creating an uncomfortable riding environment for cyclists. The right-turn channelization exceeds a length of 50 feet and would be classified as a red flag per Exhibit 4-65. For the eastbound through movement, no flag is applied because bicyclists can use the bypass option on the multiuse path section.

## 4.4.18 Turning Motorists Crossing Bicycle Path

The design flag for turning motorists crossing bicycle path is shown in Exhibit 4-67. For bicyclists proceeding straight through an intersection, the conflict zone where motor vehicle traffic can cross the bike path of travel creates a safety concern and source of user stress. This situation commonly applies to right-turning traffic at most intersections.

This conflict is also called the "right hook" conflict. A right hook occurs when a vehicle passes a (slower) bicycle in the approach to an intersection. As the vehicle slows down to make right-turns at the intersection, the bicyclist can catch up with the vehicle. As the vehicle turns, the driver may not be aware of the cyclist (in their blind spot), creating a conflict and potential crash.

This flag can only be applied to bicycle movements, as shown in Exhibit 4-68. It can be classified as either yellow or red, depending on the facility. For an exclusive turn lane or channelized

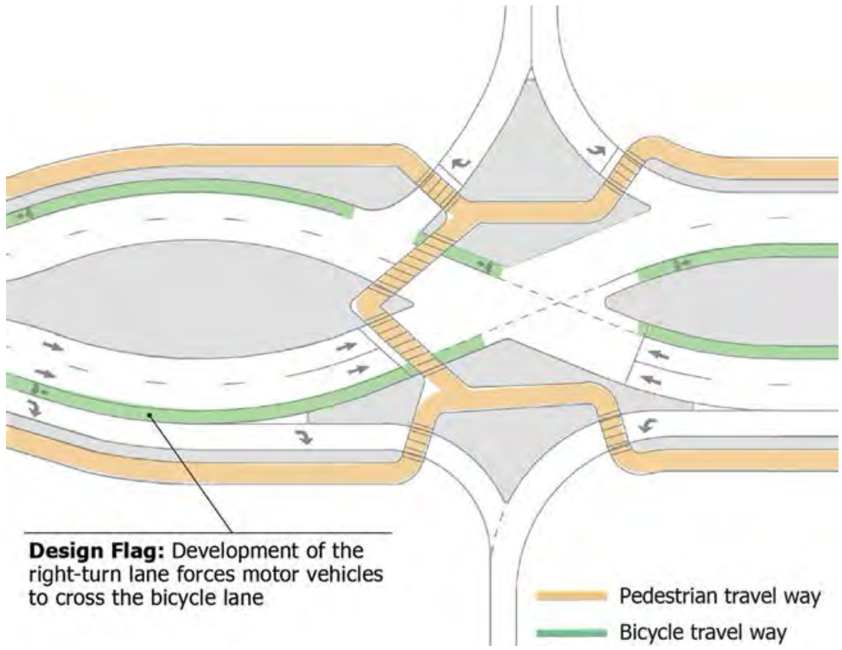


***Exhibit 4-67. Design Flag 18 – Turning motorists crossing bicycle path.***

lane, the vehicle lane change happens at a higher speed relative to the cyclist, resulting in a yellow flag. For a shared through and right lane, the "right hook" situation described above is more likely to surprise the driver, resulting in a red flag.

In Exhibit 4-69, the eastbound and westbound approaches are classified as yellow flags, because the vehicle right-turn has a dedicated lane in each case. For the northbound and southbound approaches, shared through-right lanes would result in a red flag, but no flag applies in this case because traffic is controlled by a stop sign (however, flag #1 may apply).

In Exhibit 4-70, the bike lanes in the eastbound and westbound directions are next to through-right shared lanes and are therefore considered red flags.

### 4.4.19 Riding Between Travel Lanes, Lane Additions, or Lane Merges

The design flag for riding between travel lanes, lane additions, or lane merges is shown in Exhibit 4-71. Bicyclists often travel between vehicular travel lanes, with traffic on both sides of the cyclist. There are two common occurrences of this flag:

- Upstream of intersections, with a bike lane between the vehicular right-turn-lane and through lane(s); and
- Downstream of intersections, with a bike lane between a vehicle merge or acceleration lane and the through lane(s).

**Exhibit 4-68. Design Flag 18 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Turning motor vehicles crossing the bike path | Bicycle | Motor Vehicle Lane Configuration | Exclusive Turn Lane | Shared Thru & Turn Lane |

***Exhibit 4-69. Design Flag 18 example. Right-turning vehicles crossing bicycle lane with an exclusive right-turn lane.***

***Exhibit 4-70. Design Flag 18 example. Right-turning vehicles crossing bicycle lane with shared through-right-lane.***

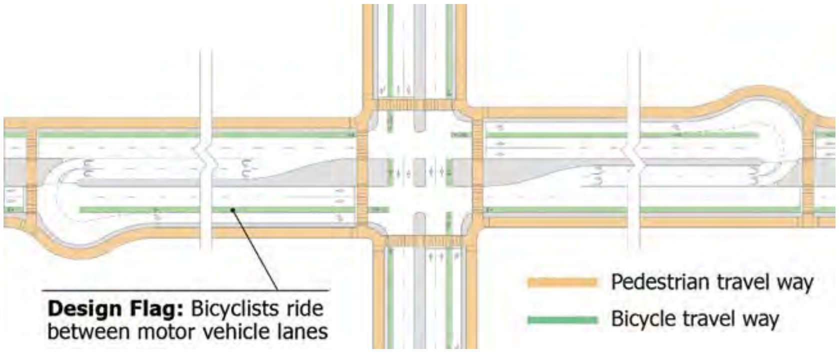


***Exhibit 4-71. Design Flag 19 – Riding between travel lanes, lane additions, or lane merges.***

**Exhibit 4-72. Design Flag 19 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Riding between Travel Lanes, Lane Additions, or Lane Merges | Bicycle | Motor Vehicle Lane configuration | Motor vehicle lanes remain parallel or diverge | Motor vehicle lanes merge |

Typically, the downstream situation is more severe because merging traffic has to switch lanes across the bike path (see flag #18), but both situations can be of concern for cyclists.

This flag can be classified as yellow or red, depending on the maneuver, as shown in Exhibit 4-72. If motor vehicle lanes remain parallel to the bike movement or diverge, the flag is generally categorized as yellow. If motor vehicle lanes merge, forcing a lane change across the bicycle path, the flag is categorized as red. This flag can only be applied to bicycle movements and should not be double-counted with flag #18.

Exhibit 4-73 shows a westbound bike lane that ends between a vehicular through lane and a right-hand merge lane. This situation would be classified as a red flag, especially given the likely high vehicle speeds on the merge lane. The flag exists even if there is not a bike lane. In Exhibit 4-74, the eastbound bike lane drops before a merge situation, but cyclists will still find themselves between two travel lanes with the right lane merging across, resulting in a red flag.

### 4.4.20 Off-Tracking Trucks in Multilane Curves

The off-tracking trucks in multilane curves design flag is shown in Exhibit 4-75. Focus group interviews with cyclists have revealed a comfort and safety concern when traveling through curved roadways alongside traffic, especially trucks. Depending on curvature and lane widths, heavy vehicles may off-track into adjacent lanes, resulting in a comfort and safety concern for cyclists. Specific examples noted in focus group research include the following:

- Traversing a crossover at a DDI,
- Traversing a multilane crossover at a DLT, and
- Traversing a multilane U-turn maneuver at an RCUT or MUT.

***Exhibit 4-73. Design Flag 19 example. Westbound bicycle lane between merging motor vehicle lanes.***

***Exhibit 4-74. Design Flag 19 example. Eastbound bicycle lane drops as the motor vehicle lane is added on the right.***

This flag can be classified as yellow or red, depending on the angle of the curve to be traversed, as shown in Exhibit 4-76. For turns at 60 degrees or less, the flag is categorized as a yellow-flag, with higher angle turns resulting in a red flag. This flag can only be applied to bicycle movements.

Besides A.I.I.s, this flag can apply to multilane turns at traditional intersections and multilane roundabouts. Another example is shown in Exhibit 4-77, where the back-to-back and reverse curvature on entering the rotary intersection can result in challenges for bikes. Given the total curvature exceeding 60 degrees, this situation would be classified as a red flag.

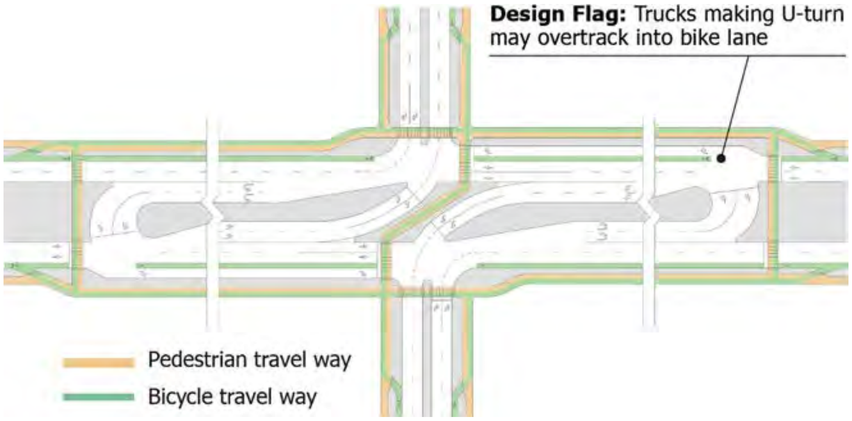


***Exhibit 4-75. Design Flag 20 – Off-tracking trucks in multilane curves.***

**Exhibit 4-76. Design Flag 20 – Yellow- and red-flag thresholds.**

| Flag | Applicable Mode | Measure of Effectiveness | Yellow-Flag Threshold | Red-Flag Threshold |
|---|---|---|---|---|
| Off-Tracking Trucks in Multilane Curves | Bicycle | Turn Angle | Curve at 60 degrees or less | Curve at greater than 60 degrees |

***Exhibit 4-77. Design Flag 20 – Example application at rotary traffic circle.***

## 4.5 Design Flag Assessment Scoring Sheets

Exhibit 4-78 and Exhibit 4-79 can be used as scoring sheets. A new sheet should be used for each design alternative. Column labels can be modified to reflect the paths (for pedestrians) or movements (for bicycles) necessary for the design.

**Pedestrian Flags**
NCHRP 7-25 Method
**Date:**
**Project:**
**Alternative:**
**Intersection/Interchange:**
**Analyst:**

Study Area Sketch with Path Assignment

| No. | Name | West | East | North | South |
|---|---|---|---|---|---|
| 1 | Motor Vehicle Right-Turn | | | | |
| 2 | Uncomfortable/ Tight Walking Environment | | | | |
| 3 | Nonintuitive Motor Vehicle Movement | | | | |
| 4 | Crossing Yield or Uncontrolled Vehicle Paths | | | | |
| 5 | Indirect Paths | | | | |
| 6 | Executing Unusual Movements | | | | |
| 7 | Multilane Crossing | | | | |
| 8 | Long Red Times | | | | |
| 9 | Undefined Crossing at Intersections | | | | |
| 10 | Motor Vehicle Left-Turn | | | | |
| 11 | Intersecting Driveways and Side Streets | | | | |
| 12 | Sight Distance for Gap Acceptance | | | | |
| 13 | Grade Change | | | | |

| | |
|---|---|
| Total Possible Flags | |
| Total Yellow Flags | |
| Total Red Flags | |
| PCT Yellow | |
| PCT Red | |
| PCT Flagged | |

*Indicate R=red flag, Y=yellow flag, or blank=no flag*

***Exhibit 4-78. Pedestrian Design Flag assessment scoring sheet.***

**Bicycle Flags**
NCHRP 07-25 Method
**Date:**
**Project:**
**Alternative:**
**Intersection/Interchange:**
**Analyst:**

Study Area Sketch with Route Assignment

| No. | Name | NBL | NBT | NBR | SBL | SBT | SBR | EBL | EBT | EBR | WBL | WBT | WBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Crossing Yield or Uncontrolled Vehicle Paths | | | | | | | | | | | | |
| 5 | Indirect Paths | | | | | | | | | | | | |
| 6 | Executing Unusual Movements | | | | | | | | | | | | |
| 7 | Multilane Crossing | | | | | | | | | | | | |
| 8 | Long Red Times | | | | | | | | | | | | |
| 9 | Undefined Crossing at Intersections | | | | | | | | | | | | |
| 10 | Motor Vehicle Left-Turn | | | | | | | | | | | | |
| 11 | Intersecting Driveways and Side Streets | | | | | | | | | | | | |
| 12 | Sight Distance for Gap Acceptance | | | | | | | | | | | | |
| 13 | Grade Change | | | | | | | | | | | | |
| 14 | Riding in Mixed Traffic | | | | | | | | | | | | |
| 15 | Bicycle Clearance Times | | | | | | | | | | | | |
| 16 | Lane Change Across Motor Vehicle Lanes | | | | | | | | | | | | |
| 17 | Channelized Lanes | | | | | | | | | | | | |
| 18 | Turning Motorists Crossing Bicycle Path | | | | | | | | | | | | |
| 19 | Riding Between Travel Lanes | | | | | | | | | | | | |
| 20 | Off-Tracking Trucks in Multilane Curves | | | | | | | | | | | | |

| | |
|---|---|
| Total Possible Flags | |
| Total Yellow Flags | |
| Total Red Flags | |
| PCT Yellow | |
| PCT Red | |
| PCT Flagged | |

*Indicate R=red flag, Y=yellow flag, or blank=no flag*

***Exhibit 4-79. Bicycle Design Flag assessment scoring sheet.***

## 4.6 References


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CHAPTER 5

# Generalized Design Treatments

This chapter presents generalized design treatments that may apply to any intersection, including A.I.I.s. Although examples of generic intersections or specific A.I.I.s may be used, the concepts in this chapter are intended to apply to a broader set of intersection configurations.

The chapter presents treatments organized into these sections:

- General segment treatments,
- General intersection treatments,
- General crossing treatments, and
- Design flag treatments and techniques.

Segment treatments are presented first because these refer to the approaches to the A.I.I. and are thus the first design elements a pedestrian or bicyclist encounters with an intersection. Intersection treatments are those within the boundary of the intersection, while crossings are the portions of the intersection that entail maximum exposure for pedestrians and conflicting paths for bicyclists with motor vehicles.

The chapter concludes with a list of specific treatments to address the twenty design flags introduced in Chapter 4.

For all treatments, sight distance for all users is an important consideration along every segment and at every node of a transportation system. Each conflict point can have sight distance issues. Static sight distance issues (e.g., landscaping, signs) and dynamic issues (e.g., moving vehicles, parked cars) should both be considered. The designer should ensure that every movement by every mode has adequate sight distance: for motorists to see pedestrians and bicyclists, for pedestrians and bicyclists to see motorists, and for pedestrians and bicyclists to see each other.

Besides sight distance and its direct effect on safety and comfort, the delay that each user experiences can affect safety and comfort. If the design and operational plan produce excessive delay for pedestrians or bicyclists relative to motorized vehicles (e.g., it takes several minutes to get from one quadrant of the intersection to another, even though there may be obvious crossable gaps in motor vehicle traffic), pedestrians and bicyclists may identify desire lines that are not part of the design and may take shortcuts that put them at risk. What might be considered excessive will be different in various contexts, but a general rule is to avoid creating delays exceeding 30 seconds for pedestrians and bicyclists at any crossing.

## 5.1 General Segment Treatments

The segments or approaches to an A.I.I. define the experience of a pedestrian or bicyclist when first approaching the intersection or interchange. The pedestrian or bicycle facility type should match the overall corridor facility or should be elevated to a higher-class facility at the

A.I.I., rather than degraded to a lower-class alternative. For example, a facility with a separate shared-use path along a roadway should not be terminated with an on-street, shared-lane facility or striped bike lane through the A.I.I. However, a facility with an on-street striped bike lane can be upgraded to a shared-use path or protected bike lane through the A.I.I.

### 5.1.1 Railings, Barriers, and Buffers

Adding railings, barriers, and buffers to bikeways and sidewalks within A.I.I.s can increase the comfort of people walking and bicycling in these areas. These types of treatments can be especially beneficial in constrained areas where right-of-way or other spatial constraints limit the ability to offset facilities for nonmotorized users from the roadway. Where continuous railings and barriers are used, such as concrete traffic barriers, utilitarian or decorative handrails, or guard rails, a shy distance of at least 2 feet from any railing is preferable in the design, with at least 1 foot in constrained locations where lane widths and other widths are also reduced to minimum dimensions. For instance, if an A.I.I. design includes a sidepath with a nominal width of 10 feet, but the sidepath will have a railing on both sides, the ultimate design should ideally incorporate 2 feet of shy distance on each side, for a total sidepath width of 14 feet (see Exhibit 5-1). Railings should be a minimum height of 42 inches next to bicycle facilities with considerations for taller 48- to 54-inch barriers if bicyclists could impact the barrier at an angle of 25 degrees or greater (*1*).

Similar shy distances should be included in the design of sidewalks or sidepaths without railings if those facilities are intended to abut adjacent travel lanes. This design acknowledges that vulnerable street users will naturally seek to put space between themselves and motor vehicle traffic and is reflected in the PLOS and BLOS analysis (see Chapter 4). Ideally, some type of street buffer should be integrated with the sidewalk or sidepath design. A recommended desirable street buffer width is 6 feet (*2*), with 2 feet being the minimum buffer width for sidepaths to preserve detectability underfoot for blind pedestrians. These street buffers should be landscaped or constructed of some contrasting and detectable material or surface treatment.

Careful attention should be given to locating where railings and barriers start and stop in relation to intersections. These barriers can create sight distance issues for both motorized and nonmotorized users at intersections, particularly where horizontal curves, vertical crests, or steep grades are present.

### 5.1.2 Pedestrian and Bicycle Facility Dimensions at Bridges/Tunnels

Where A.I.I.s include bridges, tunnels, underpasses, or other vertical elements immediately next to pedestrian and bicycle facilities, the design of these structures should consider shy distance and provide adequate usable widths for pedestrians and bicyclists. The usable width

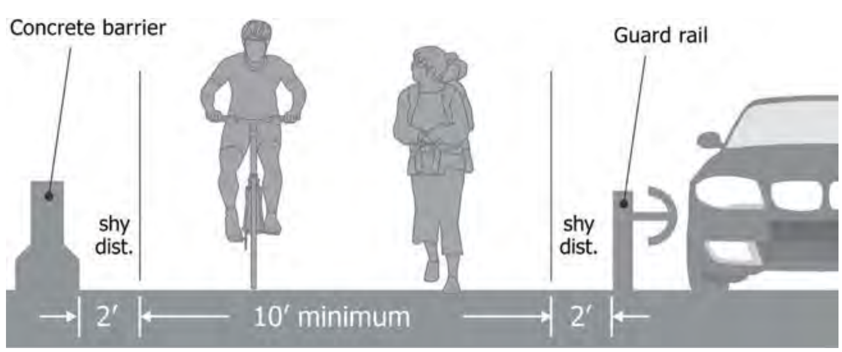


***Exhibit 5-1. Shy distance from vertical surfaces influences the effective width of a shared-use path or sidepath.***

recognizes that pedestrians and bicyclists will not travel at the edge of a facility or immediately against a wall, abutment, barrier, or other structural elements. Vertical structural elements may also affect sight distance. Pedestrian and bicyclist facilities that may be affected include, but are not limited to, bike lanes, paved shoulders, separated bike lanes, shared-use paths, and sidewalks.

### 5.1.3 Transitions Between Bike Facility Types

If on-street bicycle facilities are selected for an A.I.I., there likely will be locations where motorists must cross the bikeway to reach a ramp or change lanes before a turn. Any location where motorists must cross or enter space otherwise intended for bicyclist use represents a bicycle-vehicle conflict point. Where A.I.I.s are configured to maintain relatively high speeds and/or throughput by motorists, these zones may also be locations with a substantial speed differential between motorists and bicyclists.

Where possible, bicyclists should be directed to off-street or separated bike facilities before crossings or conflict areas with complex, high-speed, or high-volume motor vehicle maneuvers (see Sections 3.2 and 3.3). These off-street or separated facilities, including shared-use paths, sidepaths, or separated bike lanes, allow for higher visibility of crossing activity using marked crossings and signal control. The transitions from on-street to off-street bicycle facilities in these conditions are similar to those suggested for roundabouts, as described in *NCHRP Report 672* (*3*). An example configuration for a median u-turn intersection with channelized right-turn lanes is shown in Exhibit 5-2.

### 5.1.4 Manage Speeds

In some contexts, on-street bicycle facilities may be next to high-speed motor vehicle traffic. This can be an uncomfortable environment for bicyclists. If separated bicycle facilities cannot be provided, motor vehicle speeds should be managed through design and operational strategies. Several techniques may help achieve this:

- **Signal progression:** If the A.I.I. exists along a corridor with coordinated signals, it may be possible to set the desired progression speed appropriate for the intended project outcomes. The intent is to influence driver speeds in the corridor. See Chapter 3 for a discussion relating bicycle facility type selection to vehicle speeds and traffic volumes.

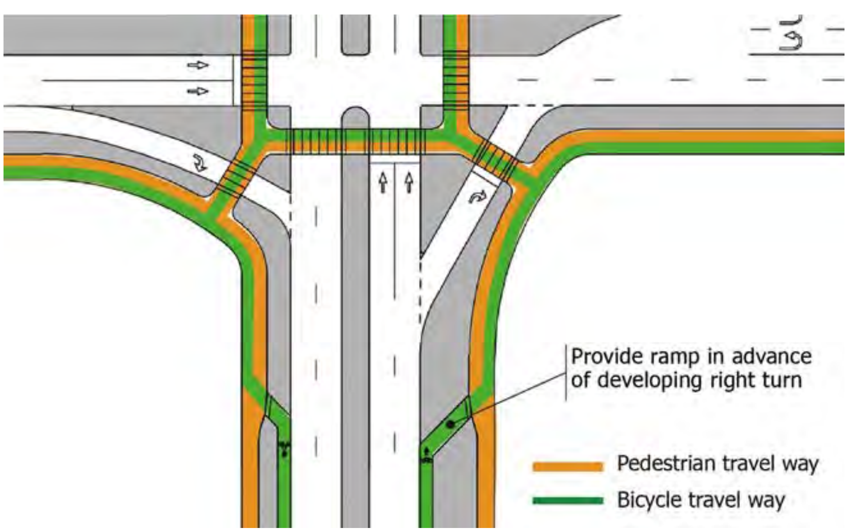


***Exhibit 5-2. Ramping on-street bike lane to sidewalk level upstream of the crossing.***

- **Deflection:** Horizontal deflection, which can be introduced with a median treatment, controls the fastest speeds at which drivers can comfortably approach the intersection, thereby reducing speeds. Speed may be controlled at the key curves through an A.I.I., most of which include several conflict points. For example, at a DLT intersection, these points include the crossover, the displaced left-turn, and right-turns whether they are channelized or not.
- **Narrow vehicle lane widths:** Narrow lanes are effective in reducing driver speeds and reduce the right-of-way and associated crossing distances. Even if vehicle lanes are narrowed, the bicycle lane width should not be reduced.
- **Speed feedback signs:** Speed feedback signs heighten motorist awareness of their approach speeds and allow them to self-correct before the intersection.

## 5.2 General Intersection Treatments

General intersection treatments refer to the walking or cycling experience within the bounds of the A.I.I., not including crossing locations (discussed in Section 5.3). Key considerations for intersection treatments include pedestrian wayfinding (including accessibility aspects of wayfinding as defined in Chapter 4) and the ability to traverse the intersection or interchange safely and comfortably.

### 5.2.1 Accessibility and Wayfinding

Many aspects of intersection design require attention to detail to make them accessible to all pedestrians, particularly those with mobility or vision disabilities. Pedestrian crossings at channelized turn lanes can be challenging for blind pedestrians to cross unless appropriate treatments are provided. Details on the needs for locating the crossing, aligning to cross, determining when it is safe to cross, and maintaining alignment while crossing are provided in Chapter 2.

Exhibit 5-3 illustrates key accessibility features at an intersection. For full guidance on ADA requirements and accessible design standards, the reader is referred to resources provided by the U.S. Access Board.

The pedestrian wayfinding process is described in Chapter 2. Pedestrian wayfinding treatments apply to all A.I.I. designs and are classified as follows:

- **Finding the crosswalk.** These treatments are not unique to A.I.I.s and are presented in *NCHRP Report 834* (*4*).
- **Aligning to cross.** Sometimes, crossing from one corner to another of an A.I.I. may require as many as five individual crossings, as in the case of a DLT intersection. If the crossings are straight and aligned at either end, the edges of crossings are identifiable with detectable warning surfaces, and the walkways are defined by detectable edges (such as landscaping) and lead to the crossings, this configuration can be manageable. However, if crossings change direction, such information needs to be communicated to the pedestrian. Additionally, most pedestrians who are blind align and use the audible cues of parallel traffic to cross. With the dispersed nature of pedestrian-vehicle conflict points at some A.I.I.s, using traffic cues for alignment may not be possible for pedestrians who are blind or have low vision.
- **Maintaining alignment.** Shorter crossings provide less opportunity for pedestrians to veer from the intended path. In this regard, the multistage crossing in Exhibit 5-4 performs well; a single-stage crossing of the mainline (i.e., no median refuge) could challenge a blind pedestrian's ability to maintain alignment.
- **Additional considerations for channelized islands.** Many A.I.I.s constructed to date have included channelized right-turn lanes. These channelized lanes bring their own set of accessibility challenges, discussed in *NCHRP Report 834* (*4*).

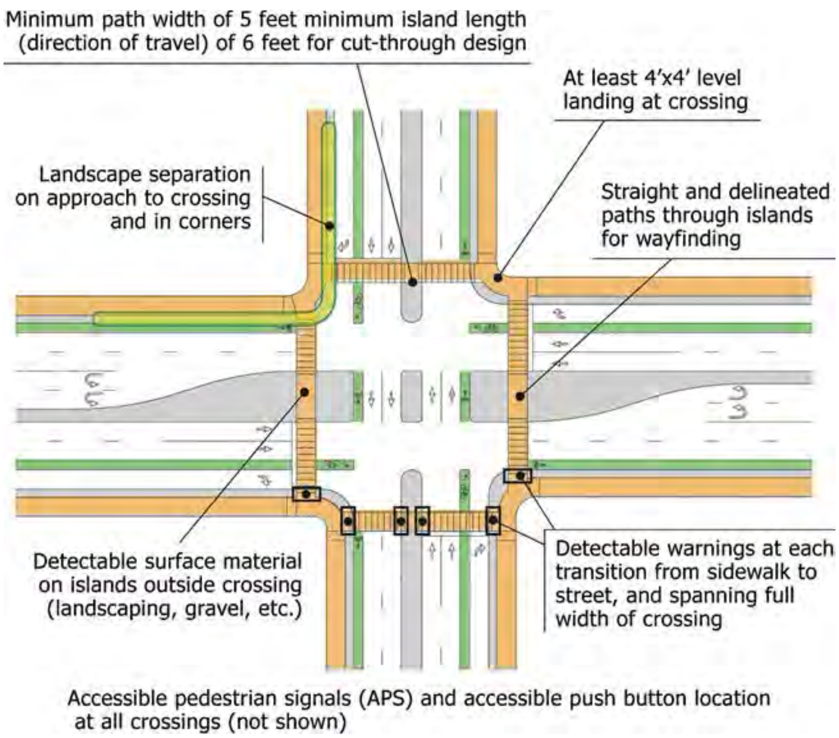


***Exhibit 5-3. Accessibility features at intersections.***

Depending on the configuration of the A.I.I., large channelization islands may be present. Pedestrians need clear guidance and information on where they should walk and where they should cross.

Cut-through island designs can indicate to pedestrians the locations of walkways and crossings. However, if a cut-through is surrounded by paved areas, a blind pedestrian may not recognize the cut-through as the pedestrian path, and they may step up onto the paved island areas outside the pedestrian path and become disoriented on the large paved island area. Landscaping or other surfaces distinct underfoot from the intended walking path (such as grass or gravel)

***Exhibit 5-4. Example of well-designed multistage crossing.***

should be used to define the boundaries of the pedestrian walkway and give pedestrians routing cues in very large channelization islands (see Exhibit 5-5).

A cut-through walkway can guide the pedestrian directly to the intended crossing point and can be angled to support pedestrians viewing oncoming vehicular traffic and potential conflicts. The channelization islands at DDIs, for example, provide the opportunity for wide walkways. The cut-through walkway should be at least 8 feet wide to accommodate pedestrians comfortably, including those with wheelchairs and other mobility devices. Where the cut-through is designed for a shared-use path, the preferred minimum width is 10 feet, not including shy distances from vertical obstruction as discussed above. The actual curb ramp landing should be aligned perpendicular to the street centerline, which minimizes crossing distance and orients pedestrians to access ramps.

Accessibility was described in Chapter 2 in the broader contexts of a project's land use environment. In this section, accessibility is explicitly focused on the policies related to the ADA and proposed PROWAG (*5*). General accessibility principles for A.I.I.s are based on those used in other intersection forms. The U.S. Access Board provides additional resources on accessibility and specific requirements for Accessible Public Rights-of-Way, to which the transportation professional should refer and be familiar with.

The basic principles for accessible design can be divided into the pedestrian walkway and the pedestrian crossing location. For pedestrian walkways, these considerations apply:

- Delineate the walkway through landscaping, curbing, or fencing to assist blind pedestrians with wayfinding. Fencing may be useful in constrained areas where there is insufficient room for landscaping or where it may be more difficult to maintain.
- Provide sufficient space (length and width) and recommended slopes for wheelchair users and other nonmotorized users such as people pushing strollers, bicycles, and others.
- Construct an appropriate landing with a flat slope and sufficient size at crossing points.

For pedestrian crossing locations, these additional considerations apply:

- Provide curb ramps and detectable warning surfaces at the end of curb ramps and transitions to the street.
- Provide audible speech information messages to communicate the directionality of traffic (from the left or right) at all crossing points. Audible walk messages should be used where the spacing between APS devices is less than 10 feet.

***Exhibit 5-5. Example of a channelized turn lane with gravel surface material indicating distinguishing nonwalking surfaces from the pedestrian path. Source: NCHRP Report 834 (4).***

- Provide accessible pedestrian signals with pushbutton locator tone at signalized crossings.
- Locate pushbuttons to be accessible by wheelchair users and adjacent to the crossing at a minimum separation of 10 feet.
- Align the curb ramp landing to the intended crossing direction.
- Crosswalk width through the intersection should be wide enough to permit people walking and using wheelchairs to pass without delay from opposing directions and accommodate bicyclists if part of a shared-use path network. Also, medians should provide sufficient storage for all nonmotorized users to wait safely when two-stage crossings are required.
- Pedestrians with vision, mobility, or cognitive impairments may benefit from targeted outreach and additional informational material created with these specific users in mind. These outreach materials may include information on crosswalk placement and intended behavior and answers to frequently asked questions. For blind pedestrians, materials need to be presented in an accessible format with a sufficient description of all features of the crossing.

### 5.2.2 Intersection Angle

The angle at which two roadways intersect, whether at an intersection or at merging and diverging points, has a strong effect on motorist behavior and the approaches to and the execution of turning movements within the intersection. The ability to manage these behaviors is important for the angles formed where motorist paths and bicycle or pedestrian paths intersect.

Where motorists enter intersecting roadways at shallow angles (for example, in a traditional merge from a highway exit ramp), higher speeds can be maintained through the curve and into the intersected traffic stream. In some locations, such as when merging with highway traffic, maintaining speed can be important. However, in environments where vulnerable road users are present, geometry that encourages higher speeds can present a critical safety issue, especially if motorists may be moving through these points without signalization that separates movements in time.

The intersection angle is also important for creating the shortest feasible crossing for pedestrians and bicyclists. At points where motorists merge or diverge from through traffic, pedestrian ramps and associated crosswalks should generally be placed at the point where motor vehicle speeds will be lowest. Often, designing these crossings requires the designer to determine where the motorist has slowed for the turn without having begun accelerating into a straightaway or merging with vehicles approaching from the left.

There may be component intersections within an A.I.I. that are not perpendicular for various reasons. Angled intersections are common, and even necessary, in A.I.I.s with a crossover element to the design. Where present (such as DDIs and DLT intersections), the angled intersections are signalized to manage conflicts between motorists and vulnerable users. Given that some intersections will be angled, the two most common options available for crosswalk design are as follows:

- **Perpendicular Crosswalks.** These crosswalks, as shown in Exhibit 5-6a, have the shortest path across the roadway. This angle also allows a pedestrian or bicyclist approaching or within the crossing to perceive approaching motorists in their peripheral vision and react if needed. This design further simplifies the placement of curb ramps and detectable warning surfaces and is generally the preferred design.
- **Parallel Crosswalks.** These crosswalks, as shown in Exhibit 5-6b, cross parallel to the driving lanes. While there is longer exposure in the roadway, this route is most direct. This design can pose wayfinding challenges for blind travelers, as well as pose difficulties in designing curb ramps and detectable warning surfaces to be in line with the direction of crossing.

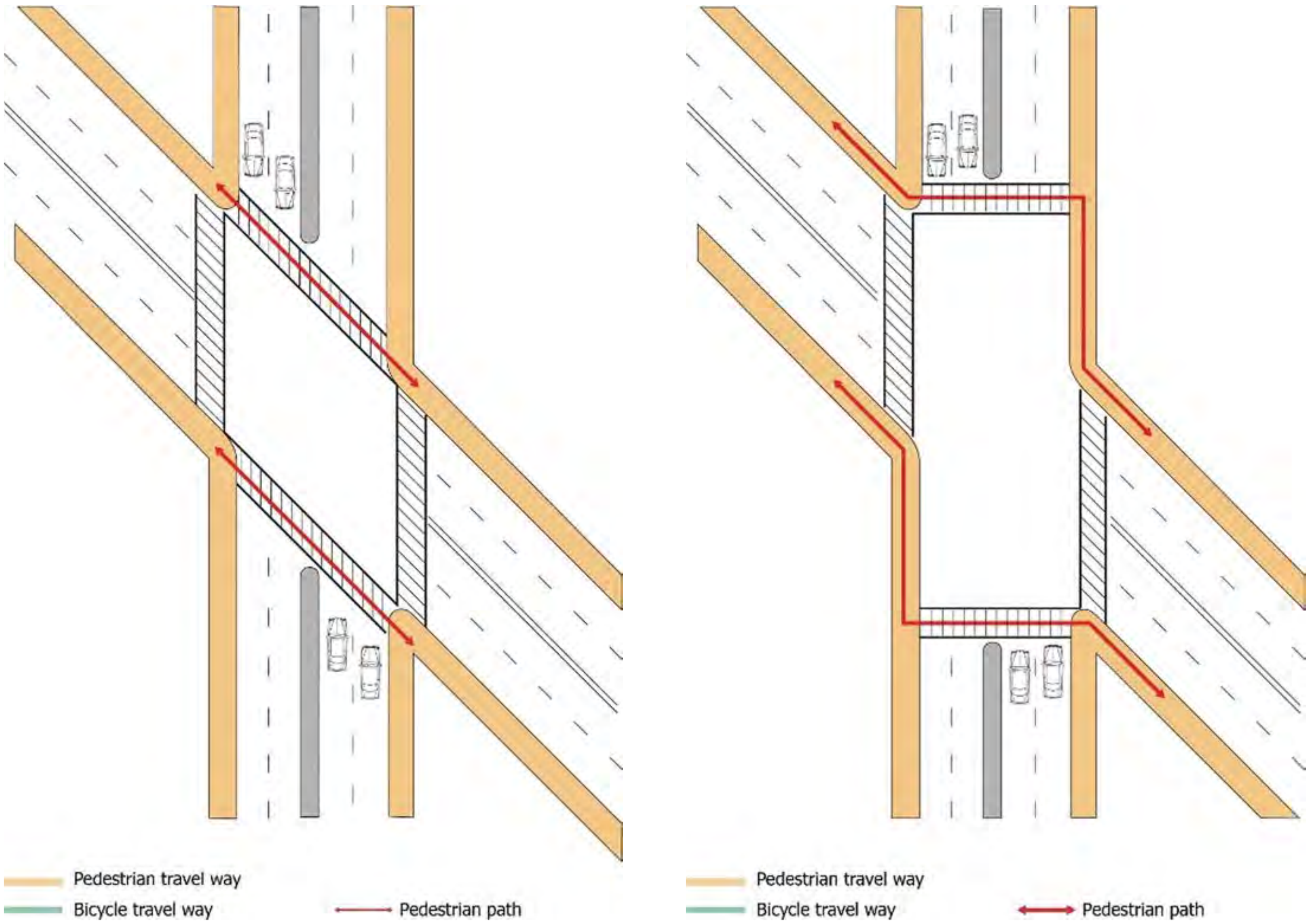


***Exhibit 5-6 (a,* left*). Crosswalk variations for a skewed intersection. (b,* right*). Crosswalk variations for a skewed intersection.***

The choice of crosswalk design depends on the context. As a starting point, designers should begin with perpendicular crosswalks at uncontrolled crossings and parallel crosswalks at controlled crossings. Factors that could alter the crosswalk type include pedestrian sight distance, ADA considerations, right-of-way and other physical constraints, and critical pedestrian signal phases affecting delay for other users.

### 5.2.3 Channelized Turn Lanes

Channelized turn lanes, principally channelized right-turn lanes, are a common feature of many intersections and A.I.I.s. In the focus group and survey research conducted in developing this guide, feedback from pedestrians was heavily critical of channelized turn lanes. Participants shared the expectation that drivers would rarely yield within channelized turn lanes.

Challenges with channelized turn lanes for nonmotorized users can include the following:

- Channelized turn lanes may create sight distance issues for crossing pedestrians;
- Channelized turns are typically taken at higher speeds than conventional right-turns at the intersection, increasing the required sight distance and potential severity of a conflict;
- Channelized turn lanes render audible clues difficult or impossible for pedestrians who are blind; and

- If decision points are not properly segregated for the motorist (pedestrian yielding versus merging into the travel lane), the motorist may be looking for gaps in traffic and fail to yield to crossing pedestrians.

### *5.2.3.1 Geometric Configuration of Channelized Turn Lanes*

A channelized turn lane should limit motor vehicle speeds. This can be done by designing the intersecting angle with the receiving roadway to be between approximately 55 to 60 degrees, as shown in Exhibit 5-7. Besides the speed-reducing effect of the higher angle, the view angles for drivers scanning for pedestrians and looking to the left for conflicting traffic are improved.

A channelized turn lane should also separate decision points from one another. A driver should be focused on the decision at the vehicle-pedestrian conflict point *before* they are looking left to judge and make a decision regarding the vehicle-vehicle conflict point. A channelized lane with at least one vehicle-length of storage between the vehicle-pedestrian and vehicle-vehicle conflict points provides this separation (consistent with the design of entry approaches at modern roundabouts).

### *5.2.3.2 Traffic Control of Channelized Turn Lanes*

*NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings*, supplemented with research on the rectangular rapid-flashing beacon (RRFB), provides guidance on improving pedestrian safety at unsignalized crossings (*6*). The NCHRP report provides tools for developing appropriate crossing treatments based on vehicle speeds, traffic volumes, and the anticipated number of pedestrian crossings. Also, *NCHRP Report 834* provides guidance on designing channelized turn lanes to be accessible to people with vision disabilities (*4*). Potential crossing treatments may include any of the following or, in some cases, a combination of two or more of the following:

- Pavement markings,
- Signing,
- Flashing beacons,
- RRFBs with audible indications,

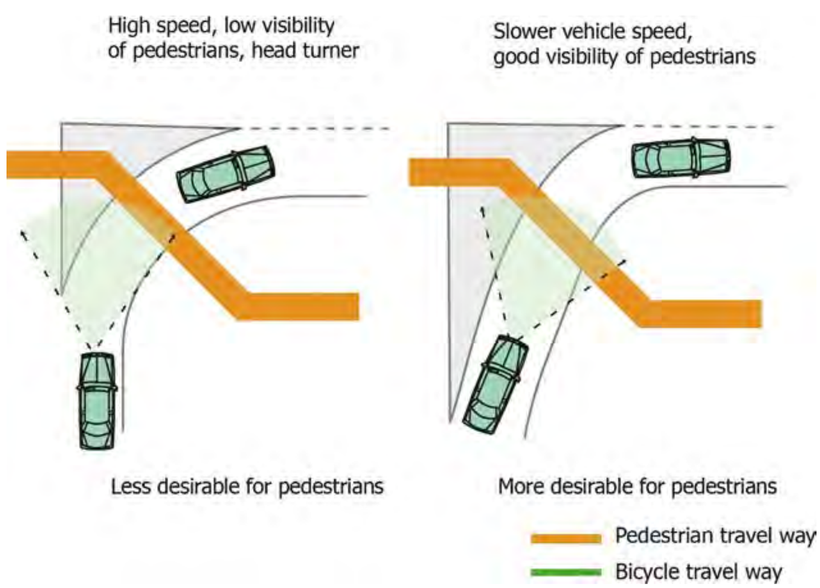


***Exhibit 5-7. Channelized right-turn design. Source: NCHRP Report 834 (4).***

- Pedestrian hybrid beacons (PHBs) with accessible pedestrian signals,
- Raised crosswalks, and
- Fully signalized crossings that are coordinated with the main intersection and with accessible pedestrian signals.

### *5.2.3.3 Replace Channelized Turn Lane with Conventional Turn Lane*

Where channelized turn lanes create challenging safety issues, removing the channelized turn lane may be an option. Removing channelization may degrade vehicular operations where there is a high volume of turns. For on-street bicyclists, some design provisions must still be provided where turning drivers cross the paths of through bicyclists (i.e., the “right hook” conflict). For pedestrian crossings, removing the channelization can reduce the number of distinct crossing stages and associated delay.

Removing the channelization consolidates pedestrian-vehicle conflict points in space. Crosswalk length may increase, which may have an undesirable effect on signal timing and cycle length. However, removing the channelized turn lane reduces the number of crossing stages for pedestrians, which may result in a net reduction in pedestrian delay. The designer should weigh several factors, including the signal timing effects of including right-turns in the main intersection, the effects on operational capacity in the presence of heavy right-turns, the effects on large vehicles, and the safety and comfort for bicyclists.

Where channelized right-turns are provided with bypass lanes, such as at DLT intersections, the angle of visibility for drivers to yield as they merge back into traffic can be challenging; if a pedestrian crossing is provided in this location, the designer should consider the traffic control device and restriction of right-turn-on-red.

### *5.2.3.4 Other Treatment Options for Channelized Turn Lanes*

Other treatment options for channelized turn lanes include the following:

- Restricting right-turns-on-red so drivers will have no incentive to position themselves for an opportune right-turn until they have a green signal;
- Providing a marked stop line or yield line before the marked pedestrian crossing (the decision for which depends on State laws regarding stopping for or yielding to pedestrians);
- Adding a raised crosswalk in the channelized turn lane to geometrically control vehicle speeds (See Exhibit 5-8);

***Exhibit 5-8. Channelized turn lane with raised crosswalk to slow vehicular traffic. Source: NCHRP Report 834 (4).***

*Exhibit 5-9. Marking right-turn lane/bike lane conflict zone with green pavement for a crossover (*left*) and for a bike signal and keep the bikes far to the right (*right*).*

- Providing adequate corner sight distance at the intersection from the stop bar to separate the two areas in space; and
- Considering queue storage for a motorist to wait between the crossing and conflicting traffic flow when wanting to turn right on red (providing separation between driver decisions).

### 5.2.4 Right-Turn Treatments for Bicyclists

Where bicyclists cannot be separated from motorists upstream of conflict points, the design should use treatments such as green pavement to draw attention to conflict areas. Weaving and merging zones where motorists can enter bicyclist space should be as short as practicable to minimize bicyclist exposure and can help control vehicle speeds where these conflicts occur. Exhibit 5-9 shows several options for how green conflict markings can be used where turning motorists may cross an on-street bike lane to access a ramp or turn. The best option will depend on the context within the approaching roadways and intersection, and the intended design user's risk tolerance.

This design may be supplemented with signage to advise motorists and define right-of-way in weaving areas. One such sign used by the MassDOT is R10-15 alt., illustrated in Exhibit 5-10, which advises motorists to yield to pedestrians and bicyclists in an adjacent parallel facility (*7*).


R10-15 alt.

*Exhibit 5-10. Turning vehicles yield to bicycles and pedestrians sign (R10-15 alt.). Source: MassDOT (7).*

### 5.2.5 Left-Turn Treatments for Bicyclists

When an on-street bicycle facility is provided, or when confident bicyclists adopt a vehicular cycling approach to the intersection, bicyclists may need to cross the motor vehicle travel lanes to use the left-turn lane(s). In some designs, this crossover also puts a bicyclist in a bike lane with motor vehicles on both sides or in no bike lane at all.

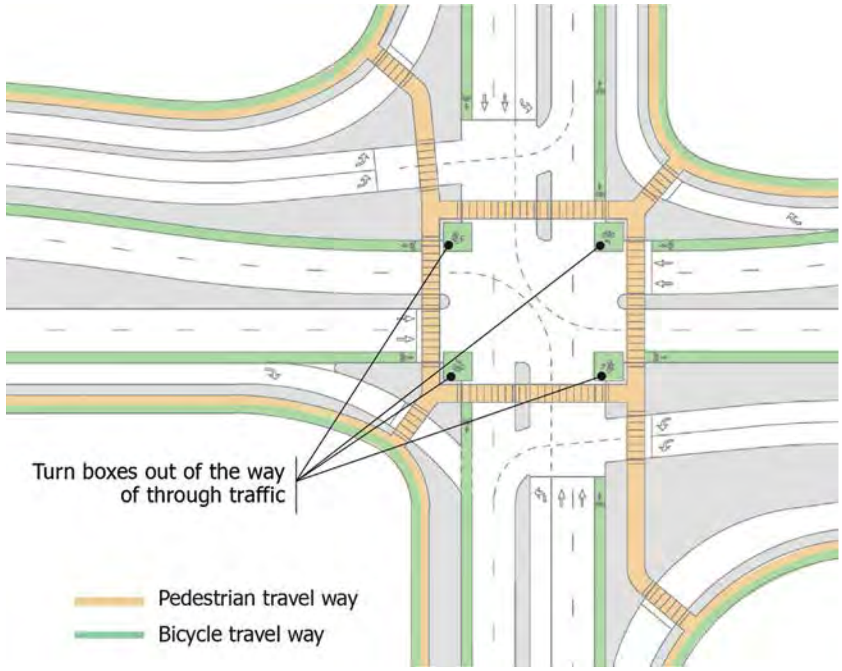


***Exhibit 5-11. Example of two-stage turn queue boxes at a DLT.***

This design feature is not exclusive to A.I.I.s; it is a feature of any intersection with left-turn lanes. This left-turn option minimizes out-of-direct travel but may come at the expense of sustained exposure, conflict points, and stressful riding conditions. This design flag is presented and discussed in Section 4.4.16, Lane Change Across Motor Vehicle Travel Lanes.

A two-stage turn queue box allows bicyclists to make left-turns in two movements without crossing over motorist travel lanes to reach a left-turn lane. The turn queue box should be properly designed per FHWA Interim Approval IA-20 (*8*) and be out of the path of through bicycle traffic (Exhibit 5-11). When the appropriate phase turns green, the bicyclists may make the second part of the movement through the intersection.

### 5.2.6 Provide Separation/Protected Intersection Concept

Separation for bicyclists can take the form of a separated bike lane or a shared-use path. The key elements of this treatment include a refuge island for bicyclists that controls effective turn radii and turning speeds of motor vehicles, a crossing set back from the corner to increase visibility and reaction time, and a queuing area for turning motorists to yield to pedestrians and bicyclists. An example of a protected intersection concept applied to a MUT intersection is shown in Exhibit 5-12.

## 5.3 General Crossing Treatments

Absent grade-separated facilities for nonmotorized users, such as overpasses or underpasses, A.I.I.s will inevitably include locations where nonmotorized paths and motorist paths must cross. These locations should be designed following the principles outlined in Chapters 2 and 3 to reduce the likelihood of crashes and the severity of any crashes that do occur.

An important determination in the design of an A.I.I. is the location of the crossings. In traditional intersections, the crossing locations are generally predetermined, but locating crossings in A.I.I.s can require more complex analysis. Maximizing the operations and safety of crossings

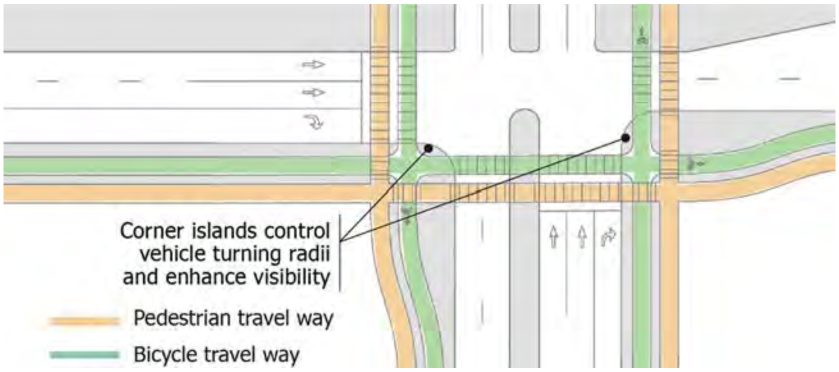


***Exhibit 5-12. Example of protected intersection components at an MUT intersection.***

could require significant geometric changes to the initial roadway design to provide adequate sight distance and encourage the desired yielding behavior. Some A.I.I.s may also require careful coordination of signals for pedestrians and bicyclists. The design for pedestrians and bicyclists must occur as early in the design phase as possible and include input from both roadway and traffic designers.

Once the higher-level design considerations are addressed, the design of individual elements and crossings requires consideration of treatments to further reduce speeds, provide adequate perception-reaction times, and heighten the visibility of vulnerable road users to motorists. In addition, nonmotorized users should also be readily able to perceive and react to any motorist approaching in a threatening way. Design treatments recommended for locations where bicyclists and pedestrians cross paths with motorists include recessed or raised crossings, high-visibility pavement markings and/or green pavement treatments, signalized crossings, pedestrian-activated beacons, properly sized refuge islands, and designing for weaving or merging zones.

### 5.3.1 Types of Crossings

The complexity of signalization and associated motor vehicle movements within an A.I.I. may require that pedestrian and bicyclist crossings be performed in stages. To the extent possible, the number of stages should be minimized, because each stage and intermittent waiting period can increase the delay to pedestrians and bicyclists, which further discourages travel by these modes.

Multiple stages and long waiting periods may also increase the likelihood that nonmotorized road users will engage in risk-taking behavior. As noted in Chapter 2, when the delay exceeds 30 seconds, pedestrians are more likely to engage in risk-taking behavior (*2*). This behavior can be exceptionally dangerous in some crossings within an A.I.I., where nonmotorized users may not see or correctly anticipate the direction, timing, or speed of approaching motor vehicle traffic.

Multistage crossings take various forms in terms of their operations:

- **Single-Stage Crossing with Multistage Option:** In these cases, the crossing is timed as a single-stage crossing using standard MUTCD guidance (*9*), but a refuge island is provided to allow an optional multistage crossing by pedestrians walking slower than the design walking speed for the crossing or by pedestrians who enter the crosswalk during Flashing Don't Walk.

- **Multistage Crossing:** In these cases, the crossing is broken into one or more components, and each crossing is controlled separately. The phases for each crossing generally occur within the same signal cycle, although phases may span the end of the first cycle and beginning of the next cycle. These crossings are distinct from multicycle crossings, discussed below.
- **Coordinated Signalized Crossing Stages:** Although stages have separate phases, the phases are coordinated to reduce or eliminate the delay associated with the crossing between refuge points. The geometric spacing between crossings can often play a critical role in how well stages can be coordinated, and coordination may be possible only in one direction of travel.
- **Combination of Controlled and Uncontrolled Crossings:** Ideally, in these crossings, the uncontrolled crossing has low delay but should consider how signal timing of the A.I.I. and adjacent signals may result in platooning or volumes that affect this uncontrolled delay.
- **Pedestrian-Only and/or Bicycle-Only Phase Crossings:** Pedestrians or bicyclists cross on signal phases timed to be separate from conflicting motor vehicle signal phases.
- **Multicycle Crossings:** These are crossings where a pedestrian or bicyclist cannot cross the intersection in one cycle, and the same signal phase is used in consecutive cycles to complete the crossing. This can be common at intersections with wide medians/deep refuge islands where the pedestrian signal timing only gives clearance for crossing one-half of the roadway at a time. These produce excessively long delays for pedestrians and bicyclists (by definition, delays exceed the cycle length) and should be avoided.

Where crossings must be staged, the design should consider the signal phasing and timing in the location and layout of pedestrian refuges and channelization for motorists. The designer should evaluate tradeoffs among the following:

- Inducing pedestrians to make long crossings with the additional signal timing and phases needed to ensure pedestrian clearance of the crossing;
- Creating a series of shorter crossings and the additional right-of-way required to construct refuges of the appropriate size at any location where pedestrians and bicyclists may dwell;
- Establishing single-stage exclusive crossings of lane groups where motor vehicle movements (including permissive turns) will not conflict with the nonmotorized movements, provided that the duration is adequate to ensure pedestrian clearance; and
- Creating geometric alterations to the roadway design that will help lessen delays between stages.

Multistage crossings can be safer than single-stage crossings, particularly at uncontrolled crossings where a median refuge breaks the crossing into shorter distances and where the number of conflicts that must be processed by the crossing user is lessened. However, if a multistage crossing results in excessive delays, or if the multistage crossing directs crossing users to out-of-direction locations, the crossing user may engage in more risk-taking behavior to reduce their delay or crossing distance. Providing efficient operations for multistage crossings is an important element in achieving the desired user behavior and safety benefits. Understanding the details of the geometric design, signal timing, and expected vehicle platooning are often critical to providing the most efficient operations.

### 5.3.2 Multiple-Threat Locations

Multiple-threat conditions can exist at crossings where vulnerable users must traverse two or more travel lanes. These crossings may be uncontrolled or signalized crossings with permissive conflicts. In a multiple-threat crash, the motorist in the lane closest to the crossing vulnerable user has stopped to yield, the vulnerable user has entered the crossing, and due to motorist inattention or poor sightlines, a motorist approaching in the adjacent lane does not stop and strikes the vulnerable user in the crossing. In a multiple-threat condition, the second

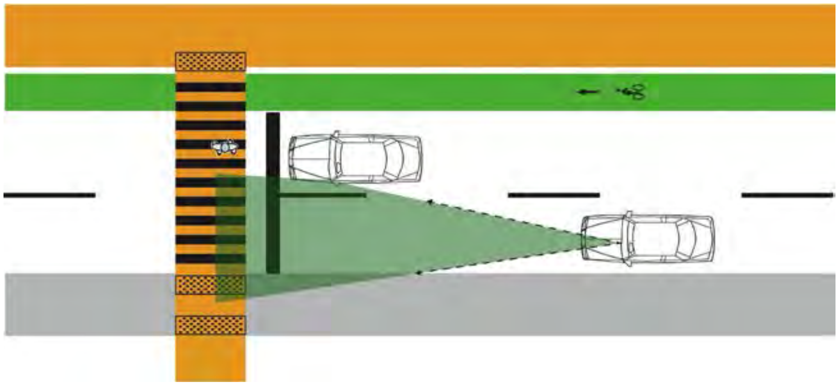

***Exhibit 5-13. Multiple-threat crash – Second motorist's view of the pedestrian is blocked on crosswalk approach by yielding motorist.***

motorist's view of the vulnerable user is not only obstructed by the first vehicle (Exhibit 5-13), but the vulnerable user's view of the approaching second vehicle is also blocked by the first vehicle (Exhibit 5-14), preventing the vulnerable user from stopping in time to avoid the crash. This is especially true for children and people in wheelchairs whose eye height is lower, preventing them from seeing beyond the stopped vehicle until they have entered the adjacent travel lane. In addition, people who are blind or have low vision may not hear the second vehicle approaching due to the sound of the yielding vehicle. If a multiple-threat condition is present, the MUTCD provides for yield line or stop line set back 20 to 50 feet from the crosswalk to reduce the likelihood of obscured lines of sight [see MUTCD Figure 3B-17 (9)].

Because A.I.I.s can include multilane crossings, the potential for multiple-threat conditions may be present in one or more locations. The design should either eliminate locations where multiple-threat crashes could occur or phase-separate the crossing. Where these conditions cannot be eliminated or fully phase-separated, the design should, at minimum, include treatments that alert motorists to vulnerable users in the crossing, such as raised crossings and/or flashing beacons. Setting the stop or yield line back from the crossing can also help maintain sightlines between approaching motorists and crosswalk users.

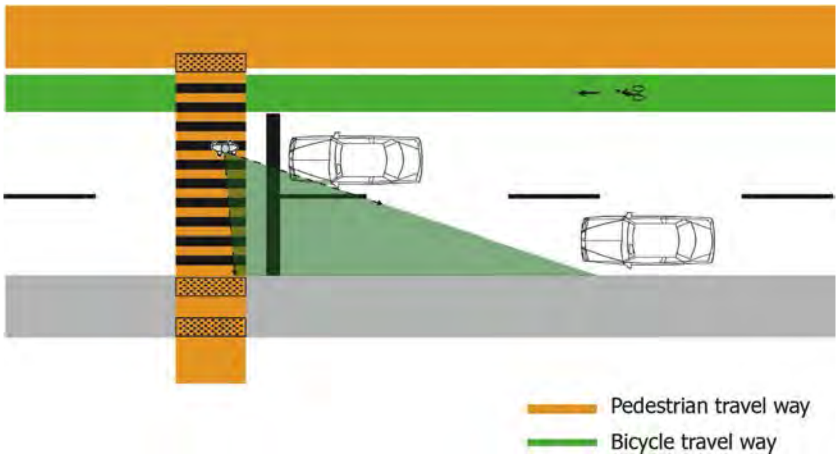


***Exhibit 5-14. Multiple-threat crash – Pedestrian's view of approaching vehicle is blocked by yielding motorist.***

Multiple-threat conditions may also exist at signalized locations when permissive turns or right-turn-on-red are allowed by multiple left- or right-turn lanes. Where these turns are permitted across crosswalks showing pedestrian Walk indications, visibility of pedestrians can be reduced along with the ability to yield without affecting through traffic. It is recommended that this condition not be introduced and that pedestrian Walk indications do not coincide with permissive turns or right-turn-on-red across the crosswalk. In these cases, protected turns for motorists or separate phases for permissive turns and pedestrian movements are recommended.

### 5.3.3 Offset Crossings

Where sidewalks, sidepaths, or separated bike lanes are aligned parallel to motor vehicle travel lanes, the designer should consider enhancing any crossings where motorists may turn left or right across these nonmotorized facilities.

Crossings offset from the parallel motor vehicle lanes, also sometimes called recessed crossings, have been shown to improve motorist yielding rates (as summarized in *7*). These crossings are commonly located 6 to 20 feet from the travel lanes, with higher offset distances corresponding to higher vehicular speeds along the mainline. This offset distance allows for additional perception and reaction time by motorists encountering bicyclists or pedestrians in the crossing, and it provides a place for the turning vehicle to queue at the crossing that is clear of the parallel motor vehicle traffic. Offset crossing locations are a standard feature of roundabouts due to their ability to separate decision points for drivers (*3*). In addition to offsetting the crossing location, sightlines between drivers and nonmotorized users should be maintained to allow motorists a clear view of nonmotorized users in or approaching the crossing.

### 5.3.4 Raised Crossings

Crossing locations can be augmented by raising the crossing, as shown in Exhibit 5-15, in which case a raised crossing is combined with an offset crossing. Raised crossings slow motorist approach speeds at the crossing and elevate users in the crosswalk to increase their visibility to motorists. Raised crossings further communicate right-of-way priority at the crossing and increase safety for pedestrians and bicyclists.

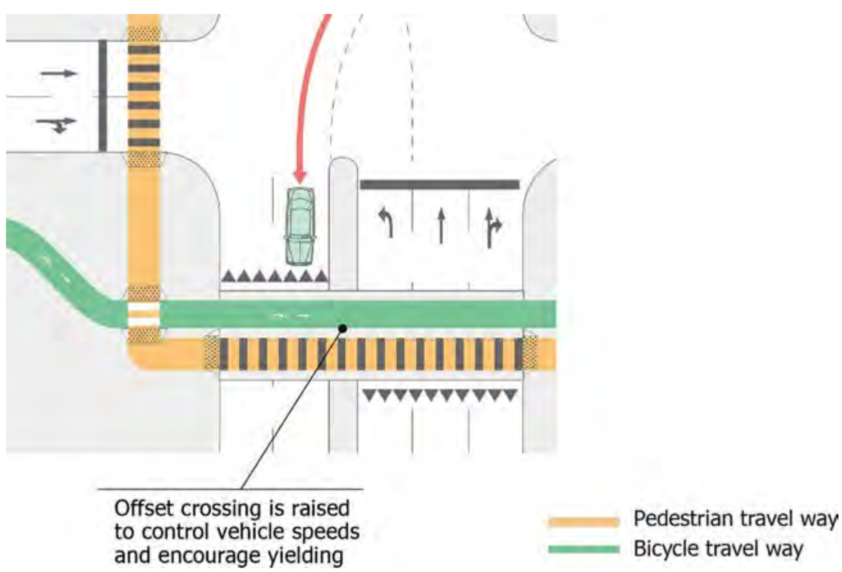


***Exhibit 5-15. Offset raised crossing.***

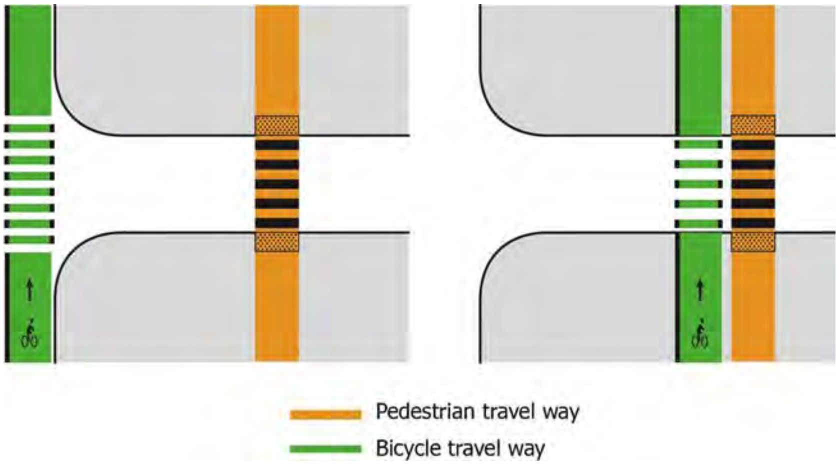


***Exhibit 5-16. Street-level bike lane at side street/ramp entry with green conflict markings** (left) **and sidewalk level separated bike lane at side street/ramp entry with green conflict markings** (right).*

### 5.3.5 Pavement Markings

Pavement markings are key to communicating right-of-way between users and alerting motorists and nonmotorists to the possible presence of other intersection users.

High-visibility crosswalk markings have been shown to increase motorist yield rates and yielding distance and increase pedestrian scanning for vehicle conflicts before crossing (*10*). These markings should be used in any location in an A.I.I. where a sidewalk, sidepath, or shared-use path crossing intersects a vehicle path.

At locations where on-street bikeways or separated bike lanes cross an intersecting travel lane, the designer should consider the use of green conflict markings, as illustrated in Exhibit 5-16. These crossing bars alert motorists to the intersecting bikeway and highlight the conflict zone. The geometry of the bars typically aligns with any adjacent high-visibility crosswalk markings and extends the full width of the bike facility.

### 5.3.6 Signalized Crossings

In cases with high volumes for any mode, locations where sidewalks, sidepaths, or shared-use paths cross a motor vehicle path ideally should be signalized. Crossings should also be signalized when there is a significant safety hazard created by leaving the crossing uncontrolled, such as in locations with limited sight distance, crossings with multiple lanes in a single direction, or crossings where motor vehicle speeds are likely to exceed 20 mph. Street-level bike lanes, whether conventional or separated, that follow the alignment of travel lanes can typically follow travel lane signalization, provided that the clearance time is calculated for the slower speed of bicyclists (12 to 18 mph). If this bicycle clearance time is not possible due to a combination of the length of the crossing, maximum allowable yellow clearance time, and bicycle speeds (which may depend on vertical grades of the intersection), additional mitigation (e.g., mid crossing refuge spaces) is likely necessary.

Signalized crossings that separate signal phases, so motorists do not move concurrently with pedestrians or bicyclists, reduce the likelihood of crashes. In contexts with significant safety concerns or moderate to high nonmotorized (pedestrian or bicycle) volumes, signals should be designed to avoid concurrent vehicle phases with conflicting nonmotorized crossings. Designers should provide adequate pedestrian clearance time to ensure that pedestrians are not within the crossing when conflicting traffic movements are released.

Pedestrian signals with countdown displays are recommended for conveying remaining phase time to crosswalk users in compliance with MUTCD requirements (*9*). These countdown displays often provide cues for drivers and on-street bicyclists regarding the remaining vehicular green time. However, sometimes pedestrian phases end earlier than the concurrent vehicular phase. This can create potential safety issues for both drivers and cyclists at the end of either phase. Designers should consider the potential safety impacts on other users when concurrent pedestrian and vehicular phases do not end simultaneously. These considerations may also affect a decision to allow or not allow a pedestrian signal head to be visible to other users.

Where full signals are not practicable, other crossing treatments, such as raised crosswalks, additional crossing signs/warnings, RRFBs, and PHBs, should be considered.

### 5.3.7 Refuge Islands

Where longer crossing distances or signalization require pedestrians and bicyclists to cross in stages, refuge islands should be provided for vulnerable users to wait. These refuge islands should be sized depending on the volume of expected users but should be no less than 5 feet wide (perpendicular to the direction of pedestrian and bicyclist travel) (*5*) and preferably at least as wide as the crosswalk to which they connect, which is at least 6 feet wide per the MUTCD (*9*). A refuge depth of 10 feet in the direction of pedestrian and bicyclist travel accommodates bicycles with trailers or with tagalong extensions; it also increases the waiting space and comfort for pedestrians who must queue on the island. The minimum refuge depth in the direction of pedestrian and bicycle travel is 6 feet, which is the minimum to allow two sets of detectable warnings (each 2 feet in depth) plus a gap between them of 2 feet. The 6-foot minimum depth is also the depth needed for the physical length of a standard bicycle or a person pushing a stroller (see Exhibit 5-17). Where higher volumes of users are expected or are congregating from crossings in multiple directions, the refuge space should be designed to fit all users. There may be a tradeoff in terms of overall travel time and the possibility of needing to split the crossing into multiple stages if the refuge dimensions are large. The context of the location, the intended operation of the intersection, and attendant tradeoffs among modes should be considered when determining the ultimate refuge island dimensions.

### 5.3.8 Long Single-Stage Crossings

Long single-stage crossing opportunities can be challenging for pedestrians when there are multiple lanes and traffic from opposing directions. As the number of lanes increases, the difference between walkable distance by an average pedestrian and a slower pedestrian increases, thus making the crossing more difficult for slower pedestrians. Longer crossings without refuges also introduce the possibility for pedestrians with vision disabilities to veer considerably from their traveled path within the crosswalk.

One solution is to provide pedestrian islands to break the crossing up and to provide refuge. The pedestrian delay and signal timing tradeoffs associated with this design decision are discussed in later chapters. The refuge islands should be sufficiently wide to meet ADA accessibility requirements and, ideally, best practices to provide room for a person with a bicycle; however, any median or refuge that is substantially wider may create extra crossing time for pedestrians.

When confronted with the tradeoff between multiple shorter crossings versus fewer longer crossings, using detailed performance measures can help to determine which option produces the desired result.

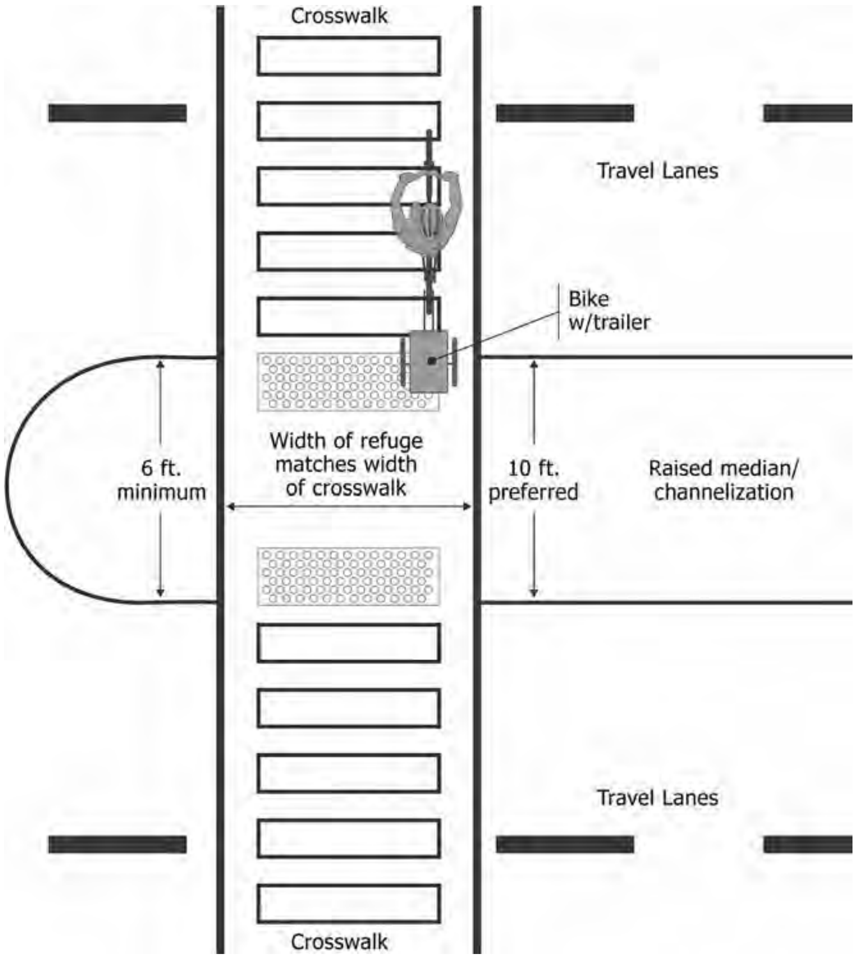


***Exhibit 5-17. Minimum and preferred widths for refuge islands.***

There is no universally optimal solution for providing pedestrian crossings along the dimensions of operations, delay, and safety. However, the tradeoffs presented here should allow the designer to consider the design option that matches the desired performance outcome.

## 5.4 Design Flag Treatments and Techniques

Chapter 4 introduced a set of twenty design flags that may affect comfort and safety for pedestrians and bicyclists. This section lists potential treatments and techniques for each of the twenty flags. These treatments and techniques can be applied without changing the overall design concept.

### 5.4.1 Motor Vehicle Right-Turns

Design techniques and treatments can include

- Providing a stop bar before the marked pedestrian crossing.
- Providing adequate sight distance at the intersection from the stop bar.
- Including space for queue storage for a vehicle to queue in-between the crossing and conflicting traffic flow, when waiting to turn right on red (providing separation between driver decisions).
- Restricting right-turns-on-red.

### 5.4.2 Uncomfortable/Tight Walking Environment

Design techniques and treatments can include

- Widening the sidewalk.
- Illuminating the walking environment.
- Increasing the size of channelization islands and corner areas.
- Providing vertical separation between pedestrians and vehicles.
- Providing horizontal separation (buffers) between pedestrians and vehicles.

### 5.4.3 Nonintuitive Motor Vehicle Movements

Design techniques and treatments can include

- Designing the approaching path to face the initial direction of opposing traffic.
- Providing signing that is viewable and understandable to the intended users, as well as appropriate speech messages for any accessible pedestrian signals or audible information devices.
- Providing pavement marking at the entrance to the crossing that indicates which direction a pedestrian or bicyclist should look to view oncoming traffic.
- Choosing different geometric features of the design to minimize or eliminate movements from unexpected directions.

### 5.4.4 Crossing Yield-Controlled Or Uncontrolled Vehicle Paths

Design techniques and treatments can include

- Providing signalized crossings.
- Providing stop-controlled crossings.
- Reducing vehicle speed through curvatures.
- Installing raised crosswalks to reduce vehicle speed.

### 5.4.5 Indirect Paths

Design techniques and treatments can include providing the following:

- Direct crossing opportunities with a dedicated pedestrian phase, if necessary.
- Midblock crossing before the intersection to address an otherwise indirect path.
- Grade-separated pedestrian and bicycle facilities, depending on the context and the origin-destination patterns for pedestrians and bicyclists.

### 5.4.6 Executing Unusual Movements

Design techniques and treatments can include

- Re-aligning pedestrian/bicycle movement to make them more intuitive.
- Constructing dedicated pedestrian or bicycle facilities.
- Following the design process to meet expectations for people walking and biking.

### 5.4.7 Multilane Crossings

Design techniques and treatments can include

- Reducing the number of travel lanes.
- Providing two-stage crossings to reduce the number of lanes and travel directions crossed at one time.
- Providing signalized or stop-controlled crossing.
- Installing raised crosswalks to reduce vehicle speed.

### 5.4.8 Long Red Times

Design techniques and treatments can include

- Reducing the overall cycle length.
- Modifying the phase sequence to reduce the total crossing time. (This particularly applies for priority movements because improvements in travel time for one origin-destination pattern may result in longer crossing times for other movements.)

### 5.4.9 Undefined Crossings at Intersections

Design techniques and treatments can include

- Striping biking pathways through an intersection to identify where drivers are entering the designated path of bike travel.
- Where off-street bicycling facilities are provided, placing the bike crossing and the pedestrian crossing next to one another to reduce undefined space.
- Designing two-stage left-turn queue boxes with queuing space for multiple bicyclists. [Two-stage turn queue boxes are allowed by and subject to FHWA Interim Approval IA-20, *Optional Use of Two-Stage Bicycle Turn Boxes* (*8*).]

### 5.4.10 Motor Vehicle Left-Turns

Design technique and treatments can include

- Converting permissive left-turn movements into protected left-turn movements with a dedicated signal phase. (At RCUTs, an option is to remove left-turns at the intersection.)
- Providing queue storage for at least one vehicle between the pedestrian crossing and the end of the channelized turn lane to separate motorist decision points.
- Using a traffic control signal to control the channelized turn movement.
- Removing the channelized turn lane.

### 5.4.11 Intersecting Driveways and Sidestreets

Design technique and treatments can include

- Reducing the number of driveways through access management.
- Controlling vehicle speeds at driveways through curvature or vertical elements.
- Providing signalized or stop-controlled crossings at driveways.

### 5.4.12 Sight Distance for Gap Acceptance Movements

Design technique and treatments can include

- Designing vertical obstructions, such as bridge abutments, tall landscaping, and signal cabinets to be positioned outside of necessary sight triangles.
- Establishing horizontal and vertical alignments that provide the necessary sight distance.

### 5.4.13 Grade Change

Design technique and treatments can include

- Constructing a dedicated protected bike lane on grade sections.
- Constructing a multiuse path on grade sections.
- Reducing vehicular speeds.

### 5.4.14 Riding in Mixed Traffic

Design technique and treatments can include

- Separating bicyclists from motor vehicles through dedicated protected lanes.
- Designing for lower motor vehicle speeds where bicyclists and motorists interact.

### 5.4.15 Bicycle Clearance Times

Design techniques and treatments can include

- Reducing the number of lanes to cross.
- Reducing lane widths.
- Reducing median widths.
- Moving ramps closer to the crossover.
- Providing refuge for bicyclists.
- Installing bicycle dilemma zone detection to extend the transition of signal phases when necessary.
- Providing a separate bicycle signal with a dedicated indication of required clearance time.

### 5.4.16 Lane Change Across Motor Vehicle Travel Lanes

Design techniques and treatments depend on the crossover movement, but can include the following:

- Designing for bicyclists to use ramps to sidewalks or shared-use paths and cross in a crosswalk.
- Designing for bicyclists to use a two-stage bicycle left-turn queue box with adequate room to maneuver and wait.
- At RCUTs, designing for bicyclists to make a through movement with a channelized direct bicycle crossing (only feasible absent a pedestrian "Z" crossing).
- Clearly marking the entry to the crossover area.
- Design for low motorist speeds (below 20 mph) through a crossover area by reducing radii or implementing speed-reducing treatments.

### 5.4.17 Channelized Lanes

Design techniques and treatments will depend on the channelized lane, but can include the following:

- Designing for bicyclists to use ramps onto sidewalks or shared-use paths and cross in a crosswalk, instead of traveling as vehicles.
- Designing for bicyclists to use a two-stage bicycle left-turn queue box with adequate room to maneuver and wait, instead of making a direct left-turn with motorized traffic.
- At RCUTs, designing for bicyclists to make a through movement with a channelized direct bicycle crossing (only feasible absent a pedestrian "Z" crossing).
- Designing for low motorist speeds (below 20 mph) in channelized lane areas by reducing curve radii.

### 5.4.18 Turning Motorists Crossing Bicycle Path

Design techniques and treatments can include

- Providing design treatments for vehicle storage between the pedestrian crossing and vehicle merge, thereby separating driver decision points.

- Installing a signal to control the channelized movement.
- Designing channelization to manage vehicular speeds through the use of compound curves.
- Implementing raised crossings at the location within the channelized turn where motorist speeds are lowest.
- Removing channelization.

### 5.4.19 Riding Between Travel Lanes, Lane Additions, or Lane Merges

Design techniques and treatments can include

- Replacing merge areas with stop- or yield-controlled movements.
- Constructing separate protected bike lanes or multiuse paths.
- Reducing vehicle speeds in conflict areas.

### 5.4.20 Off-Tracking Trucks in Multilane Curves

Design techniques and treatments can include

- Constructing separate protected bike lanes or multiuse paths.
- Increasing lane widths in curved areas.
- Using striped vane islands to separate vehicle lanes.

## 5.5 References

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CHAPTER 6

# Median U-Turn (MUT) Intersections

## 6.1 Introduction

The Median U-turn (MUT) intersection refers to any intersection replacing direct left-turns at an intersection with *indirect* left-turns using a U-turn movement downstream of the intersection, typically within a wide median. The MUT intersection eliminates left-turns on one or both intersecting streets and thus reduces the number of traffic signal phases and conflict points at the main crossing intersection. This can result in improved intersection operations and safety. The MUT is also known as a Median U-turn Crossover, a boulevard turnaround, a Michigan Left, or Thru-Turn Intersection. Exhibit 6-1. illustrates an example of an MUT intersection with a signalized main intersection and signals at each U-turn.

At an MUT intersection, vehicles on the major street that would typically turn left at a signalized intersection are directed through the main crossing intersection, and then make a U-turn movement at a downstream directional crossover (that is usually signalized) and proceed back to the main crossing intersection (in the opposite direction from which the motorist came). Such vehicles then turn right onto the minor street. Directional crossovers are one-way median openings facilitating U-turns. Exhibit 6-1 depicts these movements.

Similarly, vehicles on the minor street that would typically turn left at a signalized intersection with the major street will turn right onto the major street, make a U-turn movement at the same directional crossover downstream, and then proceed through the main crossing street. The signals at the main crossing intersection (that permit only through and right-turn movements from both streets) and the signals at the U-turn crossovers (that alternate between through traffic on the major street and U-turn movements) are typically coordinated to minimize delays to both through and turning traffic.

The geometric design of an MUT intersection introduces some unique design elements not typically present at a conventional intersection. These elements include

- A wide median, often needed to facilitate the MUT movements. Typically, this median is uniform through the intersection and main crossing street, but there are design variations reducing the length of the wide median or locating the median on the minor street.
- A large-enough vehicle path at the U-turn crossover to accommodate trucks and allow for efficient movements through the U-turn by passenger vehicles.
- Design elements providing positive guidance and signage to reduce the chances of driver error and discourage prohibited turns.
- Signing, marking, and geometric design promoting safe and efficient movements that would otherwise be unexpected or not familiar to motorists.
- Corridor-wide access strategies and management considerations to properties along the median street to promote safe and efficient access to these properties.

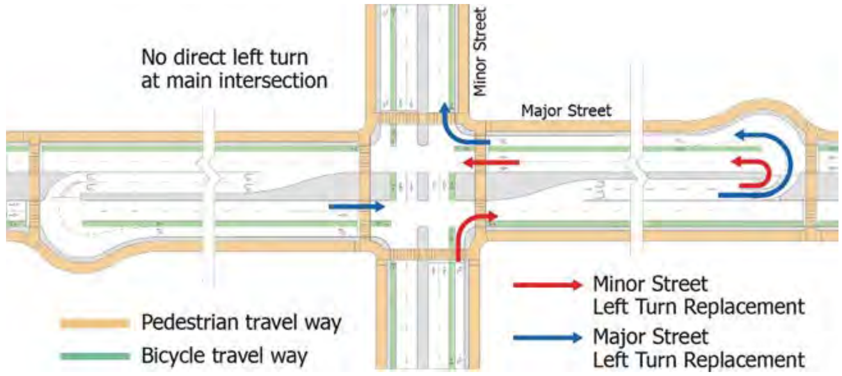


***Exhibit 6-1. Example of an MUT intersection.***

Portions of the material in this chapter are derived from earlier work for FHWA (*1*), updated to reflect the knowledge gained in this research.

## 6.2 Multimodal Operations

This section presents the multimodal operational characteristics of an MUT intersection, starting with motorized vehicles and then explaining how pedestrians and bicyclists are served.

### 6.2.1 Motorized Vehicles

The MUT intersection provides traffic operational benefits, particularly for through movements on the major street, by reducing the number of intersection signal phases and shortening overall signal cycle lengths. Despite requiring motorists to drive an additional distance compared to left-turns at a conventional intersection, MUT intersection left-turns usually have equal or improved delay times compared to a conventional intersection.

Exhibit 6-2 illustrates concurrent movements at an MUT intersection. Exhibit 6-3 shows the typical signal locations for an MUT intersection.

The MUT intersection, like many alternative intersections, removes left-turn phasing, which results in fewer clearance intervals in the intersection cycle (in this case, a reduction from four to two). The time formerly allocated for the redirected movements and eliminated clearance intervals can be allocated to other movements, thus improving intersection efficiency.

An important aspect of MUT operations is that right-turn movement volumes increase due to the redirection of left-turn movements. These right-turn movements conflict with pedestrians

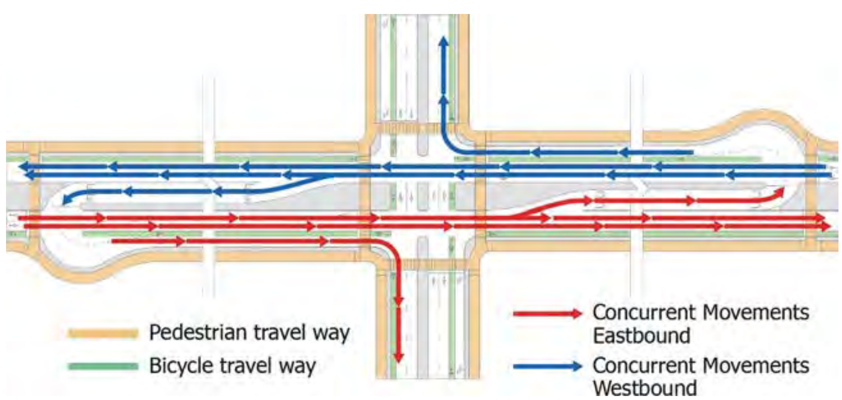


***Exhibit 6-2. Concurrent movements at the main MUT intersection.***

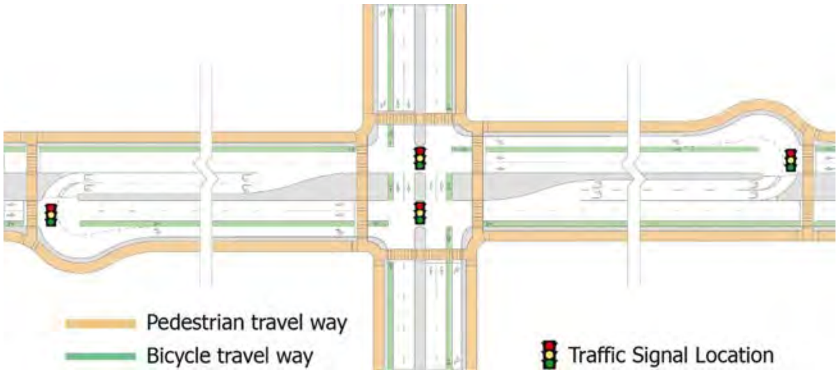


***Exhibit 6-3. Typical signal locations at an MUT intersection.***

and bicyclists. It may be necessary or desirable to restrict right-turn-on-red (RTOR) movements to provide adequate operational or safety performance for all modes, recognizing that it may increase delay for turning motorists at some MUT intersections.

## 6.2.2 Pedestrians

Pedestrians can cross at the main MUT intersection and potentially at each of the U-turn crossover locations. With vehicular left-turns (and left-turn lanes or pockets) removed from the main intersection, the lengths of crossings for pedestrians can often be reduced compared to a conventional intersection, therefore reducing exposure. Cycle lengths can be reduced due to more efficient signal phasing, reducing pedestrian wait times. The following sections discuss pedestrian considerations at MUTs further.

### *6.2.2.1 Main Intersection Crossing*

The locations of pedestrian crossings at the main MUT intersection are essentially the same as those at a conventional intersection. However, the way these crossings are operated—one-stage versus two-stage—can have a significant impact on operations for both pedestrians and motor vehicles. Exhibit 6-4 compares a single-stage versus two-stage crossing at an MUT intersection.

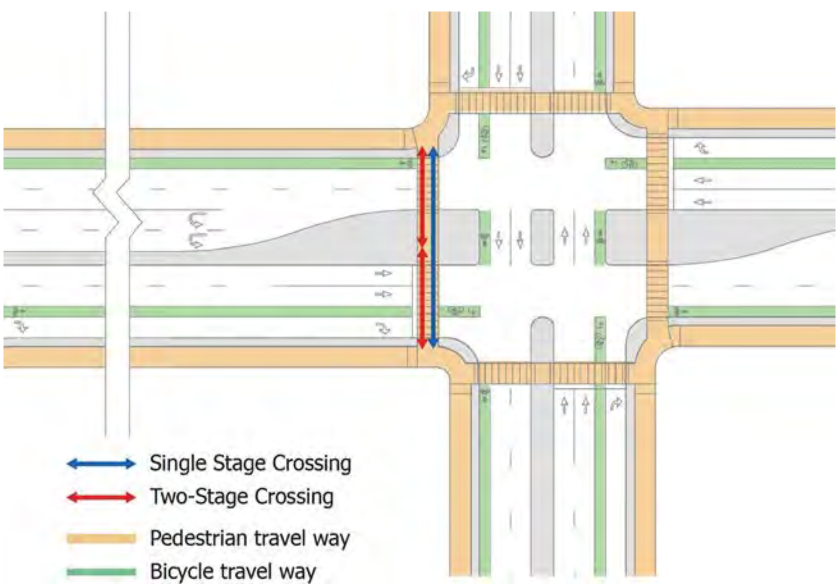


***Exhibit 6-4. Single-stage vs. two-stage crossing at MUT.***

All else being equal, single-stage crossings are preferred so pedestrians are not unduly delayed and need not wait in the median between traffic streams. Single-stage crossings are also more common and thus are more likely to meet pedestrian expectations. However, the width of the major street may result in pedestrian walk times longer than the green time required for vehicular through movements on the minor street, which could otherwise be allocated for major street traffic. The pedestrian crossing would control the signal timing. In these cases, two-stage crossings can be used if the median cannot be narrowed at the main intersection. For a two-stage crossing to be viable, the median area must be wide enough to accommodate pedestrians, wheelchairs, strollers, and/or bicycles. Despite the overall shorter cycle length that a two-stage crossing might allow (due to the shorter pedestrian clearance time required for crossing one direction of traffic at a time), the total pedestrian crossing time for an MUT intersection under a two-stage crossing is typically much greater than that of a single-stage crossing. Two-stage crossings also require pedestrians to wait within the intersection for the next crossing phase. The need to wait must be communicated to pedestrians with vision disabilities. Two-stage crossings require pedestrian detection and accessible pedestrian signals (APS) in the median.

Several techniques are available to reduce a pedestrian crossing from two stages to one stage, as shown in Exhibit 6-5.

#### *6.2.2.2 Potential Challenges With Right-turning Motor Vehicles*

Right-turning traffic volumes are higher at an MUT intersection than at the equivalent conventional intersection. This could create operational or safety challenges for both pedestrians and motor vehicles. Exhibit 6-6 presents a summary of the techniques, advantages, and disadvantages of various treatments for the conflict between pedestrians and right-turning motor vehicles.

#### *6.2.2.3 U-turn Crossover*

U-turn crossover intersections create additional opportunities for midblock pedestrian crossings using a traffic signal or pedestrian hybrid beacon (PHB). If signalized, crossover intersections typically have signals that only control major street traffic approaching the main crossing intersection. However, signals controlling both directions of the major street could be installed to facilitate pedestrian crossings, as shown in Exhibit 6-7.

### 6.2.3 Bicyclists

On-street bicyclists using an MUT intersection have different experiences when traveling as a through movement, right-turn, or left-turn. The next sections discuss each of these.

#### *6.2.3.1 Through Movements*

Bicyclists making through movements encounter relatively higher percentages of green time at MUT intersections compared to the same experience at conventional intersections. At MUT intersections, there is a higher proportion of right-turning vehicles compared to at a conventional intersection (given that traffic that would turn left at a conventional intersection is required initially to turn right at an MUT intersection), which results in more conflicts between the bicycle through and vehicle right-turn movements.

#### *6.2.3.2 Right-Turn Movements*

The right-turn movements for bicyclists are similar to the right-turn movements at conventional intersections. If a through bicycle lane is provided between through and right-turn lanes for motor vehicles, bicyclists need to share the right-turn lane with motor vehicles when making a right-turn.

**Exhibit 6-5. Techniques to reduce MUT crossing from two stages to one stage.**

| Technique | Advantages | Disadvantages |
|---|---|---|
| Increase cycle length | • Allows pedestrian crossing to be completed within one cycle | • Increases time for minor street, possibly well beyond what is needed to serve motor vehicle traffic.<br>• May require considerably longer cycle length to cover full MUTCD requirements for pedestrian clearance time. |
| Reduce median width at main intersection | • Reduces pedestrian clearance time | • May require alignment adjustments of the major street |
| Reduce the number of lanes on the major street | • The redirection of movements may allow a reduction in lanes beyond just the left-turn lanes that are removed | • Reduction in lanes may increase delay for motorized vehicles and create queuing affecting locations upstream of the main intersection. |
| Reduce the width of lanes on the major street | • Reduces pedestrian clearance time | • The effect on pedestrian clearance time is likely to be minor unless there are many lanes whose widths are being reduced<br>• Reducing lane width may be inappropriate in certain contexts |
| Allow pedestrian movements to break coordination when called | • Allows pedestrian crossing to be completed within one cycle while keeping time for minor street only to what is needed for motor vehicles during cycles without pedestrian calls | • Transitions back into coordination may disrupt progression along the major street<br>• If pedestrian calls are frequent enough, coordination may never be maintained |
| Provide pedestrian lead interval (with APS) | • Allows pedestrians to get a head start on crossing | • May increase the overall cycle length requirement |

**Exhibit 6-6. Techniques to manage conflict between pedestrians and right-turning vehicles at MUT.**

| Technique | Advantages | Disadvantages |
|---|---|---|
| Restrict right-turns-on-red (RTOR) | • Increases safety and reduces conflict potential for pedestrians and bicyclists | • May increase the green time needed for motor vehicles, resulting in longer overall cycle length and more delay for all modes |
| Provide pedestrian lead interval (with APS) | • Allows pedestrians to get a head start on crossing | • Does not necessarily provide the same safety benefit for pedestrians crossing toward the turning vehicles |
| Position stop line for through vehicles to be farther from the crosswalk than the stop line for right-turning vehicles | • Increases visibility between right-turning motorists and pedestrians | • May increase clearance time for through movements |

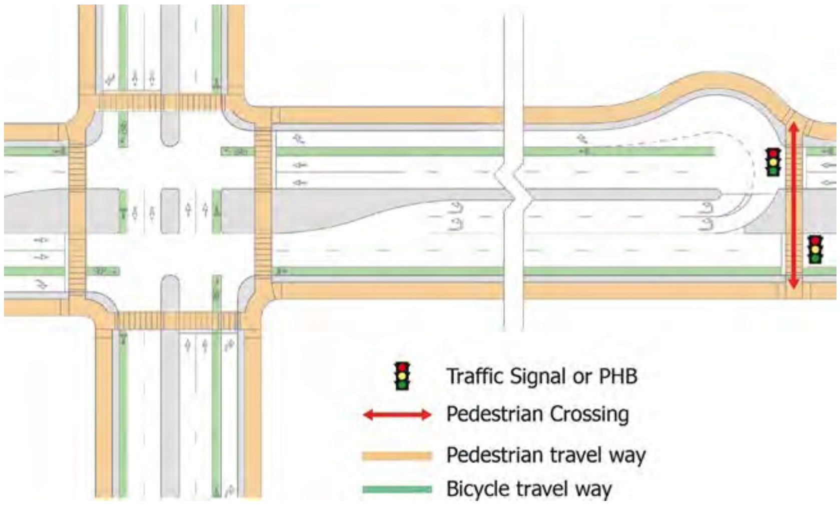


***Exhibit 6-7 Signalized midblock crossing.***

### *6.2.3.3 Left-Turn Movements*

Left-turning on-street bicyclists have three options for navigating an MUT intersection, as described below and illustrated in Exhibit 6-8 for left-turns on the major street and Exhibit 6-9 for left-turns on the minor street. These options are as follows:

- **Bicyclists making a two-stage left-turn:** Bicyclists approach the intersection on the right and follow the vehicular signal indications. When receiving the green indication, the bicyclists proceed across the intersection and stop in a two-stage bicycle turn box. When the cross street receives a green indication, bicyclists proceed along the cross street. Interim Approval IA-20, Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes (*2*) provides signing and pavement marking provisions for this option.
- **Bicyclists following pedestrian crossing rules:** Bicyclists approach the intersection and, instead of traveling through based on the vehicle indications, exit the street to the right and follow the pedestrian signal indications.
- **Bicyclists following motor vehicle rules:** Bicyclists approach the intersection on the right and follow the vehicular signal indications. When receiving the green indication or with an acceptable gap in cross-traffic (when turning on a red indication), the bicyclists enter the intersection, cross all lanes to the left side of the road, and proceed to the MUT crossover.

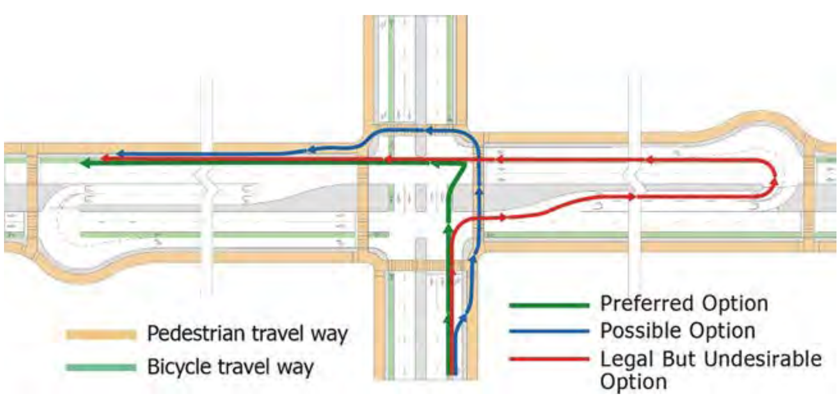


***Exhibit 6-8. Left-turn options for bicyclists on the minor street at MUT intersection.***

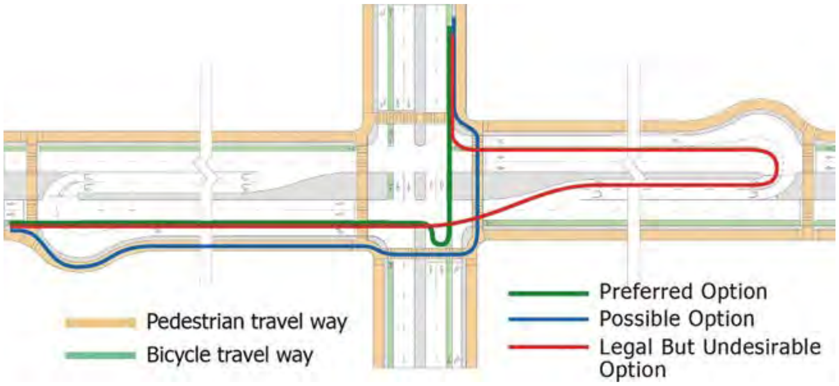


***Exhibit 6-9. Left-turn options for bicyclists on the major street at MUT intersection.***

When the green signal is received, the bicyclists complete the U-turn, crossing all lanes to the right side of the road, travel to the main intersection, and proceed through or turn right as necessary (just as a vehicle would). The bicyclist must cross all lanes of traffic between the main intersection and the MUT while vehicle traffic performs the same maneuver. This option is undesirable for bicyclists, but it is always legally permissible, even if other options are available.

Of these options, the two-stage left-turn is the most natural for bicyclists and the most likely to be obeyed. The "vehicle rules" option exposes bicyclists to significant out-of-direction travel and potential vehicle conflicts, while the "pedestrian rules" option generates potential pedestrian conflicts. However, the "pedestrian rules" option can be considered when upgrading sidewalks to multiuse paths, when an otherwise off-street bicycle path crosses the street at the intersection, or when the MUT is designed as a protected intersection (see Section 6.4 for example designs).

## 6.3 Safety and Comfort Characteristics

This section discusses safety and comfort characteristics for pedestrians and bicyclists at MUT intersections. MUT intersections have been shown to result in vehicular safety benefits compared to conventional four-legged intersections. The safety benefits for vehicles are attributed to eliminating left-turns at the main intersection and a simplification of driver decision-making (generally dealing with one direction of travel at a time). The MUT intersection offers potential safety benefits for pedestrians and bicyclists, but the effects are not well studied. The discussion of nonmotorized safety focuses on an assessment of conflict points as described below and of design flags.

### 6.3.1 Conflict Points

Pedestrians crossing an MUT intersection encounter fewer distinct conflicting traffic streams than at a conventional intersection. At a conventional intersection, pedestrians cross the street with one-stage or two-stage crossing during the adjacent street's vehicle phase. At an MUT intersection, left-turns are removed from the main intersection and occur away from the intersection, thus removing potential pedestrian exposure to left-turning vehicles. Exhibit 6-10 shows the intersection movements and pedestrian-vehicle conflict points at an MUT intersection design.

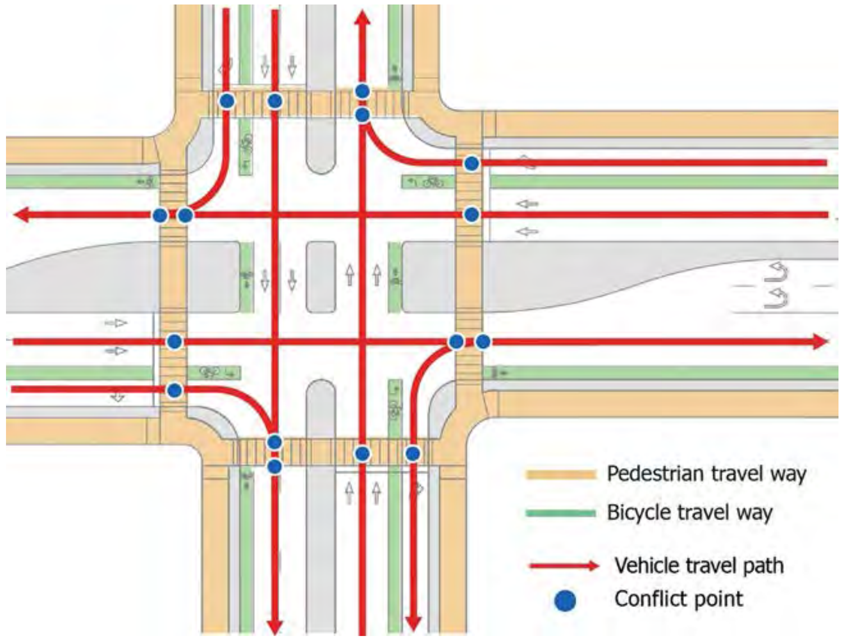


***Exhibit 6-10. Pedestrian-vehicle conflict points at MUT intersection.***

Crosswalks can be marked across all intersection legs, as at a conventional intersection. Pedestrians at an MUT intersection cross the major street during the minor street through and right-turn signal phase, when the only legally concurrent movement conflicts possible are with minor street right-turning vehicles or major street right-turning vehicles making an RTOR. The number of conflict points is limited. However, the frequency of conflicts at each conflict point increases, because left-turn movements are consolidated into right-turn movements and the total number of vehicles crossing the crosswalk remains the same. The tradeoff is a reduction in concurrent conflicts but an increased volume for the remaining conflicting traffic flow. Further empirical research is needed to test the quantitative safety effect for pedestrians.

Exhibit 6-11 shows the bicycle-vehicle conflict points at an MUT intersection with on-street bike lanes. For separated facilities, bicycle-vehicle conflicts match the pedestrian-vehicle conflicts introduced above, given that pedestrian and bicycle crossings would be co-located.

### 6.3.2 Pedestrians–Key Safety Challenges

Given the reduction of vehicular movements at the main intersection through the elimination of left-turns, the MUT offers the opportunity for a simplified pedestrian experience. Despite this, some safety concerns that should be flagged in an ICE evaluation remain, including:

- The MUT results in an increased vehicular right-turning volume compared to a conventional intersection, because left-turns have to make a right-turn to get to the U-turn bay (minor street lefts) or make a right-turn after the U-turn maneuver (major street lefts). This could exacerbate the *Motor Vehicle Right-Turns* design flag (Section 4.4.1). An MUT intersection inherently avoids the *Motor Vehicle Left-Turns* design flag (Section 4.4.10).

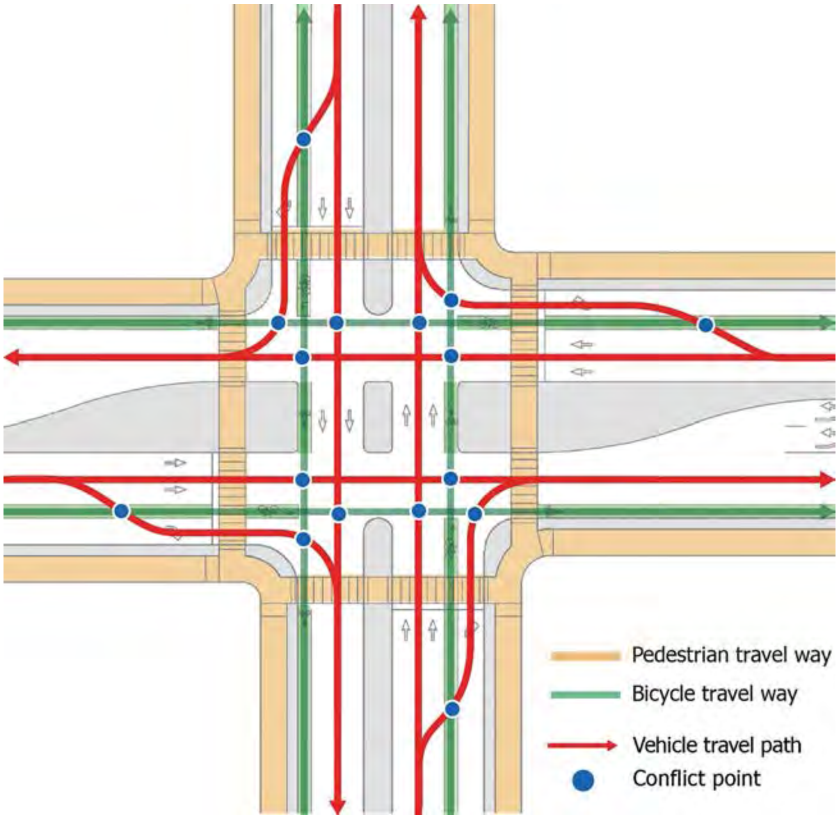


***Exhibit 6-11. Bicycle-vehicle conflict points at MUT intersection with on-street bike lanes.***

- The median at an MUT intersection can be wide, especially in retrofit applications where left-turn pockets are closed after the initial design. The mainline crossing can be relatively long, resulting in increased pedestrian exposure, and long flashing Don't Walk clearance intervals. A two-stage crossing with refuge in the (wide) median can break up these long crossings but may cause added pedestrian delay, as pedestrians have to potentially wait through two signal cycles. The median refuge helps to mitigate the multilane crossings design flag (Section 4.4.7).
- A supplemental pedestrian crossing can be provided at each U-turn location, given it is a signal-control location for the U-turns. The outbound vehicular travel lanes rarely are signalized but would need a control device or treatment if a crossing is provided to avoid forcing pedestrians to cross multiple uncontrolled high-speed vehicular travel lanes. Failure to signalize the outbound vehicular travel lanes would trigger the crossing yield-controlled or uncontrolled vehicle paths flag (Section 4.4.4).

In consideration of these challenges and pedestrian conflict points, Exhibit 6-12 presents the design flags generally applicable to pedestrians at MUTs. Design flags and treatments whose discussion applies across alternative intersection types are in Chapter 5.

Some design flags unlikely to be present at an MUT intersection include the following:

- **Nonintuitive motor vehicle movements (Section 4.4.3)**: No motor vehicle movements are crossed over or otherwise approaching from an nonintuitive direction for people crossing at an MUT.

**Exhibit 6-12. Summary of design flags for pedestrians at MUT intersections.**

| Design Flag | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | This flag would carry forward to the final design stage, based on right-turns. Because MUTs have relatively high volumes of right-turns, the geometry of the turning movement will be a critical factor in controlling speeds. | Pedestrian, all crossings |
| Crossing Yield- or Uncontrolled Vehicle Paths (Section 4.4.4) | With the right-turns identified in the design flag above, pedestrians at the four crossings at the main intersection would cross a high volume of right-turning vehicles with a green signal indication. | Pedestrian, all crossings |
| Multilane Crossings (Section 4.4.7) | The major street crossings at an MUT may be relatively long. A median refuge is common, but the single-direction travel lane configuration may remain a long crossing. | Pedestrians, all crossings |
| Undefined Crossing at Intersections (Section 4.4.9) | This flag is not unique to MUTs but given the relatively high volume of right-turning vehicles conflicting with the pedestrian crossing, lack of clearly defined user space would be stressful for pedestrians. | Pedestrians, all crossings |

- **Indirect paths (Section 4.4.5)**: An MUT intersection typically provides four crossings at the main intersection, meaning that circuitous pedestrian routes are unnecessary.
- **Executing unusual movements (Section 4.4.6)**: The wayfinding, traversing, and crossing at MUTs is relatively straightforward, without unexpected directionality or nonintuitive turns.
- **Long red times (Section 4.4.8)**: This design flag seems unlikely to be triggered at an MUT intersection, given that the two-phase signal via the reduction of left-turn is the essence of the MUT. These reductions allow for shorter cycle lengths and thus no long red time.
- **Motor vehicle left-turns (Section 4.4.10)**: Left-turns are eliminated at an MUT intersection.

### 6.3.3 Bicycles–Key Safety Challenges

For bicyclists using a shared-use path, the safety challenges discussed for pedestrians above apply. For bicycles traveling in on-street facilities, additional safety challenges include the following:

- Bicycle left-turns traveling in vehicular lanes face significant out-of-direction travel (to and from the U-turn), as well as safety risks in needing to perform a two-sided weaving maneuver across vehicle travel lanes with potentially high speeds, high volumes, or both. This safety concern is presented as the design flag **Lane Change Across Motor Vehicle Travel Lane(s)** (Section 4.4.16).

- Bicycle through movements face potential "right hook" conflicts with vehicles turning right at the MUT intersection. With the vehicular right-turn movement increased, the frequency of this conflict (the **Turning Motorist Crossing Bicycle Path** design flag, Section 4.4.18) may also increase.
- If channelized lanes are provided on any approach, the design issues in **Channelized Lanes** (Section 4.4.17) apply. Safety concerns related to the design of the channelized lanes are described further in Chapter 5.

Exhibit 6-13 presents the design flags applicable to bicycles at MUT intersections. Design flags and treatments whose discussion applies across alternative intersection types are presented in Chapter 5.

**Exhibit 6-13. Summary of design flags for bicyclists at MUT intersections.**

| Design Flag | Description | Mode / Travel Path |
|---|---|---|
| Indirect Paths (Section 4.4.5) | For bicyclists seeking to make a left-turn at the intersection, the U-turn as designed represents considerable out-of-direction travel (several hundred feet), which may exceed thresholds for yellow or red flags (see Section 4.4.6). | Bicyclists making left-turns via U-turn maneuver at MUTs |
| Multilane Crossings (Section 4.4.7) | For bicyclists crossing with pedestrians or using a path, the major street crossings at an MUT may be relatively long. A median refuge is common, but the single-direction travel lane configuration may remain a long crossing. | Bicyclists, all path crossings |
| Undefined Crossing at Intersections (Section 4.4.9) | The movements are not clearly demarcated for the common expectation for left-turning bicyclists to proceed straight through the signal and cross over traffic to make a U-turn. | Bicyclists making left-turns via U-turn maneuver at MUTs |
| Lane Change Across Motor Vehicle Travel Lane(s) (Section 4.4.16) | Bicyclists making the U-turn maneuver must cross over one or several lanes of motor vehicle traffic on a tangent roadway section to position for the U-turn. | Bicyclists making left-turns via U-turn maneuver at MUTs |
| Turning Motorists Crossing Bicycle Path (Section 4.4.18) | The expected relative high right-turn volumes at an MUT exacerbate potential conflicts between right-turning vehicles and through bicyclists. | Through bicyclists (particularly on the minor street) |

### 6.3.4 Other Safety Concerns

Besides the preceding discussion of key pedestrian and bicycle safety concerns, there are other general benefits and concerns presented by MUT intersections.

Design flags that are more universal and not unique to MUTs include the following:

- **Intersection Driveways and Side Streets** (Section 4.4.11);
- **Sight Distance for Gap Acceptance Movements** (Section 4.4.12)**;**
- **Grade Change** (Section 4.4.13); and
- **Off-tracking Trucks in Multilane Curves** (4.4.20).

Sometimes, these design flags may need to be resolved in subsequent stages of design.

## 6.4 MUT Intersection-Level Concepts

Three design concepts are presented in this section to illustrate techniques for improving the pedestrian and bicyclist safety and operational performance of MUTs. These concepts are *not* suggested as designs to be replicated as is; rather, each concept illustrates design options within a context. The concepts mix design approaches and are intended to address the design flags presented in Sections 6.3.1 and 6.3.2. The designer should consider the factors discussed previously in this guidebook when matching designs and treatments to the appropriate context.

Following each concept is a discussion of the flags remaining with the design—the flags not obviated by the design that would still need to be addressed.

The designs include the following:

- MUT On-Street Bikeway Concept
- MUT Protected Intersection Concept
- MUT Shared-Use Path Concept

Sections 6.3.1 and 6.3.2 present other key design flags subject to site-specific concerns and are not obviously presented or solved with the concepts presented below.

### 6.4.1 MUT On-Street Bikeway Concept

This MUT concept (shown in Exhibit 6-14) is readily distinguished by its provision of on-street bike lanes. The concept would be appropriate for a low-speed and/or low-volume context

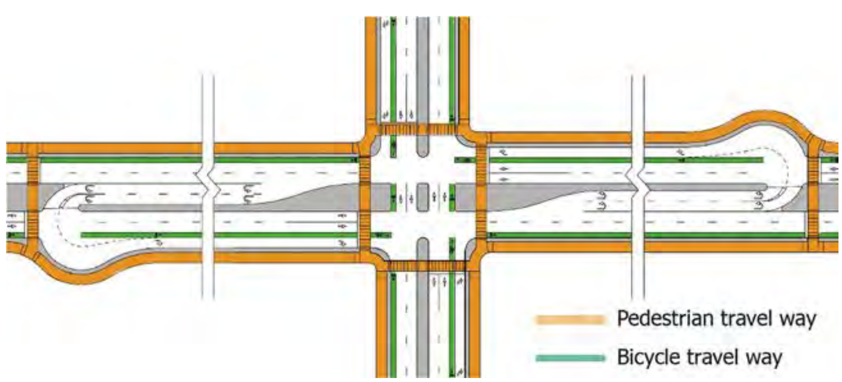


***Exhibit 6-14. MUT on-street bikeway concept.***

and provides an example for carrying existing bike lanes through an MUT; consult Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

#### *6.4.1.1 Benefits*

The design addresses these key elements regarding safety and comfort:

- **Motor Vehicle Right-Turns design flag:** Corner refuge islands tighten right-turn radii and extend physical protection for crossing pedestrians. This turn radius may ultimately need to be modified based on the intended design vehicle path, but the design would control speeds of right-turning vehicles.
- **Indirect Paths design flag:** For bicyclists, the design includes on-street bike lanes with two-stage turn boxes at the intersection to facilitate left-turns. This feature has the benefit of providing an intuitive left-turn movement for all bicyclists and mitigates the *Indirect Paths* design flag. (Note the two-stage turn box has interim approval with FHWA—item IA-20). The two-stage turn boxes also prevent bicyclists from the need to cross over vehicle travel lanes at speed, eliminating the *Lane Change Across Motor Vehicle Travel Lane(s)* flag. For pedestrians, the midblock (at the U-turn) crossings provide more potential for route directness by allowing pedestrians to cross upstream or downstream of the intersection.
- **Multilane Crossings design flag:** For pedestrians, the design includes a separate sidewalk system with exclusively signal-controlled crossings, including supplemental crossings at the U-turn locations. A refuge is provided for every pedestrian crossing to allow for two-stage crossings. This mitigates the *Multilane Crossings* design flag, though not completely (see Exhibit 6-13).
- **Crossing Yield- or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, eliminating the possible associated design flag.
- The design includes a narrowed median with loons (localized widening) to accommodate U-turns.
- The concept features a relatively compact main intersection footprint—the smallest footprint among MUT concepts shared in this guide. This brings potential right-of-way acquisition or construction cost benefits, and residual benefits related to the pedestrian and bicyclist experiences (e.g., shorter crossings generally).

#### *6.4.1.2 Challenges*

Emphasizing again that the design is not intended to be "ready-made," this concept leaves some design flags remaining, as presented in Exhibit 6-15.

### 6.4.2 MUT Protected Intersection Concept

This MUT concept (shown in Exhibit 6-16) is distinguished by its implementation of a protected intersection concept with separated bike lanes. The concept would be implemented in locations with either relatively high motor vehicle volumes or high speeds. The separated bike lane and intersection treatment provide a low-stress riding environment for people biking, including less confident bicyclists. This design is most associated with an urban or suburban environment; the intersection could either match back into existing separated bike lanes or provide ramps for bicyclists to enter or exit the lane. The separated bike lane could be implemented as a shared-use path with pedestrian facilities, as shown in the next concept; the decision would rely upon expected pedestrian and bicyclist volumes (with a multiuse path supporting lower volumes). Consult Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

**Exhibit 6-15. Summary of design flags remaining with MUT on-street bikeway concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | The right-turn volume will likely be relatively high for most approaches because at an MUT it is a consolidation of right-turn and left-turn movements. However, if the curb radii can keep speeds from exceeding 25 mph, the flag may be mitigated. | Pedestrian, all crossings |
| Multilane Crossings (Section 4.4.7) | Although median refuges are included for crossing the major street, a crossing pedestrian would still cross three concurrent same-direction travel lanes crossing all streets, meriting a yellow flag. | Pedestrians, all main intersection crossings |
| Riding in Mixed Traffic (Section 4.4.14) | The provision of the on-street bike lanes does require a bicyclist to ride alongside motor vehicle traffic entering, traversing, and exiting the intersection. Depending on prevailing speeds and volumes, this environment could deter some potential, less confident riders. | Bicyclists, all approaches |
| Bicycle Clearance Times (Section 4.4.15) | Due to the wide median on the major street, bicyclists may face challenges completing a crossing of the major street before the clearance time is elapsed. | Bicyclists, major street crossing |
| Turning Motorists Crossing Bicycle Path (Section 4.4.18) | Turning motorists cross the bike lane in this design with developing the major street right-turn lanes. On the major street, this crossover occurs at the supplemental U-turn intersection. | Bicyclists, all approaches |
| Riding between Travel Lanes, Lane Additions, or Lane Merges (Section 4.4.19) | The right-turn lane development causes a "pocket bike lane" for through cyclists on all intersection approaches, wherein they are forced to ride between motor vehicle traffic. | Bicyclists, all approaches |

### *6.4.2.1 Benefits*

This design addresses these key elements regarding safety and comfort:

- **Motor Vehicle Right-Turns design flag:** The design includes the protected intersection concept with corner refuge islands that tighten turn radii and extent physical protection for crossing pedestrians. The turn radius would need to be refined based on the intended design vehicle path but would control right-turning vehicle speeds. Crossing pedestrians are pulled back to enhance their visibility.

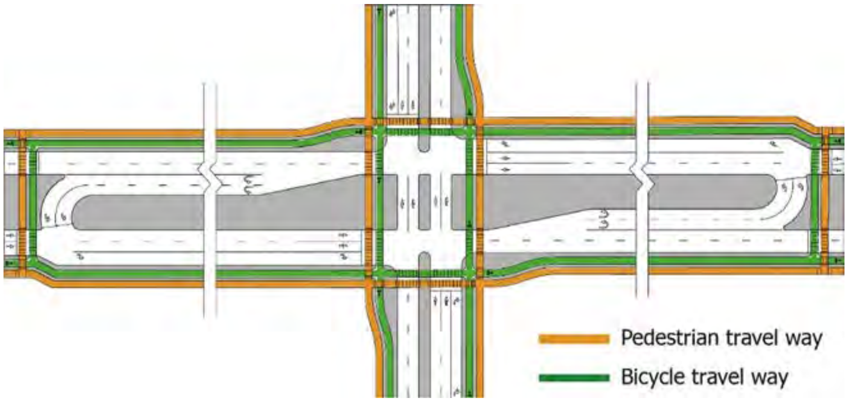


***Exhibit 6-16. Protected intersection concept.***

- **Indirect Paths design flag:** For bicyclists, the design includes separated-street bike lanes with the ability to complete left-turns in two stages using the bike lane. This has the benefit of providing a more intuitive left-turn movement for all bicyclists and mitigates the *Indirect Paths* design flag. For pedestrians, the midblock (at the U-turn) crossings provide more potential for route directness by allowing pedestrians to cross the major street upstream or downstream of the intersection.
- **Crossing Yield- or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, providing safe crossing opportunities and eliminating the possible associated design flag.
- **Undefined Crossing at Intersections design flag:** Crossings for pedestrians and bicyclists are defined with this design; particularly for bicyclists, the separated bike lane gives positive guidance and wayfinding benefits throughout the intersection.
- **Physical Separation for Bicyclists:** This concept moves all riding away from mixed traffic with physical (horizontal and vertical) separation. Bicyclists would cross motor vehicle paths using marked crossings; consult Chapter 5 for guidance on these crossings. This design eliminates the following design flags:
  - Riding in Mixed Traffic;
  - Lane Change Across Motor Vehicle Travel Lane(s);
  - Turning Motorists Crossing Bicycle Path; and
  - Riding between Travel Lanes, Lane Additions, or Lane Merges.

  Where right-turning vehicles would cross the through bike movements, the crossings are recessed to promote bicyclist visibility.

### *6.4.2.2 Challenges*

The protected intersection concept leaves some design flags remaining, as presented in Exhibit 6-17.

## 6.4.3 MUT Shared-Use Path Concept

This MUT concept (shown in Exhibit 6-18) is distinguished by its implementation of a shared-use path. The concept would be implemented in locations with either relatively high motor vehicle volumes or high speeds such that physical separation is advisable for bicycle facilities. The shared-use path would be appropriate where a relatively low mix of walking and biking would be expected; with high expected volumes, separate facilities would be recommended. The shared-use path treatment provides a low-stress riding environment for

**Exhibit 6-17. Summary of design flags remaining with on-street bikeway concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | The right-turn volume will likely be relatively high for most approaches because at an MUT it is a consolidation of right-turn and left-turn movements. However, if the curb radii can keep speeds from exceeding 25, the flag may be mitigated. | Pedestrian, all crossings |
| Multilane Crossings (Section 4.4.7) | Although median refuges are included for crossing the major street, a crossing pedestrian would still cross three concurrent same-direction travel lanes crossing all streets, meriting a yellow flag. | Pedestrians, all main intersection crossings |

people biking, including less confident bicyclists. This design may be appropriate where an MUT intersection was tying into an existing roadway without bicycle facilities through bicycle ramps before and after the intersection. The path, which expands in width when it transitions to include bicycles, would be appropriate in the presence of heavy right-turns or trucks by allowing bicyclists to avoid these conflicts. Consult Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions; consult Chapter 5 for information regarding the design requirements (e.g., width) of multiuse paths.

A key concern with this concept is maintenance, especially in the snow. The presence and accumulation of snow can change the user experience considerably and must be accounted for when implementing a design with channelization and other similar roadway features. As with all intersections that feature channelizing islands with multimodal access, coordination is

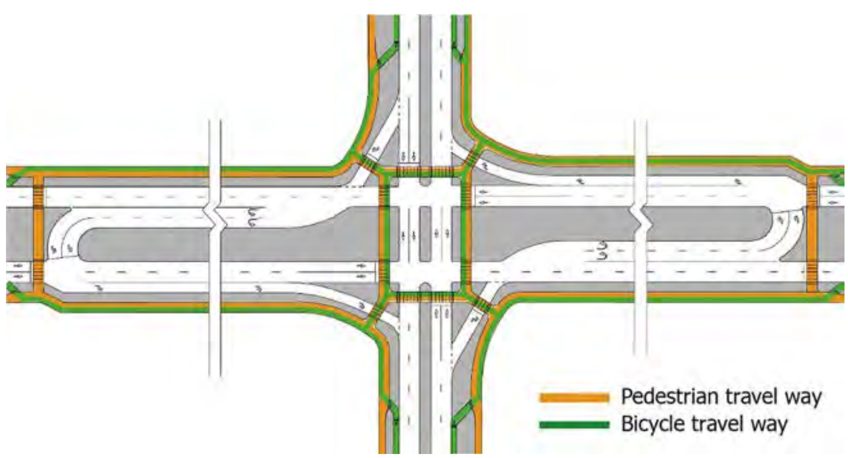


***Exhibit 6-18. MUT shared-use path concept.***

required between partner agencies in determining who maintains access through the islands during snow events.

### *6.4.3.1 Benefits*

This design addresses these key elements regarding safety and comfort:

- **Motor Vehicle Right-Turns design flag:** The design includes channelized right-turns with signal control. The right-turn vehicle conflict with pedestrians would be separated and controlled, eliminating this flag.
- **Multilane Crossing design flag:** The provision of channelized right-turn lanes on all approaches ensures that no single pedestrian crossing is over two lanes wide, eliminating the need for pedestrians to cross more than two lanes at one time.
- **Indirect Paths design flag:** For bicyclists, the design includes separated-street bike lanes with the ability to complete left-turns in two stages using the bike lane. This has the benefit of providing a more intuitive left-turn movement for all bicyclists and mitigates the *Indirect Paths* design flag. For pedestrians, the midblock (at the U-turn) crossings provide more potential for route directness by allowing pedestrians to cross the major street upstream or downstream of the intersection.
- **Crossing Yield- or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, providing safe crossing opportunities and eliminating the possible associated design flag.
- **Undefined Crossing at Intersections design flag:** Crossings for pedestrians and bicyclists are defined with this design; particularly for bicyclists, the separated bike lane gives positive guidance and wayfinding benefits throughout the intersection.
- **Physical Separation for Bicyclists at conflict points:** This concept moves riding away from mixed traffic at the intersection with ramps to transition bicyclists off-street. Bicyclists would cross motor vehicle paths using marked crossings; consult Chapter 5 for guidance on these crossings. This design eliminates the following design flags:
  - Riding in Mixed Traffic;
  - Lane Change Across Motor Vehicle Travel Lane(s);
  - Turning Motorists Crossing Bicycle Path design flags; and
  - Riding between Travel Lanes, Lane Additions, or Lane Merges.

  Where right-turning vehicles would cross the through bike movements, the crossings are recessed to promote bicyclist visibility.
- **Bicyclist Traveling in Channelized Lane Adjacent to Motor Vehicles:** Although the design provides channelized right-turn lanes, the shared-use path and the ramps leading to the path allow for right-turning cyclists to bypass this conflict point.
- **Channelized turn lanes for motorist right-turns with loons to keep intersection as close to perpendicular as possible.** The channelized turns also separate the conflict between right-turning vehicles and crossing pedestrians and provide visibility at these conflict points. These channelized crossings would be signalized.

### *6.4.3.2 Challenges*

Emphasizing again that the design is not intended to be "ready-made," this concept leaves several design flags as described in Exhibit 6-19.

A separate challenge with this concept is the considerable footprint of the intersection and the right-of-way required. This can drive up costs and has indirect effects on the pedestrian and bicyclist experience (e.g., longer distances to cross).

**Exhibit 6-19. Summary of design flags remaining with MUT shared-use path concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | If not signalized or stop-controlled, the pedestrian and bicycle crossing of the channelized right-turn lane would result in a flag. | Pedestrians and Bicyclists, channelized turn crossings |
| Long Red Times (Section 4.4.8) | If the channelized turn lanes are signalized, pedestrians likely could not cross the turn lane, the major street, and the second turn lane in one phase. Depending on the cycle length, this may trigger a flag. | Pedestrians, all crossings at the main intersection |
| Sight Distance for Gap Acceptance Movements (Section 4.4.12) | Adequate sight distance should be provided for any channelized turn movement not signalized. | Pedestrians and Bicyclists, channelized turn crossings |

## 6.5 Detailed Design Techniques

The design flag procedure and corresponding flags are outlined in Chapter 4, and generalized design techniques common to many intersection forms are discussed in Chapter 5. Discussion in this section is limited to unique characteristics or design aspects to assist in addressing potential flags in an MUT intersection. This includes:

- Right-turn movements;
- ADA and accessibility.

### 6.5.1 Right-Turn Movements

Due to the redirection of left-turn movements at an MUT intersection, right-turn vehicular volumes tend to be higher at MUT intersections than at traditional intersections. These higher vehicular volumes can increase safety risks for both pedestrians and bicyclists. Single right-turn lanes are most likely to provide the best safety performance for pedestrians and bicyclists if designed under the guidance in Section 6.5.2 and Chapter 5.

Channelized right-turns, particularly if signalized, may be desirable for pedestrians and cyclists in certain contexts when turning volumes are high. The separation of vehicle movements can remove the concurrent pedestrian-vehicle conflict with crossings between the through and right-turn movement. Any channelized turn lanes should be accessible per the guidance in *NCHRP Report 834* (*3*) and discussed in Chapter 5.

Some MUT intersections have used multiple lanes for right-turn movements, particularly on the minor street. Multiple right-turn lanes allow the rightmost lane to be dedicated to right-turning motorists and the leftmost lane to be dedicated to motorists making U-turn movements at the downstream crossover in the median. However, using multiple exclusive right-turn lanes creates challenges:

- They increase pedestrian crossing distance;
- They may introduce sight distance challenges between pedestrians and motorists;

- They may provide more motorist capacity than is needed to serve expected demand;
- If bicyclists are served by on-street bike lanes, the two right-turn lanes create substantial conflicts at the point where the right-turn lanes are developed; and
- The right-turn lanes may require additional right-of-way.

Some MUT intersections have used shared through-right lanes. These can introduce substantial conflicts for on-street bicyclists if bicycle lanes are intended to be extended into and through the intersection. If shared through-right-turn lanes are used, separated bicycle facilities should be provided, and signal phasing should allow at least a leading interval for through bicyclists. This allows bicyclists to cross before the right-turning motorists can proceed. RTOR restrictions should be considered in these cases.

Uncontrolled channelized right-turn lanes are seldom used at MUT intersections for various reasons:

- They induce undesirable weaving conflicts between the MUT main intersection and downstream U-turn crossover that otherwise would not occur if vehicles had to stop or yield;
- They introduce longer crossings for pedestrians;
- They create accessibility challenges for pedestrians crossing the uncontrolled channelized turn lane; and
- They require additional street width and potentially additional right-of-way.

### 6.5.2 ADA and Accessibility

Pedestrians with vision, mobility, or cognitive impairments should find crossing an MUT intersection similar to crossing a conventional intersection. The cues that pedestrians with vision impairments rely on to cross intersections, such as the sound of traffic parallel to their crossing, are similar in both intersection forms. The direct crossing path of an MUT intersection is relatively easy and convenient to use. All pedestrians will experience two-phase signal timing and a reduced number of conflicting traffic streams than at a conventional intersection. The basic principles for wayfinding and crossing tasks are presented in Chapter 2, and design techniques are presented in Chapter 5.

## 6.6 References

1. Reid, J., L. Sutherland, B. Ray, A. Daleiden, P. Jenior, and J. Knudsen. August 2014. *Median U-turn Informational Guide.* Report FHWA-SA-14-069. FHWA, Washington, DC.
2. FHWA. *Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes (IA-20)*. https://mutcd.fhwa.dot.gov/resources/interim_approval/ia20/index.htm. FHWA, Washington, DC. Accessed March 28, 2019.
3. Schroeder, B. J., L. Rodegerdts, P. Jenior, E. Myers, C. Cunningham, K. Salamati, S. Searcy, S. O'Brien, J. Barlow, and B. L. Bentzen. 2016. *NCHRP Report 834: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook*. Transportation Research Board of the National Academies, Washington, DC.

CHAPTER 7

# Restricted Crossing U-Turn (RCUT) Intersections

## 7.1 Introduction

The Restricted Crossing U-Turn (RCUT) intersection, also called a reduced conflict intersection (RCI), a superstreet intersection, a J-turn intersection, or a synchronized street intersection, differs from a conventional intersection by eliminating the left-turn and through movements from cross street approaches. To accommodate these movements, the RCUT intersection requires minor street drivers to turn right onto the major street and then make a U-turn maneuver at a one-way median opening downstream of the main intersection. At the major street approaches, the left-turn movements are typically accommodated similarly to left-turn movements at conventional intersections. Sometimes, left-turn movements from the major street can be removed and redirected to the downstream U-turn crossover.

The RCUT intersection is similar to the MUT intersection. However, these alternative intersection types each have unique design features and are implemented at different locations with unique characteristics:

- Both intersections reroute minor street left-turn movements. However, the RCUT intersection also reroutes minor-street through movements; the MUT does not. The MUT typically reroutes major street left-turn movements; the RCUT typically does not.
- The RCUT intersection typically has better signal progression than the MUT intersection but does not serve minor street approaches with high through demand as well as the MUT intersection.
- The RCUT intersection may complement a corridor with MUT intersections by serving intersections that are mostly turning movements to and from the minor street, with the MUT intersections serving those intersections that also have significant through movements on the minor street.

RCUT intersections can have either three or four legs. With a four-legged RCUT intersection, there are two U-turn crossovers, and minor street left-turn and through movements are not allowed to be made directly at the intersection.

There are three main types of RCUT intersections:

- **Signalized.** A signalized RCUT intersection can provide favorable progression along an urban or suburban corridor. RCUT intersection signals typically require only two phases, which can minimize the lost time at the intersection. Because each direction of the major street is controlled by a two-phase signal that can be operated independently of the other direction, efficient progression can be provided in both directions with any speed or signal spacing.
- **Stop-controlled.** A stop-controlled RCUT intersection is sometimes used as a safety treatment at an isolated intersection on a four-lane divided arterial in a rural area. There are known

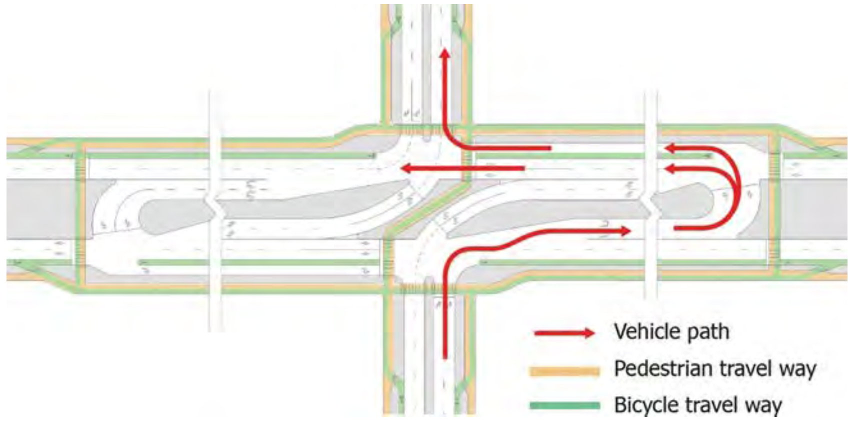


***Exhibit 7-1. Example of an RCUT intersection with signals.***

vehicular safety benefits with this RCUT intersection. Sometimes, a stop-controlled RCUT intersection is later converted to a signalized RCUT intersection if traffic volumes increase.

- **Merge- or yield-controlled.** Where funding for interchanges and overpasses may not be readily available, a merge-controlled RCUT intersection can allow a rural high-speed divided four-lane corridor to function similarly to a freeway corridor. This RCUT intersection relies on long distances to U-turn crossovers to enable motorists to make the movement.

Hybrids of the three main types of RCUT intersections are possible, and the RCUT intersection is sometimes converted from one type to another. Exhibit 7-1 presents vehicular movements at an RCUT, overlaid on pedestrian and bicycle routes.

Much of the material in this chapter is derived from earlier work for FHWA (*1*) and has been updated to reflect the knowledge gained in this research.

## 7.2 Multimodal Operations

This section presents the multimodal operational characteristics of an RCUT intersection, starting with motorized vehicles and then explaining how pedestrians and bicyclists are served.

### 7.2.1 Motorized Vehicles

Exhibit 7-2 shows the concurrent eastbound movements and concurrent westbound movements at a typical signalized RCUT intersection. Mainstreet through movements at an RCUT intersection can operate independently of each other, allowing for unique cycle lengths and offsets in each direction. Exhibit 7-3 shows the typical signal locations for this configuration. Signals at the RCUT main intersections (Signals 1 and 4 in the exhibit) traditionally operate with two phases: one for the major street through movement and one for the major street left-turn movement and minor street movements. As will be seen later, an additional phase is sometimes added to facilitate minor street pedestrian and bicycle crossing movements at the main intersection. Similarly, the signals at the RCUT crossover intersections (Signals 2 and 3 in the exhibit) traditionally operate in two phases. A phase is sometimes added at the crossover signals to serve traffic turning right from a driveway or side street.

Signal timing at an RCUT intersection or corridor is fundamentally different from that of any other intersection or corridor, due to the ability to have different cycle lengths in each direction of the major street. Signal timing at an RCUT intersection or corridor can use a common

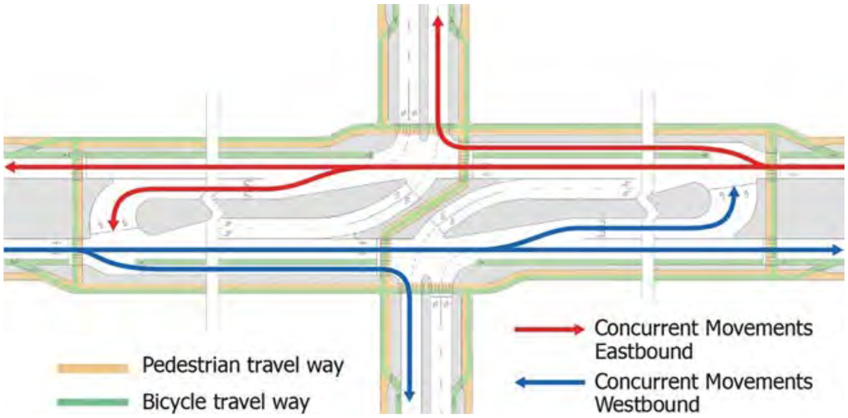


***Exhibit 7-2. Concurrent eastbound movements and concurrent westbound movements at signalized RCUT intersection.***

cycle length in both directions of the major street or a different cycle length for each direction of the major street. If a common cycle length in both directions is used, there is an opportunity to provide for some progression for the movements using the crossovers. This can also facilitate design configurations (see Section 7.4) that facilitate one-stage crossings for pedestrians and bicyclists. With different cycle lengths in each direction, most pedestrians and bicyclists will likely cross the major street in two stages (with a delay in the median), and minor street motorist movements will likely not be progressed. These challenges can be mitigated by using cycle lengths with a common denominator and prioritizing bicycle and pedestrian progression.

### 7.2.2 Pedestrians

Depending on their configuration, RCUT intersections may require pedestrian crossings that differ substantially from those at conventional intersections. The RCUT intersection's wide geometric footprint can make it challenging to accommodate pedestrians, but the short cycle lengths associated with RCUT intersection operations can help make the crossing times of pedestrian movements more comparable to those at conventional intersections.

Pedestrian crossings at RCUT intersections must be accessible for all users, including those with visual impairments. Therefore, the provisions for pedestrians must consider the need to

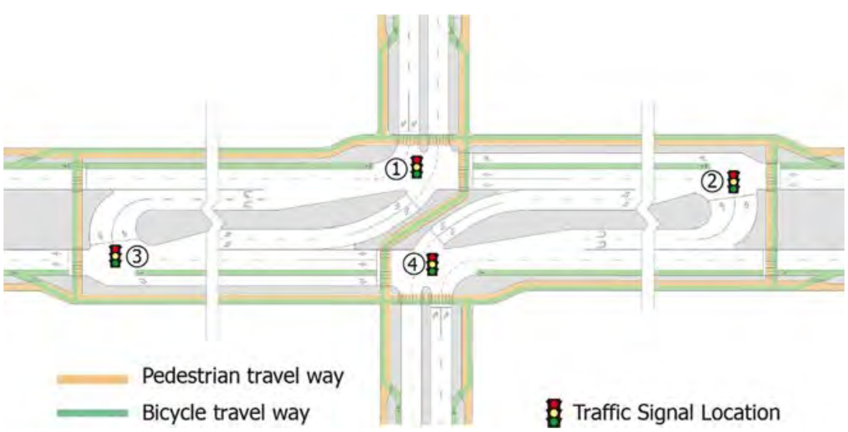


***Exhibit 7-3. Signal placement at signalized RCUT intersection.***

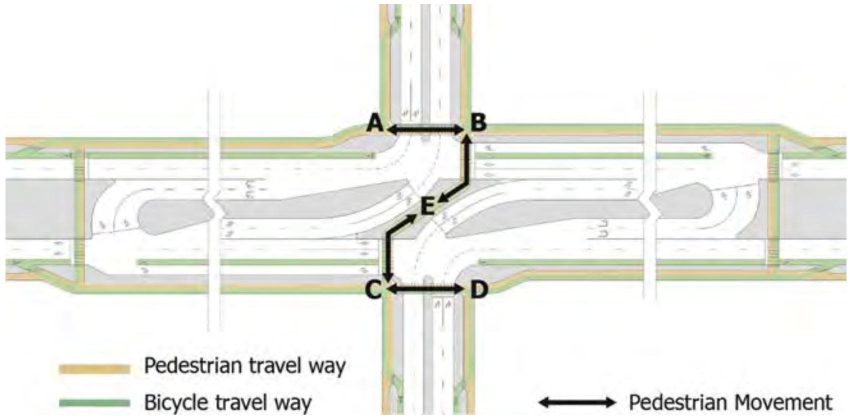


***Exhibit 7-4. Pedestrian movements in an RCUT intersection.***

communicate crossing patterns in nonvisual ways, using wayfinding techniques discussed in the PROWAG (*2*). This may include audible devices, channelization, and separation and detectable delineation of the pedestrian route and crossing. These concepts are discussed in more detail in Chapter 2.

### *7.2.2.1 Main Intersection*

One of the common means of serving pedestrians at an RCUT intersection is a "Z" crossing treatment, shown in Exhibit 7-4. A "Z" crossing allows all six desired pedestrian movements at an intersection. The two minor street crossings (A to B, C to D) are made similarly to those at a conventional intersection. Three of the movements (A to C, B to D, and A to D) require pedestrians to take a longer route via the "Z" crossing. The sixth movement (B to C) allows pedestrians to make a more direct diagonal movement across the intersection. Exhibit 7-5 shows a "Z" crossing at a signalized RCUT intersection near San Antonio, TX.

The major road crossing distance could be shortened by adding a raised barrier or channelization between major street through lanes and major street right-turn lanes.

***Exhibit 7-5. Signalized RCUT with "Z" crossing near San Antonio, TX (2).***

Despite the common application of the "Z" crossing, RCUT intersections can be served with pedestrian crossings that are more direct and reduce both geometric and operational pedestrian delay. In Section 7.4, pedestrian crossing options that differ from the common "Z" crossing are shown.

### *7.2.2.2 U-turn Crossover*

U-turn crossover intersections create additional opportunities for midblock pedestrian crossings. The details and options for the U-turn crossover are the same for RCUT intersections as for MUT intersections. Detail on U-turn crossovers is in Chapter 6.

## 7.2.3 Bicyclists

The three primary ways to serve minor street through and left-turn bicyclists in an RCUT intersection are by using the following:

- A "Z" crossing with pedestrians (if one is provided);
- A more direct route (if provided); and
- A route similar to motor vehicle traffic using the U-turn crossover.

These options are illustrated in Exhibit 7-6. Designs can vary substantially, depending on the context and travel patterns for each mode being served.

Although the "Z" crossing may be suitable if the pathway through the intersection is designed for shared use and is wide enough to be comfortable for bicyclists, it introduces substantial out-of-direction travel for bicyclists.

The second option, the direct bicycle crossing, features some alternatives introduced in Section 6.4. These allow separated bicycle facilities and the protected intersection concept (see Section 5.2.6) to be applied to the main RCUT intersection. An unsignalized version may also be used in some contexts, such as in Exhibit 7-7, which shows a treatment used in North Carolina to aid minor street left-turning and through bicyclists in negotiating a rural RCUT intersection with stop-control and no pedestrian facilities due to the lack of nearby pedestrian-generating land uses. The treatment consists of curb cuts and narrow paths through the median. Signs should direct bicyclists to the crossing, because it otherwise may not be apparent that it is intended for them.

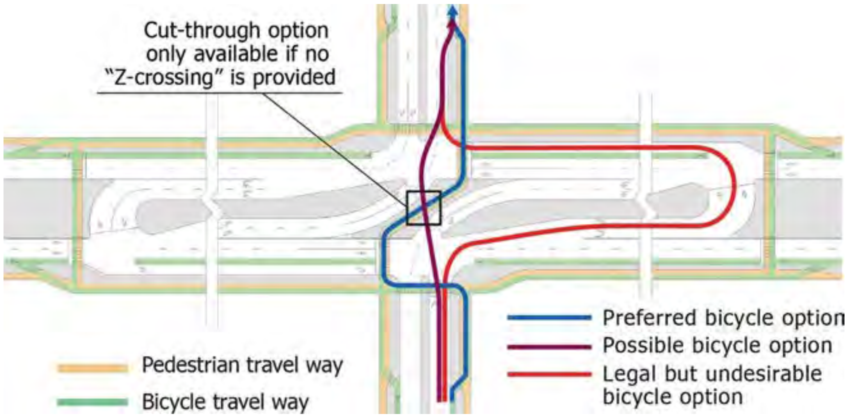


***Exhibit 7-6. Minor street through options for bicycles.***

***Exhibit 7-7. Curb cut design used in North Carolina to assist bicyclists crossing at a rural RCUT with a stop sign.***

The third option, using the U-turn crossover, introduces a substantial safety challenge for bicyclists, because the path to the U-turn crosses that of through motorists. The U-turn itself may be difficult for bicyclists, because motorists making U-turns may have difficulty staying in lanes, and large vehicles may produce greater off-tracking into lanes occupied by bicyclists.

## 7.3 Safety and Comfort

This section discusses safety and comfort principles for pedestrians and bicyclists at RCUT intersections. For motor vehicles, RCUT intersections have been shown to result in significant safety benefits compared to standard four-legged intersections. The safety benefits for vehicles are attributable to eliminating left-turns at the main intersection and simplifying driver decision-making (that is, by generally dealing with one direction of travel at a time). The RCUT offers potential safety benefits for pedestrians through reduced conflict points, but no safety data have shown quantitative safety benefits for pedestrians or bicyclists. The biggest safety risk for pedestrians and bicyclists is for those users who, due to excessive delay or indirect paths, try to find paths that differ from the intended design. Desired pedestrian and bicycle operations need to be developed at the beginning of Stage 2 of the ICE Process to develop geometric elements. Once geometric elements are developed, the focus can shift to the specific safety elements within the geometry, as described below.

### 7.3.1 Conflict Points

The conflict points for pedestrians at an RCUT can vary depending on the geometric configuration. At an RCUT intersection, left-turns are removed from the minor street and occur away from the intersection, thus removing potential pedestrian exposure to left-turning vehicles. However, the volume of vehicles turning right to the minor street is higher than at a conventional intersection.

Exhibit 7-8 shows the pedestrian conflict points with an RCUT intersection design using a “Z” crossing. An RCUT intersection reduces the number of vehicle-pedestrian conflict points relative to conventional intersections by using a “Z” crossing. However, movements requiring a longer unconventional route (against the “Z”) or having more conflict points may tempt

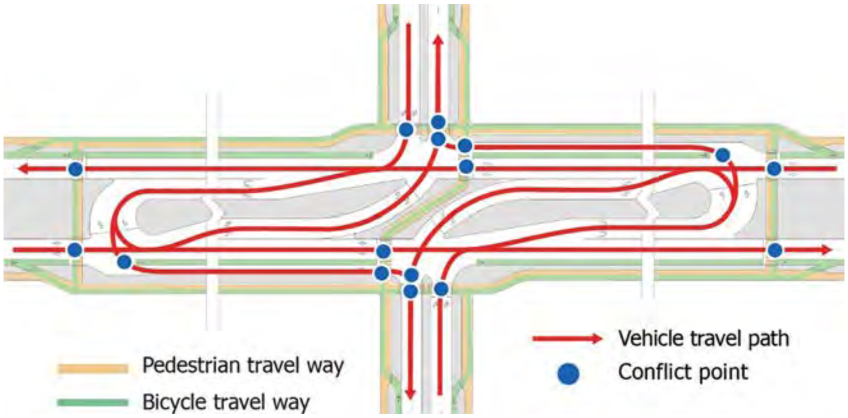


***Exhibit 7-8. Pedestrian-vehicle conflict points at an RCUT intersection.***

pedestrians to cross the major street directly or to cross from the center diagonal island to one of the alternate quadrants.

Bicyclists on the major street travel though an RCUT intersection the same way they travel through a conventional intersection. Minor street left-turning or through bicyclists do not have a direct route at a typical RCUT intersection unless such facilities are provided, as discussed in Section 7.4. RCUT intersections can reduce or eliminate out-of-direction travel by bicyclists. Both the challenges and benefits that RCUT intersections offer bicyclists must be evaluated carefully to guide project planning and design decisions.

### 7.3.2 Pedestrians–Key Safety Challenges

Similarly to the MUT intersection, the RCUT intersection can enhance pedestrian safety by simplifying vehicular movements and eliminating left-turns. The remaining pedestrian safety concerns specific to the RCUT intersection are as follows:

- Compared to a conventional intersection, the RCUT intersection is likely to result in an increased vehicular right-turning volume, because left-turns have to make a right-turn to get to the U-turn crossover (minor street left-turn and through movements) and make a right-turn after the U-turn maneuver (minor street through movements). These right-turns may be controlled to ensure safe pedestrian crossings, and the high volume of right-turns could exacerbate the *Motor Vehicle Right-Turns* design flag (Section 4.4.1). However, RCUTs inherently avoid the *Motor Vehicle Left-Turns* design flag (Section 4.4.10) for the minor street.
- The Z-crossing configuration at some RCUT intersections results in some out-of-direction travel for pedestrians crossing "against the Z." For these movements, additional exposure and delay are introduced for the additional crossing points. The additional length should be evaluated using the *Indirect Paths* design flag (Section 4.4.5).
- Depending on the signal timing, pedestrian delay for a full crossing can be high, because the middle segment of the Z-crossing usually requires a two-stage crossing with multiple delay points. This condition triggers the *Long Red Times* design flag (Section 4.4.8).
- A supplemental pedestrian crossing can be provided at each U-turn location, given it is a signal-control location for the U-turns. The outbound vehicular travel lanes rarely are signalized but would necessitate a control device or treatment if a crossing is provided so as to avoid forcing pedestrians to cross multiple uncontrolled high-speed vehicular travel lanes. If no signal was provided for the outbound vehicular movement, the *Crossing Yield-controlled or Uncontrolled Vehicle Paths* flag (Section 4.4.4) would be triggered.

In consideration of these challenges and pedestrian conflict points, Exhibit 7-9 presents the design flags applicable to pedestrians, along with the location of their discussion and applicable treatments (design flags and treatments whose discussion applies across alternative intersection types are in Chapter 5).

Some design flags unlikely to be present at an RCUT intersection include the following:

- **Nonintuitive motor vehicle movements (Section 4.4.3)**: No motor vehicle movements are crossed over or otherwise approaching from an unintuitive direction for people crossing at an RCUT.
- **Executing unusual movements (Section 4.4.6)**: The wayfinding, traversing, and crossing at RCUTs are relatively straightforward, without unexpected directionality or unintuitive turns.

**Exhibit 7-9. Design flags applicable to pedestrians at RCUTs.**

| Flag | **Description** | **Mode/Travel Path** |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | This flag would carry forward to the final design stage, based on right-turns. Because RCUTs have relatively high volumes of right-turns, the geometry of the turning movement will be a critical factor in controlling speeds. | Pedestrian, all crossings |
| Crossing Yield- or Uncontrolled Vehicle Paths (Section 4.4.4) | With the right-turns identified in the design flag above, pedestrians at the main intersection crossings would cross a high volume of right-turning vehicles with a green signal indication. | Pedestrian, all main intersection crossings |
| Indirect Paths (Section 4.4.5) | Major street crossings that conflict with high-volume minor street right-turns are sometimes closed at an RCUT. In such cases, pedestrians are rerouted via a Z-crossing or similar arrangement. | Pedestrians with an origin-destination pattern contrary to the walking path conveyed by the intersection in a Z-crossing |
| Multilane Crossings (Section 4.4.7) | The major street crossings at an RCUT may be relatively long. A median refuge is common, but the single-direction travel lane configuration may remain a long crossing. | Pedestrians, all crossings |
| Undefined Crossing at Intersections (Section 4.4.9) | This flag is not unique to RCUTs, but given the relatively high volume of right-turning vehicles conflicting with the pedestrian crossing, lack of clearly defined user space would be stressful for pedestrians. | Pedestrians, all crossings |
| Long Red Times (Section 4.4.8) | If trying to cross "against the Z," pedestrians or bicyclists may have a high amount of travel time delay that would incentivize risk-taking behavior. | Pedestrians with an origin-destination pattern contrary to the walking path conveyed by the intersection in a Z-crossing |

### 7.3.3 Bicycles–Key Safety Challenges

At RCUTs, bicycles may travel on shared-use path systems along with pedestrians, travel on a dedicated separated bicycle facility, or operate in a shared environment with vehicles. For bicycles traveling in on-street facilities, these additional safety challenges apply:

- Bicycle left-turn and through movements from the minor approach face significant out-of-direction travel (to and from the U-turn), as well as safety risks in needing to perform a crossover maneuver across potentially busy and fast-moving vehicular travel lanes. This is described by the **Lane Change Across Motor Vehicle Travel Lanes** design flag (Section 4.4.16).
- No clear direct path option exists for bicycle left-turns and minor street through movement without modifying the design (see Section 7.3). This triggers the **Indirect Paths** design flag (Section 4.4.5).
- Bicycle right-turns may conflict with pedestrian crossings and potentially high right-turning vehicle volumes.
- If channelized lanes are provided on any approach, the design issues in **Channelized Lanes** (Section 4.4.17) apply. Safety concerns related to the design of the channelized lanes are discussed further in Chapter 5.

Exhibit 7-10 presents the design flags applicable to bicycles at RCUTs. Design flags and treatments whose discussion applies across alternative intersection types are provided in Chapter 5.

### 7.3.4 Other Safety Concerns

In addition to the preceding discussion of key pedestrian and bicycle safety concerns, RCUT intersections present other general benefits and concerns.

Design flags that are more universal and not unique to RCUTs include the following:

- Intersection Driveways and Side Streets (Section 4.4.11);
- Sight Distance for Gap Acceptance Movements (Section 4.4.12);
- Grade Change (Section 4.4.13); and
- Off-tracking Trucks in Multilane Curves (4.4.20).

Some design flags typically eliminated by the RCUT design include nonintuitive motor vehicle movements (Section 4.4.4). The RCUT introduces no crossover movements or atypical travel directions that would be unintuitive to a road user.

Sometimes, these design flags may need to be resolved in subsequent stages of design.

## 7.4 RCUT Intersection-Level Concepts

Four design concepts have been developed to present options for improving pedestrian and bicycle safety and operational performance at RCUT intersections. These concepts are not suggested as designs to be replicated as is; rather, they illustrate the RCUT options possible in various contexts. These concepts mix design approaches. The designer must consider traffic volume and speed when matching designs and treatments to the appropriate context.

Following each concept is a discussion of the flags remaining with the design—the flags not obviated by the design that would still need to be addressed. The designs include the following:

- RCUT Bike Lane and Path Concept
- RCUT Shared-Use Path Concept
- RCUT Separated Bike Lane Concept
- Rural RCUT Shoulder Concept

**Exhibit 7-10. Design flags applicable to bicyclists at RCUTs.**

| Design Flag | Description | Mode/Travel Path |
|---|---|---|
| Indirect Paths (Section 4.4.5) | For bicyclists seeking to make a left-turn at the intersection or a through movement along side streets, the U-turn as designed represents considerable out-of-direction travel (several hundred feet), which may exceed thresholds for yellow or red flags (see Section 4.4.6). | Bicyclists making left-turns via U-turn maneuver at RCUTs |
| Multilane Crossings (Section 4.4.7) | For bicyclists crossing with pedestrians or using a path, the major street crossings at an RCUT may be relatively long. A median refuge is common, but the single-direction travel lane configuration may remain a long crossing. | Bicyclists, all path crossings |
| Undefined Crossing at Intersections (Section 4.4.9) | The movements are not clearly demarcated for the common expectation for left-turning bicyclists to proceed straight through the signal and cross over traffic to make a U-turn. | Bicyclists making left-turns via U-turn maneuver at RCUTs |
| Lane Change Across Motor Vehicle Travel Lane(s) (Section 4.4.16) | Bicyclists making the U-turn maneuver must cross over one or several lanes of motor vehicle traffic on a tangent roadway section to position for the U-turn. | Bicyclists making left-turns via U-turn maneuver at RCUTs |
| Turning Motorists Crossing Bicycle Path (Section 4.4.18) | The expected relative high right-turn volumes at an RCUT exacerbate potential conflicts between right-turning vehicles and through bicyclists. | Through bicyclists (particularly on the major street) |

## 7.4.1 RCUT Bike Lane and Path Concept

This RCUT concept (shown in Exhibit 7-11) is distinguished by its provision of on-street bike lanes along with a shared-use path. The concept would be appropriate for a low-speed and/or low-volume context and provides an example for carrying existing bike lanes through an RCUT; consult Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

### *7.4.1.1 Benefits*

The RCUT concept is shown in Exhibit 7-11 and includes the following key elements:

- **Motor Vehicle Right-Turns design flag:** Where pedestrian crossings exist, corner refuge islands tighten right-turn radii and extend physical protection for crossing pedestrians. Though this turn radius may need to be modified based on the intended design vehicle path, the design would control speeds of right-turning vehicles. Additionally, although the removal of a crossing triggers other flags, this removal eliminates pedestrian conflicts with the anticipated high volume of vehicle right-turns.

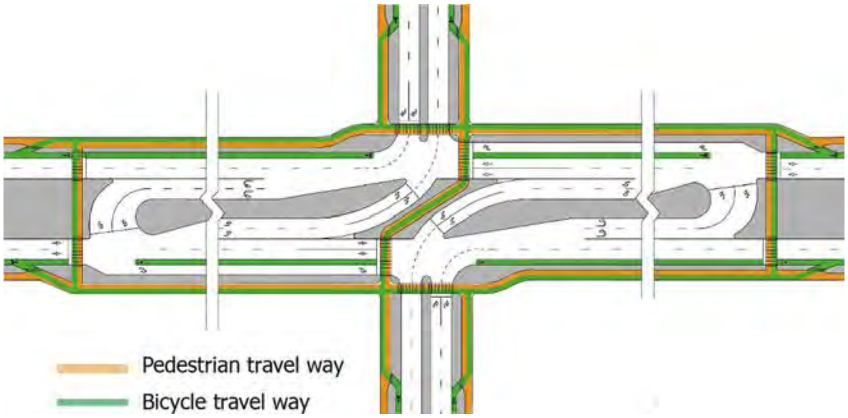


***Exhibit 7-11. RCUT bike lane and path concept.***

- **Indirect Paths design flag:** For bicyclists, the design includes on-street bike lanes with ramps to shared-use paths. This feature has the benefit of providing an off-street left-turn or minor street through movement for all bicyclists (through the "Z") and mitigates the *Indirect Paths* design flag. For pedestrians, the ability to cross all four legs of the intersection (as well as the supplemental crossings at the U-turn) promotes accessibility and eliminates circuitous paths.
- **Crossing Yield-Controlled or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, providing safe crossing opportunities and eliminating the possible associated design flag.
- **Physical Separation for Bicyclists:** For bicyclists who use the available ramps, this concept moves their riding away from mixed traffic with physical separation. Bicyclists would cross motor vehicle paths using marked crossings; consult Chapter 5 for guidance on these crossings. This design eliminates the following design flags:
  - Riding in Mixed Traffic;
  - Bicyclist Crossing Motor Vehicle Travel Lane(s);
  - Turning Motorists Crossing Bicycle Path; and
  - Riding between Travel Lanes, Lane Additions, or Lane Merges.

  Where right-turning vehicles would cross the through bike movements, the crossings are recessed to promote bicyclist visibility.

- Shared-use path system in the Z-crossing configuration for pedestrians and bicyclists with all signalized crossings;
- Two-stage pedestrian crossings across the major roadway with wide median refuge.

#### *7.4.1.2 Challenges*

The bike lane and path concept leaves some design flags remaining (see Exhibit 7-12). As two paths for the bicyclists are provided, this analysis will be conducted assuming the bicyclist uses the shared-use path. If the on-street bicycle lanes were considered for analysis, different flags would apply.

### 7.4.2 RCUT Shared-Use Path Concept

This RCUT shared-use path concept (shown in Exhibit 7-13) is distinguished by its implementation of a shared-use path through the intersection. The design concept also features crossings on all four intersection approach legs. The concept is intended to be implemented in

**Exhibit 7-12. Summary of design flags remaining with RCUT Bike lane and path concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | The right-turn volume will likely be relatively high for most approaches because it is a consolidation of multiple movements. However, if the curb radii can be designed to keep speeds from exceeding 25 mph, the flag may be mitigated. | Pedestrians and Bicyclists, all crossings at the main intersection |
| Uncomfortable/Tight Walking Environment (Section 4.4.2) | The careful design of the median walkway is necessary as the design progresses to ensure the walkway provides adequate space for all users. | Pedestrians and Bicyclists, center median crossing |
| Indirect Path (Section 4.4.5) | The Z-crossing design requires users wanting to cross directly across the major street or from the southeast to northwest quadrants to experience out-of-direction travel. The midblock crossing may mitigate this flag for some users depending on the location of volume generators. | Pedestrian and Bicyclist, direct major street crossing |
| Multilane Crossings (Section 4.4.7) | Although median refuges are included for crossing the major street, a crossing pedestrian would still cross three concurrent same-direction travel lanes crossing all streets, meriting a yellow flag. | Pedestrians, all main intersection crossings |
| Long Red Times (Section 4.4.8) | RCUTs allow for independent signal timing for each major street direction of travel. If the signals are not coordinated, users crossing the major street would likely need to cross in two phases, likely resulting in a flag. | Pedestrians and Bicyclists, major street crossings |

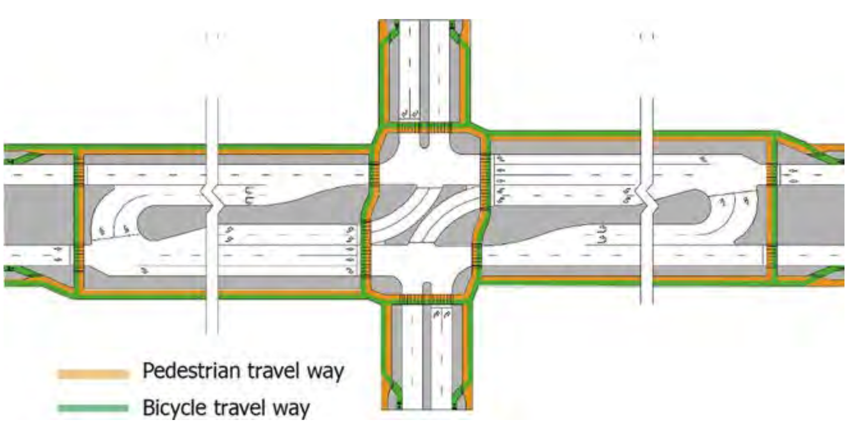


*Exhibit 7-13. RCUT shared-use path concept.*

locations with either relatively high motor vehicle volumes or high speeds. The separated path provides a low-stress riding environment for people biking, including less confident bicyclists. The path would be appropriate for a relatively low combined expected volume of bicyclists and pedestrians. With higher volumes of both, separate facilities for each mode would be appropriate. See Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

### *7.4.2.1 Benefits*

The RCUT shared-use path concept, shown in Exhibit 7-13, features the following design elements:

- **Motor Vehicle Right-Turns design flag:** The design includes corner refuge islands that tighten turn radii and extend physical protection for crossing pedestrians. The turn radius would need to be refined based on the intended design vehicle path but would control right-turning vehicle speeds. Crossing pedestrians are pulled back to enhance their visibility.
- **Indirect Paths design flag:** For bicyclists, the design includes separated paths that enable riders to complete left-turns in two stages and to complete a minor street through movement without a U-turn. This provides more intuitive movements for all bicyclists and mitigates the *Indirect Paths* design flag. For pedestrians, the midblock (at the U-turn) crossings and the four approach legs being striped provide more potential for route directness by allowing pedestrians to cross in some locations.
- **Crossing Yield-Controlled or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, providing safe crossing opportunities and eliminating the possible associated design flag.
- **Undefined Crossing at Intersections design flag:** Crossings for pedestrians and bicyclists are defined with this design; particularly for bicyclists, the path gives positive guidance and wayfinding benefits throughout the intersection.
- **Physical Separation for Bicyclists:** This concept moves all riding through the intersection away from mixed traffic with physical (horizontal and vertical) separation and ramps to and from the shared-use paths. Bicyclists would cross motor vehicle paths using marked crossings; consult Chapter 5 for guidance on these crossings. This design eliminates the following design flags:
  - Riding in Mixed Traffic;
  - Lane Change Across Motor Vehicle Travel Lane(s);
  - Turning Motorists Crossing Bicycle Path; and
  - Riding between Travel Lanes, Lane Additions, or Lane Merges.

  Where right-turning vehicles would cross the through bike movements, the crossings are recessed to promote bicyclist visibility.
- **An exclusive pedestrian phase** would allow the possibility of a complete pedestrian crossing in one stage. Additionally, the pedestrian crossings could be coordinated to minimize the delay between stages, with minimal to no disruption to vehicle signal progression. Both options would require the major street signals to be coordinated, reducing the vehicular operational benefit of the RCUT. Signal timing details would be finalized in later stages of design. Introducing a third phase at the RCUT would result in less efficient vehicle operations, compared to the standard operation with two critical phases.

### *7.4.2.2 Challenges*

The RCUT shared-use path concept leaves several design flags remaining, as presented in Exhibit 7-14.

**Exhibit 7-14. Summary of design flags remaining with RCUT shared-use path concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | The right-turn volume will likely be relatively high for most approaches because it is a consolidation of multiple movements. However, if the curb radii can be designed to keep speeds from exceeding 25 mph, the flag may be mitigated. | Pedestrians and Bicyclists, all crossings at the main intersection |
| Multilane Crossings (Section 4.4.7) | Users crossing the major street encounter a five-lane cross section on one approach. This distance meets the flag threshold and may affect signal timing, making a complete major street crossing in one phase difficult for some pedestrians. | Pedestrians and Bicyclists, major street crossing |
| Long Red Times (Section 4.4.8) | RCUTs allow for independent signal timing for each major street direction of travel. If the signals are not coordinated, users crossing the major street would likely need to cross in two phases, probably resulting in a flag. | Pedestrians and Bicyclists, major street crossings |

### 7.4.3 RCUT Separated Bike Lane Concept

The RCUT separated bike lane concept (shown in Exhibit 7-15) is distinguished by the separated bike lane and the removal of the major street left-turns. The design concept also features crossings on all four intersection approach legs. The concept is intended to be implemented in locations with either relatively high motor vehicle volumes or high speeds; the separated bike lane provides a low-stress riding environment for people biking and separates bicyclists from pedestrians. The removal of the major street left-turn movement would either make this

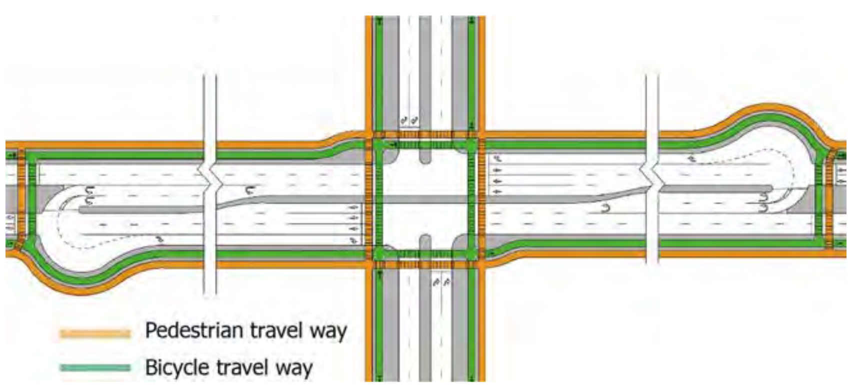


*Exhibit 7-15. RCUT separated bike lane concept.*

design feasible only with low volumes of left-turns or with left-turn operations as an explicit tradeoff of the design. The bike lanes would either be matched to the existing roadway or could be developed through a ramp from the approach lanes. See Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

#### *7.4.3.1 Benefits*

This design addresses these key elements regarding safety and comfort:

- **Motor Vehicle Right-Turns design flag:** The design includes the protected intersection concept with corner refuge islands that tighten turn radii and extend physical protection for crossing pedestrians. The turn radius would need to be refined based on the intended design vehicle path but would control right-turning vehicle speeds. Crossing pedestrians are pulled back to enhance their visibility. All right-turn movement volumes are increased with this design, given the elimination of all left-turn vehicle movements. Providing an exclusive pedestrian phase would provide time-separation of the minor street right-turns and the major street pedestrian and bicycle movement.
- **Indirect Paths design flag:** For bicyclists, the design includes separated bike lanes enabling bicyclists to complete left-turns in two stages. This provides a more intuitive left-turn movement for all bicyclists and mitigates the *Indirect Paths* design flag. For pedestrians, the mid-block (at the U-turn) crossings provide more potential for route directness by allowing pedestrians to cross the major street upstream or downstream of the intersection. All four main intersection legs include pedestrian crossings, allowing for direct walking routes.
- **Motor Vehicle Left-Turns design flag:** The concept eliminates all vehicle left-turns at the intersection, mitigating the associated design flag completely. This elimination of the movement also increases signal design flexibility, which may provide other benefits for pedestrians (although the details would be determined in a subsequent design stage).
- **Crossing Yield-Controlled or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, providing safe crossing opportunities and eliminating the possible associated design flag.
- **Undefined Crossing at Intersections design flag:** Crossings for pedestrians and bicyclists are defined with this design; particularly for bicyclists, the separated bike lane gives positive guidance and wayfinding benefits throughout the intersection.
- **Physical Separation for Bicyclists:** This concept moves all riding away from mixed traffic with physical (horizontal and vertical) separation. Bicyclists would cross motor vehicle paths using marked crossings; consult Chapter 5 for guidance on these crossings. This design eliminates the following design flags:
  - Riding in Mixed Traffic;
  - Lane Change Across Vehicle Travel Lane(s);
  - Turning Motorists Crossing Bicycle Path; and
  - Riding between Travel Lanes, Lane Additions, or Lane Merges.

  Where right-turning vehicles would cross the through bike movements, the crossings are recessed to promote bicyclist visibility.

#### *7.4.3.2 Challenges*

Operationally, if an exclusive pedestrian phase were used, this concept would remove the total independence of each major street approach from one another. The concept would not entirely remove the opportunity for two-way signal progression, but a corridor of RCUTs would need to be timed around this one to preserve the progression. The protected intersection concept leaves some design flags remaining, as presented in Exhibit 7-16.

**Exhibit 7-16. Summary of design flags remaining with RCUT separated bike lane concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | The right-turn volume will likely be relatively high for most approaches because it is a consolidation of multiple movements. However, if the curb radii can be designed to keep speeds from exceeding 25 mph, the flag may be mitigated. | Pedestrians, all crossings |
| Multilane Crossings (Section 4.4.7) | Although median refuges are included for crossing the major street, users would still cross four concurrent same-direction travel lanes crossing all streets, meriting a yellow flag. | Pedestrians and Bicyclists, major street crossings |
| Long Red Times (Section 4.4.8) | RCUTs allow for independent signal timing for each major street direction of travel. If the signals are not coordinated, users crossing the major street would likely need to cross in two phases, likely resulting in a flag. | Pedestrians and Bicyclists, major street crossings |

### 7.4.4 Rural RCUT Concept with Biking on Shoulder

The rural RCUT concept (shown in Exhibit 7-17) is presented with a distinctly different lane configuration and context from the other three concepts. The context for this design is along a rural corridor with a two-lane cross street. This design would be expected to be installed in a location with biking on the shoulder along the major street and limited or no existing pedestrian facilities. The concept offers a "cut-through" bike path across a single-lane U-turn and a bicycle refuge. Bicyclists on the minor street would proceed through the channelized turn lane and then

*Exhibit 7-17. Rural RCUT concept with biking on shoulder example.*

cross the median. Bicyclists on the major street could pull into the refuge area to cross the major street traffic at a perpendicular angle instead of crossing lanes at speed to enter the channelized left-turn lane. This concept would apply in a rural context, consistent with intended bicycle design users and guidance found in Sections 3.1 and 3.3.

#### *7.4.4.1 Benefits*

This design concept addresses these key elements regarding safety and comfort:

- The concept has the benefit of retaining a **relatively small footprint** compared to other RCUT concepts in this guide. The compact footprint would help with costs and could have residual benefits for pedestrians and bicyclists (e.g., shorter crossings and walking distances).
- **Indirect Paths**: The concept reduces required out-of-direction travel for bicyclists at an RCUT by providing the cut-through lanes for minor street crossings. This design feature also eliminates the *Lane Change Across Motor Vehicle Travel Lanes* design flag; bicyclists would not need to cross over for a U-turn to make a minor street through or major street left-turn movement.
- The concept retains the ability to be retrofitted to include a pedestrian Z-crossing between the major street left-turns.

#### *7.4.4.2 Challenges*

The concept lacks pedestrian facilities. This approach is common in many rural areas. The lack of pedestrian facilities where people are not walking or biking perpetuates an intimidating walking environment and suppresses any latent active transportation demand. Although pedestrian paths are not conveyed, people may need to walk through the intersection.

The design flags in Exhibit 7-18 would apply for bicyclist movements. Due to the lack of pedestrian facilities, the pedestrian assessment is not completed.

This design leaves flags remaining given its context and lack of pedestrian facilities. Again, the reader is cautioned that the concepts in this guide represent treatments, rather than concepts to be replicated as is.

## 7.5 Detailed Design Techniques

The design flag procedure and corresponding flags are outlined in Chapter 4, and techniques are discussed in Chapter 5. Because many flags and techniques appear in the same fashion at many A.I.I.s, those common flags and design treatments/techniques are discussed solely in Chapter 5. Discussion in this section is limited to unique characteristics or design responses of these flags *in the context of an RCUT*. This includes:

- Minor street turn channelization
- Traffic control devices
- Pedestrian crossing options
- Channeling pedestrians to crossing
- Crossings that conflict with minor street right-turning motorists

### 7.5.1 Minor Street Turn Channelization

Usually, the minor street approach to an RCUT intersection will have a median dividing the two directions of travel. As with any street or channelization separating oncoming movements, medians on the minor street help drivers to avoid head-on conflicts and discourage wrong-way

**Exhibit 7-18. Rural RCUT concept with biking on shoulder.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Crossing Yield- or Uncontrolled Vehicle Paths (Section 4.4.4) | As presented, this intersection is unsignalized. Any bicyclist crossing the major street would need to find gaps in vehicular traffic. | Bicyclists, major street crossings |
| Executing Unusual Movements (Section 4.4.6) | Bike refuge areas in the channelized island may not be common in the local area and bicyclists may not understand the purpose of the facility. | Bicyclists, major street left-turns |
| Undefined Crossing at Intersections (Section 4.4.9) | With minimal positive guidance for bicyclists, all crossings are undefined. | Bicyclists, all crossings |
| Riding in Mixed Traffic (Section 4.4.14) | Bicyclists riding through the intersection have no physical separation from motor vehicle traffic. Shoulders of appropriate width can be identified using Chapter 3 resources, but no physical separation would be provided. | Bicyclists, all movements |
| Channelized Lanes (Section 4.4.17) | Minor street bicyclists must share the lane with right-turning vehicles in a channelized right-turn lane. | Bicyclists, minor street movements |
| Turning Motorists Crossing Bicycle Path (Section 4.4.18) | Turning motorists cross the bike lane in this design with the development of the major street right-turn lanes. | Bicyclists, major street through and left-turn movements |
| Riding between Travel Lanes, Lane Additions, or Lane Merges (Section 4.4.19) | The right-turn lane development requires bicyclists to travel between the through and right-turn lanes. | Bicyclists, major street though and left-turn movements |

maneuvers. Minor street medians should be at least 6 feet wide. Three options exist for channelizing minor street traffic:

- No channelizing island;
- A channelizing island (or channelizing end treatment on a median) separating the right-turn lanes from the minor street lanes leaving the intersection; or
- A channelizing island separating minor street right-turns that remain on the major street from minor street right-turns that make a U-turn on the major street (i.e., the redirected movements).

The advantages and disadvantages of right-turn channelization on the minor street at an RCUT intersection are described in Exhibit 7-19.

There are multiple ways to treat the RCUT intersection's minor street approach, depending on the storage bay length to the U-turn crossover. One option is to align the curve leading out of the

| Advantages | Disadvantages |
|---|---|
| • Guides drivers more firmly, likely reducing sideswipe conflicts during the turn<br>• Shortens pedestrian crossing distances to a refuge<br>• Reduces the paved surface area<br>• Provides the opportunity for a lane addition and a free right-turn (merge), reducing delay for that maneuver | • Requires pedestrians to cross more vehicle pathways, with the right-turns moving faster and/or more freely; uncontrolled right-turns are more difficult to navigate for visually impaired pedestrians<br>• Creates potential for uneven lane utilization on the minor street<br>• Requires drivers on the minor street to select a lane earlier<br>• Increases right-of-way to accommodate the channelization |

***Exhibit 7-19. Advantages and disadvantages of right-turn channelization.***

minor street to continue directly into the storage bay for the U-turn crossover. The other option is to align it to the major street through lanes, with the U-turn crossover storage bay taper beginning farther downstream. If the U-turn crossover storage bay needs to extend back to the minor street, the first option (aligning the turn directly into the bay for minor street vehicles) is preferred.

Exhibit 7-20 shows a signalized RCUT intersection with one of the two minor street lanes leading directly into the storage bay for the U-turn. Exhibit 7-21 shows a signalized RCUT intersection with two of the three minor streets lanes leading directly into the storage bay for the U-turn; in this case, a channelizing island separates the two lanes leading into the storage bay from the third right-turn lane. The tradeoffs of channelizing islands are noted above.

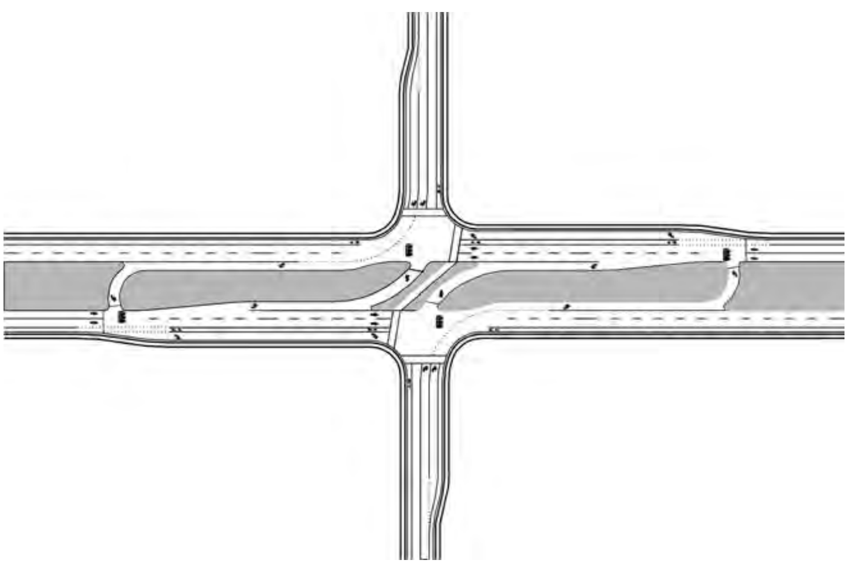

***Exhibit 7-20. Schematic of RCUT intersection with one-lane, minor street approaches.***

*Exhibit 7-21. Signalized RCUT intersection with multiple lanes and channelization on the minor street.*

### 7.5.2 Traffic Control Devices

#### 7.5.2.1 Pedestrian Signals

Pedestrian signals at an RCUT intersection should be installed to accommodate a two-stage crossing, even if it is possible to make both major street crossings in a single stage. This is because pedestrians who are slower or faster than the design value for walking speed may get caught in the median with a red signal. This means a set of pedestrian signal heads, pushbuttons, and accessible pedestrian signals would be provided in the median for each crossing, as well as on the roadside.

#### 7.5.2.2 Bicycle Signals

Bicycle signals are used to direct and control bicycle movements that are atypical compared to conventional intersections and not concurrent with vehicle movements. Section 7.2.3 discusses some options for the minor street through and left-turn movements by bicyclists, some of which involve passing through the channelizing island in the center of the main intersection. Although there are no known installations, bicycle signals could be provided at an RCUT intersection for such movements.

### 7.5.3 Pedestrian Crossing Options

Exhibit 7-22 shows a variation of the RCUT intersection design in which the minor street approaches are offset to allow a perpendicular pedestrian crossing of the major street. This has a minimal impact on vehicle operations at most RCUT intersections. A shorter crossing distance decreases pedestrian exposure to moving vehicles on the major street. Wayfinding signing and other devices would be needed to direct pedestrians to the crossing locations and deter them from crossing at the minor street intersections. This minor street offset design is typically not feasible where streets already exist, but in a developing area where the minor street or driveway locations have not been established, this variation may be considered.

An advantage of the RCUT intersection, compared to many other at-grade intersections and arterials, is the flexibility for traffic signal placement on the corridor. Because each direction of travel on the arterial can operate independently (i.e., similar to individual one-way streets), negligible vehicle delay to major street vehicles results when installing additional traffic signals, as the signals can be timed to progress major street vehicles. This feature allows mid-block

***Exhibit 7-22. RCUT intersection with minor street approaches offset to produce a shorter pedestrian crossing.***

pedestrian signals to be installed with minimal effect on vehicular travel time. Exhibit 7-23 shows two U-turn crossover configurations lending themselves to signalized mid-block pedestrian crossings, including one where there are two U-turn crossovers near each other and one where there is only one U-turn crossover.

If back-to-back U-turn crossovers are provided, as shown in Exhibit 7-23(a), these crossovers should be close to one another to facilitate pedestrian crossing and minimize out-of-direction travel for pedestrians.

In the case of Exhibit 7-23(b), the signal controlling the eastbound traffic can be a specialized signal, such as a pedestrian hybrid beacon (PHB), to further minimize the effect on main street vehicle traffic.

The pedestrian crossing of a three-legged RCUT intersection requires at least one mid-block crosswalk, as shown in Exhibit 7-24. The crossing route is direct. The optional second mid-block crosswalk, just beyond the U-turn crossover, would reduce out-of-direction travel for some pedestrians. Because it benefits pedestrians at a minimal cost and effect on major street vehicles, the second crossing should be strongly considered.

***Exhibit 7-23. Two types of signalized mid-block crossing feasible on RCUT corridor.* (a, left) *Two U-turn crossovers near one another.* (b, right) *single U-turn crossover.***

7-22 Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges

***Exhibit 7-24. Pedestrian crossing of three-legged RCUT intersection.***

### 7.5.4 Channeling Pedestrians to Crossing

Wayfinding signing (and other wayfinding devices for the visually impaired) can help direct pedestrians through the intersection to their desired destinations. Adequate wayfinding signing and other devices help direct pedestrians unfamiliar with an RCUT intersection's designated crossing patterns to cross streets at the appropriate locations.

Channelization, such as curbs, railings, or landscaping, may help pedestrians locate and use intended crossing locations. However, choices of the channelizing devices or features should consider the proximity to traffic and appropriate roadside design principles. An example of a shared-use path across an RCUT intersection is shown in Exhibit 7-25. Exhibit 7-26 shows an example of a two-stage channelized pedestrian crossing at a conventional intersection in Tucson, Arizona. Similar to an RCUT intersection, each crossing operates independently to enable bidirectional progression on the corridor.

### 7.5.5 Crossings that Conflict with Minor Street Right-Turning Motorists

Some RCUT intersection concepts include pedestrian crossings that cross the paths of right-turning motorists. These crossings have similarities to the minor street right-turn movements at MUT intersections (refer to Chapter 6 for further discussion of this condition). Treatments may include, but are not limited to, using exclusive pedestrian and bicycle phases, using leading pedestrian intervals equipped with accessible pedestrian signals, and restricting right-turns-on-red for motorists.

***Exhibit 7-25. Median shared-use path design for the U.S. Route 15/501 RCUT intersection in North Carolina.***

***Exhibit 7-26. Two-stage channelized pedestrian crossing at a conventional intersection.***

## 7.6 References


1. Hummer, J., B. Ray, A. Daleiden, P. Jenior, and J. Knudsen. August 2014. *Restricted Crossing U-Turn Informational Guide.* Report No. FHWA-SA-14-070. FHWA, Washington, DC.
2. United States Access Board. 2011. *Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG)*. https://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way/proposed-rights-of-way-guidelines.

CHAPTER 8

# Displaced Left-Turn (DLT) Intersections

## 8.1 Introduction

The displaced left-turn (DLT) intersection, also called a continuous flow intersection (CFI), is an at-grade intersection form that relocates left-turn movements at one or more approaches to the other side of the opposing traffic using a crossover upstream of the main intersection. This crossover allows vehicular left-turn movements on an approach and opposing vehicular through movements to proceed simultaneously, eliminating the need for a separate left-turn signal phase for the approach. The number of traffic signal phases and vehicular conflict points (locations where user paths cross) is reduced at a DLT intersection relative to a conventional intersection serving the same volume of traffic, which can result in improvements in vehicular operations and vehicular safety performance. The green time that would be allocated for the left-turn can be reallocated to serve other performance objectives. Exhibit 8-1 highlights the key characteristics of a DLT intersection.

Pedestrian movements at DLT intersections often cross vehicle paths multiple times, while bicycle movements have typically been accommodated with shared use of travel lanes. Both multi-stage crossings and shared bicycle movements can pose safety and quality of service challenges; the needs of these road users need to be evaluated as part of the design process.

Developing the geometric layout for an intersection configuration requires considering the relationship and interaction of safety, operations, and design. In addition, it requires understanding the tradeoffs of the physical, environmental, and right-of-way constraints for the proposed DLT intersection when local conditions preclude ideal intersection layouts.

The essential characteristics of a DLT intersection—the crossover and the reduction in signal phases—create tradeoffs for the designer to address in providing a safe and comfortable facility for bicyclists and pedestrians. This chapter conveys the geometric, operations, and safety considerations, as well as design flags specific to a DLT intersection design. In light of these characteristics, this chapter also provides techniques and treatments at a DLT intersection to help meet the design objectives presented earlier in this guide: maximizing safety, providing access and accessibility, managing delay and travel time, and providing reasonable comfort.

## 8.2 Multimodal Operations

This section provides information about the unique multimodal operational characteristics of DLT intersections and how they affect elements such as traffic signal phasing and coordination. The discussion on operations relates these characteristics to the pedestrian and bicyclist experience to convey tradeoffs associated with designs and treatments. The guidance presented here builds on existing DLT intersection studies, which include operational performance studies, comparative performance studies, and simulation analysis (*1*).

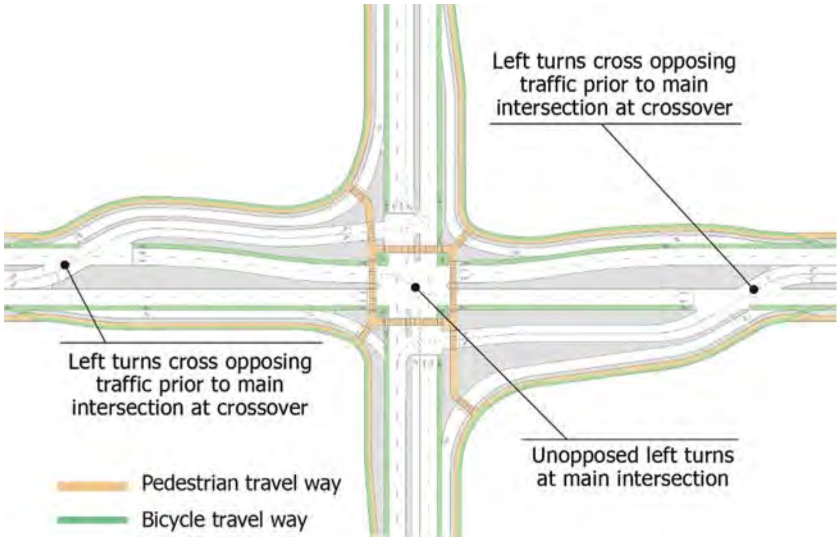


***Exhibit 8-1. DLT intersection characteristics.***

## 8.2.1 Motor Vehicles

A DLT can have up to four crossovers at a four-leg intersection. However, most of the DLT intersections in the United States include crossovers on one or two approaches (Exhibit 8-2). DLT intersections have also been implemented at three-leg intersections.

The DLT intersection's core trait—the reduction of signal phases by displacing the left-turn—is a design feature that can reduce operational delay for vehicles. The goal of this design is to reduce signal phases by providing as many concurrent movements as possible. The removal of phases can increase the green time for all movements and reduce the cycle length.

In turn, the DLT intersection can achieve vehicular capacity higher than that of a conventional intersection with the same basic lane configuration, specifically when a heavy left-turn conflicts with a heavy opposing through movement. This efficiency is amplified for motor vehicular capacity when all approaches include a DLT (i.e., when all four approaches, rather than two

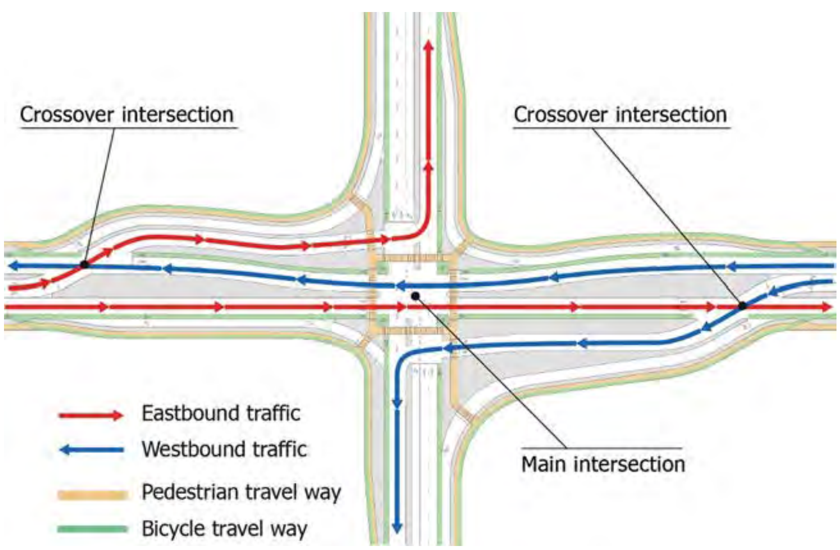


***Exhibit 8-2. Four-legged DLT intersection with displaced lefts on the major street.***

approaches, use the displaced left-turns). This provides the opportunity to reduce four signal phases (both protected left-turn pairs and both through movements) to two (both pairs of through and left-turn movements together). To design a DLT intersection that is safe and comfortable for bicyclists and pedestrians, this vehicular efficiency must be weighed against the needs of these users.

#### *8.2.1.1 Traffic Signal Phasing*

The traffic signal phasing of a DLT intersection affects how pedestrians and bicyclists experience the intersection. These characteristics can change in the development of the design and thus can be influenced early in concept development. Key features of signal operations as they pertain to pedestrians and bicyclists are as follows:

- If right-turn bypass lanes are provided, pedestrian crossings across the bypass lanes may or may not be controlled by a signal. This can heavily influence the safety and comfort of those using the crossing. The design approach is discussed more in the next section and Section 8.5.2.
- Left-turning bicyclists may face the undesirable task of making the movement as motorists do, using the DLT and sharing space with motorists in a long-channelized left-turn lane. Alternatives include two-stage bicycle turn boxes or a separated facility with crossing treatments, as presented in Section 8.3.4. Depending on the treatment, sufficient time for bicyclists to clear the intersection safely is necessary.
- Although motorists making the DLT do not conflict with oncoming vehicular traffic, the pedestrian crossings of the minor street do compete in time and, in some designs, in space, with this movement. The design approaches to address this conflict are discussed in Section 8.2.2.

#### *8.2.1.2 Right-Turns*

Right-turns at DLT intersections can either be controlled at the main intersection or channelized with a bypass lane. The decision to channelize a right-turn lane is made based on the assumed motor vehicle turning movement volumes and on the performance objectives of the design. A right-turn lane developed alongside an on-street bicycle lane represents a design flag (*Riding between Travel Lanes, Lane Additions, or Lane Merges*; Section 4.4.19), and the design should follow the guidance in Chapters 3 and 5. A channelized turn lane also represents a design flag, discussed in Sections 4.4.17 and 8.5.3.

Exhibit 8-3 provides an example of a DLT intersection with both a right-turn lane addition and channelization implemented.

***Exhibit 8-3. DLT intersection with right-turn lane addition and channelization, Austin Blvd and SR 741 in Miami Township, OH.***

## 8.2.2 Pedestrians

Pedestrian crossings at DLT intersections differ from those at conventional intersections. The main reason for this difference is the position of left-turn lanes between opposing through lanes and right-turn lanes, which presents pedestrians with an unfamiliar crossing scenario (i.e., motor vehicle traffic approaching from a nonintuitive direction). Additionally, the geometry of the crossover may create a wide median that adds length to the mainline pedestrian crossing. As discussed in Section 8.2.1.1, a pedestrian competes for time with displaced left-turns, given the simplified signal phasing.

There are two primary design approaches (locations) for providing pedestrian crossings: an outside crossing or an inside crossing. These crossing options affect the experience of pedestrians and operations for all users.

### *8.2.2.1 Outside Crossing*

This chapter will refer to the crossing concept in Exhibit 8-4 as the "outside" crossing, so named because the pedestrian crossing of the minor street (labeled *b* in Exhibit 8-4) crosses outside the concurrent DLT movement for the major street (i.e., the corner island between crossings *a* and *b* is physically outside of the northbound DLT). Although this example of an outside crossing is shown with channelized right-turn lanes on the minor street, they are not essential to the design.

The key operational elements of this design are as follows:

- Pedestrian crossings of the minor street (e.g., the *b* crossing) compete for time with the major-street DLT movement. In this example, a leading or lagging turn phase would be desirable to avoid concurrency with the adjacent left-turn movement. In some cases, the left-turn movement could be timed as a permissive left-turn movement with a flashing left arrow, but this would significantly increase the safety risk for pedestrians (refer to the *Motor Vehicle Left-*

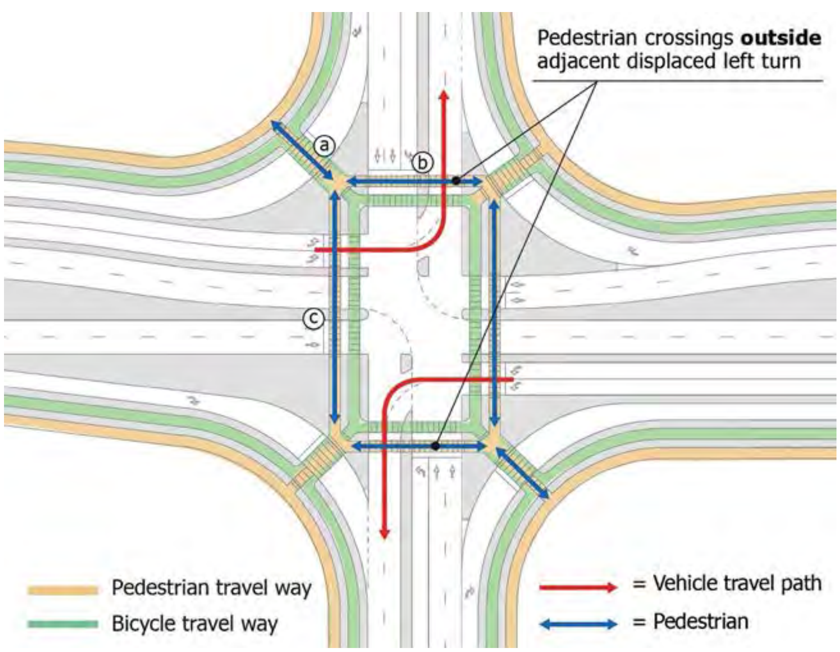


***Exhibit 8-4. Partial DLT intersection with outside crossing option. The mainline pedestrian crossings are located outside of the displaced left-turns.***

*Turns* design flag in Section 4.4.10). This minor street pedestrian crossing (crossing *b*) can operate at the same time as the major-street right-turn (westbound right), but this concurrent operation would not allow pedestrians to execute both crossings in a single protected phase.

- The pedestrian crossing is typically designed to be completed in one stage (i.e., no intermediate refuge).
- Pedestrian crossings of the major street (e.g., the *c* crossing) may require checking multiple traffic streams from alternate directions that include the DLT. Although the vehicle movements are controlled, this directional pattern is not common and therefore not intuitive (refer to the *Nonintuitive Motor Vehicle Movements* design flag in Section 4.4.3).

Depending on the crossing length, the outside crossing design may result in a relatively long cycle length (greater than 120 seconds) with associated delay for pedestrians and bicyclists due to the desire to run the left-turn movements and pedestrian crossings sequentially rather than concurrently. With longer crossings, the potential is greater for a pedestrian with a lower walking speed to not be able to cross the entire street in one cycle, thus introducing more delay. (See design flags *Multilane Crossings*, Section 4.4.7, and *Long Red Times*, Section 4.4.8). This option is most appropriate when crossing lengths (and thus pedestrian clearance times) are relatively short as a function of the intersection geometry.

### *8.2.2.2 Inside Crossing*

The second crossing option is the "inside crossing," which provides refuge islands separating the DLT movements on the major street from the adjacent through movements on the major street, as shown in Exhibit 8-5. The inside crossing example presented here also includes a channelized right-turn lane on the minor street, which may not be essential to the design. The key operational elements of this design are as follows:

- The design separates the DLT crossing (labeled *d* in Exhibit 8-5) from the main crossing *c*. This allows for shorter crossings and can provide additional time for pedestrians to cross the DLT movement. Pedestrians crossing with major-street traffic may cross in a concurrent phase (but will need to cross the DLT separately).

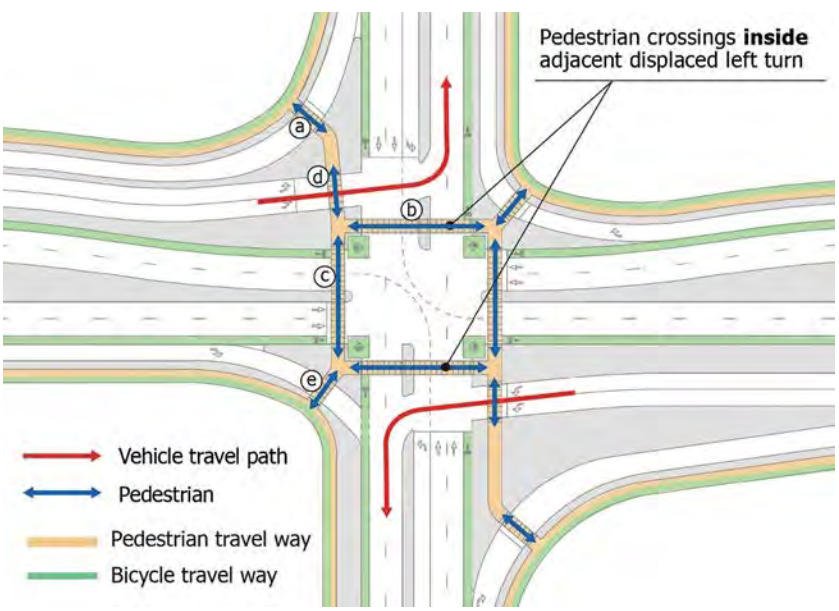


***Exhibit 8-5. Partial DLT Intersection with Inside crossing option. The mainline pedestrian crossings are inside the displaced left-turns.***

- The inside crossing achieves a shorter mainline crossing but requires more stages (compare *c* and *d* in Exhibit 8-5 to *c* in Exhibit 8-4).
- The shorter crossings may benefit pedestrians by breaking up long crossings and providing additional refuge, which may be of particular benefit to pedestrians with disabilities and slower-walking pedestrians.

Operationally, a key question to consider is which pedestrian phases can run concurrently with vehicular phases. Crossing *d* (but not *c*) could run concurrently with the minor street through and left-turn phases. Crossings *a* and *e* could run with either phase. Because pedestrians could be coming from either direction (e.g., *a* to *e* or *e* to *a*), it is difficult to establish a phase sequence optimal for both crossing directions. If *c* and *d* are timed sequentially, one crossing direction could be provided optimal timing, but the delay for pedestrians would consistently be longer in the reverse direction.

In a DLT intersection with four displaced left-turns, the additional displaced left-turns complicate the pedestrian phasing demands, but the general technique is the same. The inside crossing design includes shorter stages for crossing relative to the outside crossing, but it introduces more locations for potential delay.

The inside crossing design further separates and simplifies each crossing by creating more shorter crossings. The design may pose challenges by requiring pedestrians to cross the intersection through multiple signal cycles. The signal phasing may be adjusted to benefit certain crossing movements and directions, but not all.

A possible permutation of the inside crossing for pedestrian operations is to separate the DLT even farther from the main intersection, as shown in Exhibit 8-6. This form essentially removes the crossing of the displaced left-turns from the main intersection, thus simplifying the phasing and reducing those potential sources of pedestrian delay at the main intersection. The corner land uses in this example are far from the main intersection. With the displaced left-turns at an extended distance, the achievable distance to access corner-adjacent land uses increases.

### 8.2.3 Bicycles

Depending on vehicle volumes, speeds, and separation both approaching and through the DLT intersection, bicyclists will have varied options (and associated risks) for movements through the intersection.

The likely desired approach for some left-turning bicyclists with on-street facilities would be to make the movement in two stages, shown in Exhibit 8-7 on a DLT intersection with the

***Exhibit 8-6. Relocating DLT movement farther from the main intersection.***

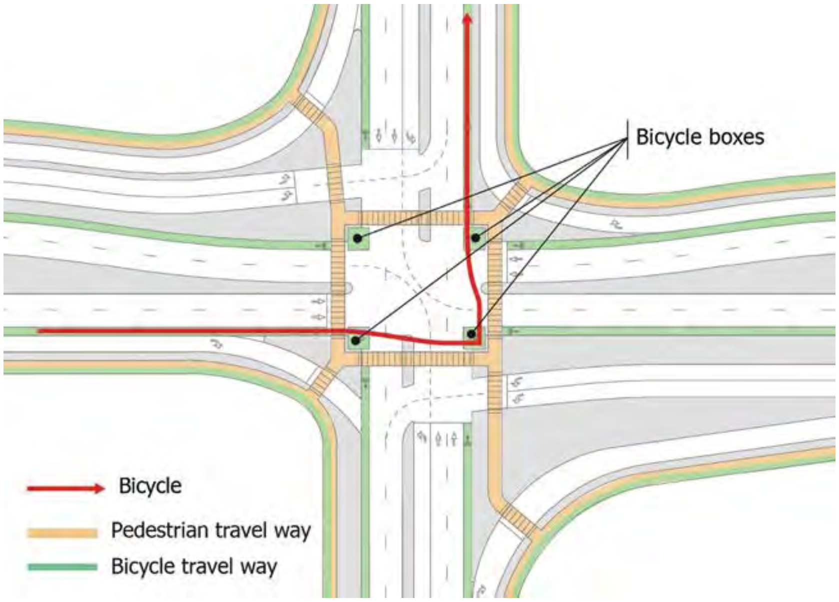


***Exhibit 8-7. Two-stage left-turning bicycles with a two-stage turn queue box through a DLT intersection.***

inside crossing design. The left-turn for a bicyclist at a DLT intersection is complicated by the design location of the displaced left-turns (inside crossing versus outside crossing). This design provides a natural location for the two-stage left-turn queue box; the initial outside crossing design option in Exhibit 8-4 does not, as drawn, provide such a location to easily accommodate this movement. This example illustrates the need for the iterative, performance-based approach (discussed in Chapter 1) to adapt initial designs when such challenges are identified.

The benefit of short cycle lengths especially applies to left-turning bicyclists completing a two-stage left-turn. If they arrive without enough time to clear the intersection, they would then wait for the opposing phase to finish and proceed through their two-stage left-turn over the next two phases. They would thus require 1.5 cycles (three phases) to traverse the intersection.

An alternative approach for the left-turn is by providing a path or separated bike lane, as shown in Exhibit 8-8. The details of these facility types are presented in Chapter 5, and DLT intersection concepts showing these separated options are presented in Section 8.3.4. Here, the operational considerations of the crossing would be much the same as for pedestrians.

A final option that is always available but typically chosen by only the most confident cyclists is to make a left-turn like a motor vehicle, making the crossover movement before the intersection and using the DLT. This approach may be unlikely in the peak hour with heavy vehicle volumes but could be used in off-peak periods, when motor vehicle volumes are lower, by highly confident cyclists. In consideration of all such movements, the designer should establish signal timing that provides adequate time for bicyclists to clear the intersection before conflicting movements proceed (and that bicyclists are detectable at approaches).

## 8.3 Safety and Comfort

Although crash data are often used to develop models or other tools that can help professionals make safety decisions about transportation facilities, crash data are often limited or unavailable for some facilities. With DLT intersections, the small number of existing intersections makes it difficult to make inferences or develop tools related to their safety performance or expected crash frequency or severity. One before-and-after study in Baton Rouge, Louisiana, showed a

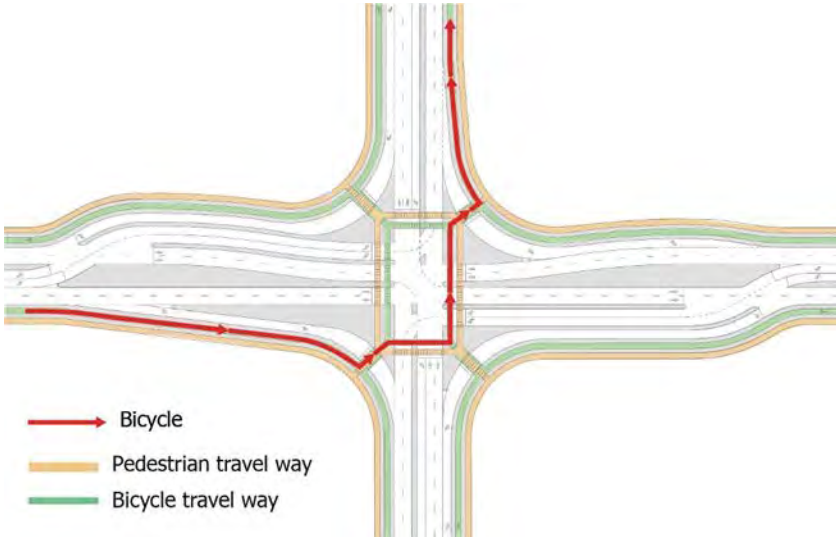


***Exhibit 8-8. Left-turning bicycle movements with a separated facility through a DLT intersection.***

reduction in vehicle collisions and severity following the implementation of a DLT intersection (*2*) relative to comparable conventional intersections, while a 2018 study showed a total crash CMF of 0.88 (*3*). Other research on DLT safety has been limited.

## 8.3.1 Conflict Points

In place of crash data, an often-applied strategy is to examine the number of conflict points at an intersection. Conflicts are correlated with collisions and are often used as a surrogate measure, particularly to compare different intersection forms. The nature of vehicle movements (accelerating or decelerating) and traffic control helps to focus attention on the conflict points at which pedestrian and bicyclist safety may be most affected by design.

### *8.3.1.1 Pedestrian Conflict Points at DLTs*

A pedestrian-vehicle conflict point exists anywhere a pedestrian walkway and a vehicular travel path cross, and a bicycle-vehicle conflict point exists anywhere a bicyclist path and a vehicle path cross. The pedestrian-vehicle conflict points for outside crossing and inside crossing DLT intersections are illustrated in Exhibits 8-9 and 8-10, respectively.

The key conflict points denoted by an asterisk (those across the channelized right-turn lanes) may be uncontrolled crossing locations, with vehicles free-flowing and/or accelerating, depending on the design of the intersection. Although this conflict is not exclusive to DLT intersections, in some existing designs they are both uncontrolled and along accelerating vehicle paths, which represents a design flag (*Crossing Yield- or Uncontrolled Vehicle Paths*, Section 4.4.4). Section 8.5.3 discusses the design of channelized turn lanes at DLT intersections.

The outside crossing design presents pedestrians with a crossing over three traffic streams of alternating direction, including the DLT movement. By contrast, the inside crossing presents more distinct crossing phases than the outside crossing for a diagonally crossing pedestrian.

### *8.3.1.2 Bicycle Conflict Points at DLT Intersections*

The bicycle-vehicle conflict points for a single approach of on-street bicycle movements and off-street bicycle movements through the intersection are presented in Exhibits 8-11 and 8-12, respectively.

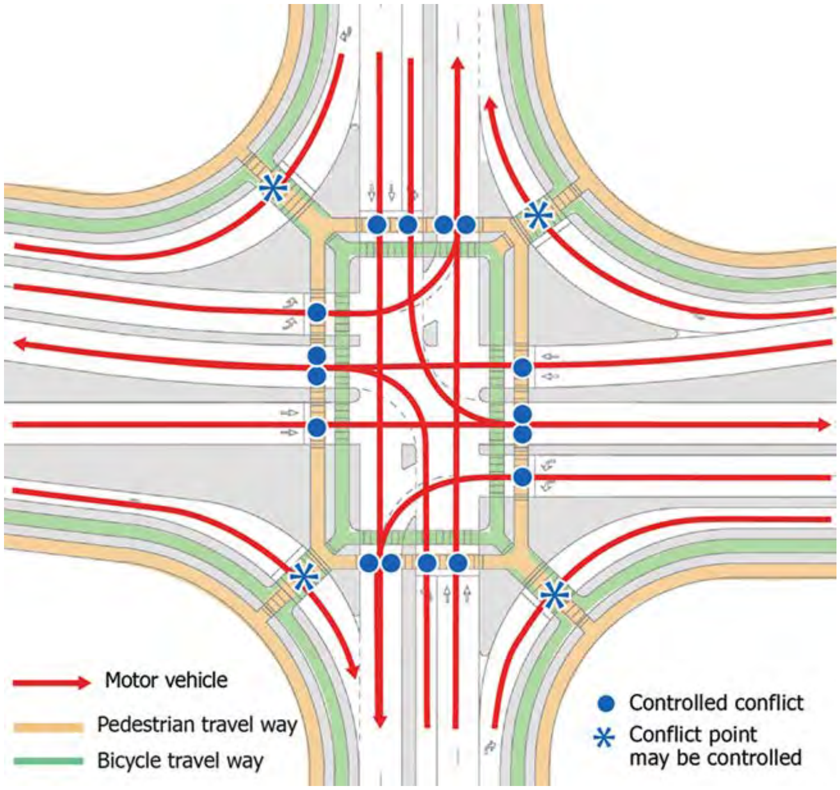


***Exhibit 8-9. Pedestrian-vehicle conflict point diagram for a DLT intersection with outside crossing design.***

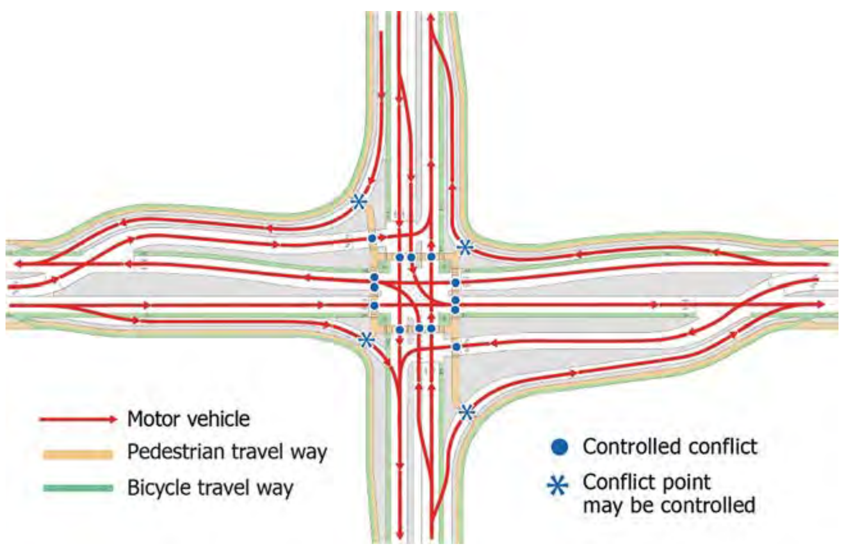


***Exhibit 8-10. Pedestrian-vehicle conflict point diagram for a DLT intersection with an inside crossing design.***

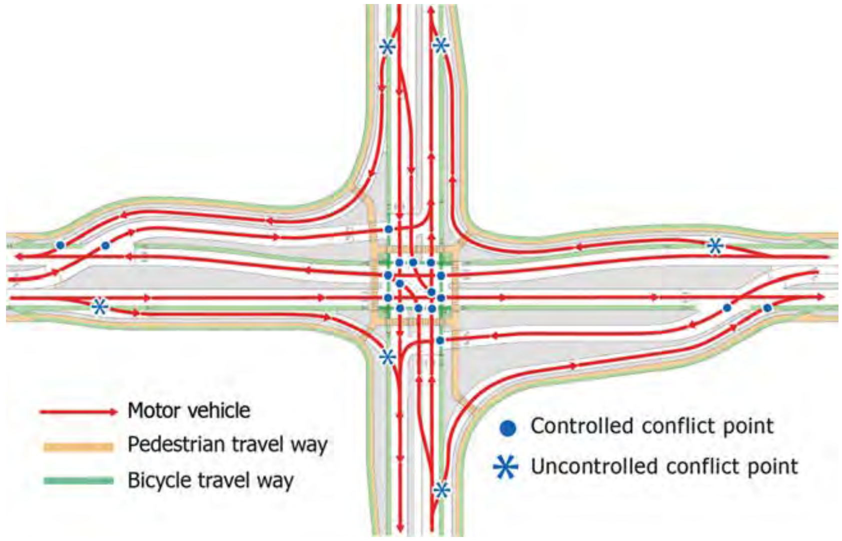


***Exhibit 8-11. Bicycle-vehicle conflict point diagram for a DLT intersection with an on-street bicycle facility.***

For on-street bicyclists, a right-turn lane represents an uncontrolled conflict point. Depending on the distance from the intersection at which bicycle and motor vehicle paths cross, it may be a decelerating vehicle movement. If channelization is provided, the conflict point is upstream of the intersection; otherwise, the conflict point is at the intersection (see *Turning Motorists Crossing Bicycle Path*, Section 4.4.18). Although this is not a unique challenge to DLT intersections, the common use of channelized right-turn lanes makes this a focus of their design.

For bicyclists riding in a separated facility, the conflict points are more spatially concentrated, and the right-turn conflict point is recessed, or offset, relative to the design with an on-street bicycle lane. See Section 5.3.3 for details on offset crossings.

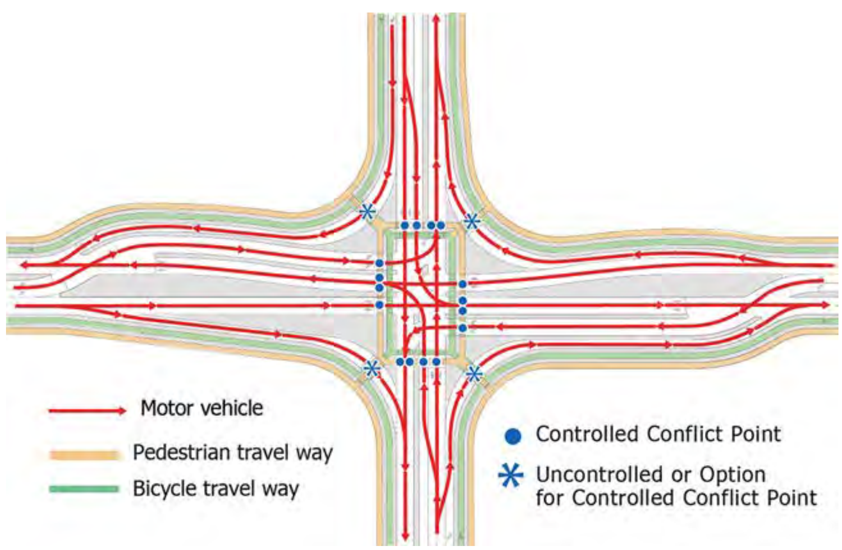


***Exhibit 8-12. Bicycle-vehicle conflict point diagram for a DLT intersection with an off-street bicycle facility.***

## 8.3.2 Pedestrians–Key Safety Challenges

An analysis of the design characteristics of the DLT intersection reveals several key safety challenges for pedestrians:

- **Providing a reasonable path and quality of service.** A reasonable path through the intersection–one that is relatively direct and has minimal travel delay—will keep pedestrians from circumventing the intended design. As discussed in Section 8.2.2, the inside crossing design approach may create a delay for pedestrians, given the number of crossing stages. Conversely, a long major-street crossing with an outside crossing design may extend cycle length and increase the delay in a different manner. Absent a reasonable path or with excessive delay, pedestrians will seek their own paths, sometimes placing themselves at risk. This idea is captured in the *Indirect Path* and *Long Red Times* design flags (Sections 4.4.5 and 4.4.8, respectively).
- **Right-turn vehicular movements.** Whether or not the turn is channelized, the speed, visibility, and traffic control need to be managed to reduce the risk for pedestrians; this concern is represented by the *Motor Vehicle Right-Turns* design flag (Section 4.4.1).
- **Pedestrian confusion.** Pedestrians crossing the DLT may not know intuitively which way to look for conflicting vehicle traffic streams. Simplifying crossings (i.e., isolating conflicting movements to be crossed) reduces the burden for crossing pedestrians. This concern is represented by the *Nonintuitive Motor Vehicle Movements* design flag (Section 4.4.3).

Exhibit 8-13 presents the design flags applicable to pedestrians, along with where to find discussion and applicable treatments. (Design flags and treatments whose discussion applies across alternative intersection types are in Chapters 4 and 5).

## 8.3.3 Bicycles–Key Safety Challenges

Bicycle safety at DLT intersections is a function of the bicycle facility type and level of separation between bicycles and vehicular traffic. For bicyclists traveling on shared-use paths, the crossing concerns for pedestrians discussed above apply. The additional considerations of particular concern for bicycle safety at DLT intersections include the following:

- As discussed in Section 8.2.3, there are three primary approaches for left-turning bicyclists through DLT intersections. The conflict points for all three such left-turning bicyclist movements are presented in Exhibits 8-11 and 8-12. Bicyclist safety at these conflict points depends on the vehicle speed/geometry and traffic control–factors controlled by the intersection design—as well as vehicle volume, which aids in the decision facility selection.
- Short cycle lengths that still preserve adequate clearance time are essential for bicyclist comfort and safety. The two-stage left-turn, or a left-turn with a separated path and crossings, is subject to delay given the need for subsequent phases. Preventing excessive delay for these cyclists promotes the use of the design as intended (*Long Red Times,* Section 4.4.8).
- Through or left-turning bicyclists may struggle to clear the intersection during the allocated green time. This safety challenge depends on the street width—particularly the major street, which may be relatively wide in some configurations. This challenge is represented in the *Bicycle Clearance Times* design flag, discussed in Section 4.4.15.
- The entrance to a channelized right-turn (merging) is a critical bicycle-vehicle conflict point. This conflict point is not unique to DLT intersections, and absent a channelized right-turn, drivers must still cross the path of through cyclists as they turn right at the intersection. Channelized right-turns are typically used at DLT intersections, as presented in Section 8.5.3. Thus, the motor vehicle right-turn manifests either as *Channelized Lanes* (Section 4.4.17) or as *Turning Motorists Crossing Bicycle Path* (Section 4.4.18).

**Exhibit 8-13. Design flags applicable to pedestrians at DLT intersections.**

| Design Flag | Description | Mode / Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | This flag would carry forward to the final design stage. The right-turns at full or partial DLT intersections typically are channelized, so sight distance and control must be considered for pedestrian safety. | Pedestrians, all main intersection crossings |
| Nonintuitive Motor Vehicle Movements (Section 4.4.3) | Pedestrians crossing the DLT would not typically expect vehicles in the given direction—whether crossing is on the departing or receiving end of the displaced left-turn. | Pedestrians, all main intersection crossings |
| Multilane Crossing (Section 4.4.7) | DLTs typically include multiple through lane approaches and one or two displaced left-turns, bringing a major-street crossing to six or seven lanes, sometimes without refuge. | Pedestrians, major-street crossings, and often minor street crossings |
| Long Red Times (Section 4.4.8) | Due to high volumes, DLTs typically have longer cycle lengths, even though they may have only two or three phases. Additionally, the presence of signalized channelized right-turns may result in a high number of stages required to cross the intersection. | Pedestrians, all crossings |
| Motor Vehicle Left-Turns (Section 4.4.10) | As discussed in Section 8.2, pedestrians compete in time and space with the displaced left-turns. Signal phasing can reduce the effect on pedestrians, and geometric design can promote appropriately slow left-turn speeds. | Pedestrians, all main intersection crossings |

- Traveling along a turn lane and sharing the lane with turning vehicles (displaced left or channelized right-turn) can create difficulties. Although the left-turn is displaced, making a turn through the lane alongside a motor vehicle exposes a cyclist to risk. (*Channelized Lanes*, Section 4.4.17).

Exhibit 8-14 presents the design flags applicable to bicyclists, along with reference to more detailed discussion and applicable treatments.

Several of these conflict locations are addressed in the discussion of the respective design flag treatments beginning in Section 8.5. Others for which the design flag is not unique to DLT intersections are discussed in the relevant sections of Chapter 4.

### 8.3.4 Other Safety Concerns

In addition to the preceding discussion of key pedestrian and bicyclist safety concerns, there are other general benefits and concerns presented by DLT intersections. Design flags relevant to bicyclists that are more universal and not unique to DLT intersections include the following:

- Intersection Driveways and Side Streets (Section 4.4.11);
- Sight Distance for Gap Acceptance Movements (Section 4.4.12);
- Grade Change (Section 4.4.13); and
- Off-tracking Trucks in Multilane Curves (Section 4.4.20).

**Exhibit 8-14. Design flags applicable to bicycles at DLTs.**

| Design Flag | Description | Mode/Travel Path |
|---|---|---|
| Long Red Times (Section 4.4.8) | Because the preferred bicycle left-turn options include either a two-stage left-turn or off-street path with crossings, bicyclists' travel time is sensitive to the entire cycle length and red times. The intersection design will optimally minimize excessive delay for bicyclists to discourage risk-taking behavior. | Bicyclists, left-turn movements along approaches with DLT |
| Bicycle Clearance Times (Section 4.4.15) | The typically relatively large footprint of a DLT means that yellow and all-red phases designed around motor vehicle trajectories are probably insufficient for bicyclists to clear the intersection during the intended phase. | Bicyclists, through movements |
| Channelized Lanes (Section 4.4.17) | The displaced left-turn is a channelized movement, and DLT intersections typically feature channelized right-turn movements. Riding alongside vehicles in either channelized movement creates stress. | Bicyclists, left-turns and right-turns |
| Turning Motorists Crossing Bicycle Path (Section 4.4.18) | Developing a right-turn lane creates a motorist movement crossing over a bicycle path. | Bicyclists, through movements |

## 8.4 DLT Intersection-Level Concepts

Three design concepts have been developed to present options for improving pedestrian and bicyclist safety and operational performance at DLT intersections. These concepts are not suggested as designs to be replicated as is; rather, they illustrate the DLT intersection options possible in various contexts. These concepts show displaced left-turns on the major street only (two of four approaches). Finally, these designs show various treatment options, especially for bicyclists. The designer must consider traffic volume and speed when matching designs and treatments to the appropriate context (discussion in Chapter 3, Section 3.3.2).

Following each concept is a discussion of the design flags remaining with the design—the flags not obviated by the design that would still need to be addressed.

The designs include the following:

- DLT Bike Lane and Path Concept
- DLT Protected Intersection Concept
- DLT Median Walk Concept

### 8.4.1 DLT Bike Lane and Path Concept

This partial DLT intersection concept (shown in Exhibit 8-15) is distinguished by its provision of on-street bike lanes along with a shared-use path for right-turning bicyclists. The concept would be appropriate for a context of low motor vehicle speeds, low motor vehicle volumes,

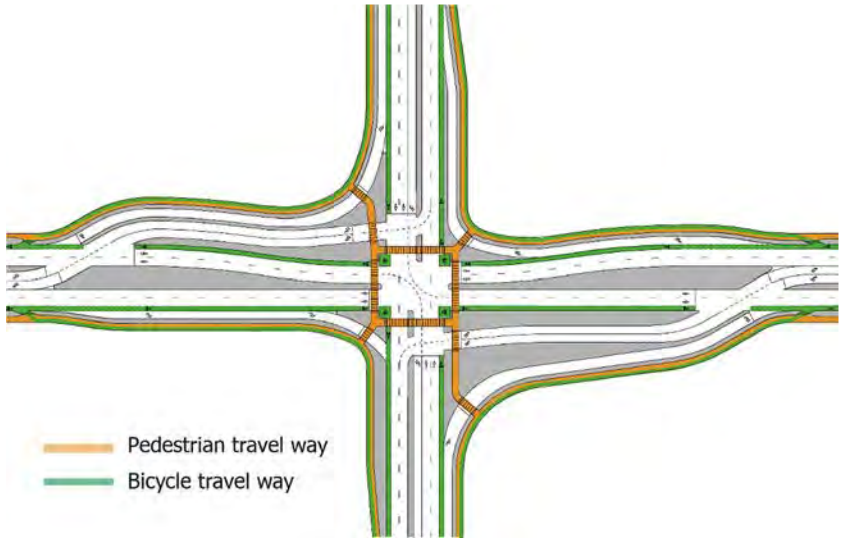


***Exhibit 8-15. DLT bike lane and path concept.***

or both; the concept also provides an example for carrying existing bike lanes through a DLT intersection. Consult Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

#### *8.4.1.1 Benefits*

This DLT intersection concept includes these benefits for bicyclists and pedestrians:

- **Crossing Yield-Controlled or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings are controlled in this concept.
- **Multilane Crossings design flag:** An inside crossing pedestrian mainline crossing minimizes crossing distance and exposure to vehicular traffic. A tapered median also allows for a relatively narrow median at the mainline crossing, to shorten the crossing distance.
- **Riding in Mixed Traffic design flag:** The provision of the on-street bike lane and the shared-use path allows users to select their desired riding position, providing for more highly confident cyclists and those who would not use on-street facilities in this context.
- **Channelized Lanes design flag / Lane Change Across Motor Vehicle Travel Lanes design flag:** For left-turning bicyclists, using a two-stage turn queue box removes the need to cross over vehicle travel paths and travel in a channelized left-turn lane on the major-street approach. Similarly, for right-turning bicyclists, the ramp to a shared-use path allows bypass of the channelized right-turn lane with a downstream ramp to return to an on-street bike lane.
- **Riding between Travel Lanes, Lane Additions, or Lane Merges design flag:** The right-turn bypass lane includes (along the major street) a signalized reentry to control the bicycle-vehicle conflict for through bicyclists at this location.

#### *8.4.1.2 Challenges*

Emphasizing again that the design is not intended to be "ready-made," this concept leaves several design flags as described in Exhibit 8-16. In this analysis, the right-turning bicyclists are assumed to use the off-street path.

### 8.4.2 DLT Protected Intersection Concept

This DLT intersection concept (shown in Exhibit 8-17) is characterized by the separated bike lane on all approaches and the shared crossings over channelized right-turn lanes. The separated

**Exhibit 8-16. Summary of design flags remaining with DLT bike lane and path concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | Channelized right-turn lanes can lead to high vehicle speeds. This flag can be eliminated by signalizing the movement or reducing speeds below 10 mph with raised crosswalks or other methods. | Pedestrians, all movements |
| Nonintuitive Motor Vehicle Movements (Section 4.4.3) | For pedestrians crossing the major street, crossing over the DLT is unintuitive. Although the conflict point is controlled, it may be unexpected and presents accessibility challenges. | Pedestrians, major-street crossings |
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | If not signalized or stop-controlled, the pedestrian crossing of the channelized right-turn lane would result in a flag. | Pedestrians, all movements |
| Indirect Paths (Section 4.4.5) | The large channelizing island in the southeast quadrant results in the need for east- and westbound pedestrians to encounter significant out-of-direction travel to cross the channelized turn lane. | Pedestrians, eastbound or westbound through the southern approach |
| Multilane Crossings (Section 4.4.7) | The minor street would require crossing over three lanes without refuge. | Pedestrians, minor street crossings |
| Long Red Times (Section 4.4.8) | Pedestrians may require multiple phases or cycles to cross the intersection, given the separation of many crossings of conflicting phases. This is amplified if the channelized turn lanes are signalized. Because the design is a partial DLT, the signal phasing would likely include three phases, increasing the relative red share during which pedestrians must wait. | Pedestrians, all crossings |
| Motor Vehicle Left-Turns (Section 4.4.10) | Pedestrians crossing the major street experience conflicts with the non-displaced left-turns from the minor street. | Pedestrians, major-street crossings |
| Sight Distance for Gap Acceptance Movements (Section 4.4.12) | Adequate sight distance should be provided for any channelized turn movement not signalized. | Pedestrians, all crossings |

*(continued on next page)*

**Exhibit 8-16.** ***(Continued).***

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Riding in Mixed Traffic (Section 4.4.14) | Bicyclists using the on-street lanes would face increased safety risks if vehicle speeds or volumes along the road were elevated. | Bicyclists, all movements except right-turns |
| Bicycle Clearance Times (Section 4.4.15) | Bicyclists using the on-street lanes may not clear the intersection with the yellow and all-red phases programmed to accommodate vehicle trajectories. | Bicyclists, through movements |
| Turning Motorists Crossing Bicycle Paths (4.4.18) | Right-turning motor vehicles have to cross over the on-street bicycle lane to move into the right-turn pocket. | Bicyclists, left and through movements |
| Riding between Travel Lanes, Lane Additions, or Lane Merges (Section 4.4.19) | For on-street through bicyclists, the right-turn lane add before the intersection results in bicyclists riding between the right and through lanes for an extended period. | Bicyclists, through and left-turn movements |

bike lane would be an appropriate design technique for locations with relatively high motor vehicle volumes, speeds, or both. The separated bike lane would provide a low-stress riding environment and encourage use by less confident bicyclists. Depending on the surrounding facilities, the separated lane could match back into existing separated bike lanes or provide ramps back to on-street facilities. Using a separated bike lane versus a shared-use path would depend on the number of pedestrians and bicyclists expected to use the facility; consult Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

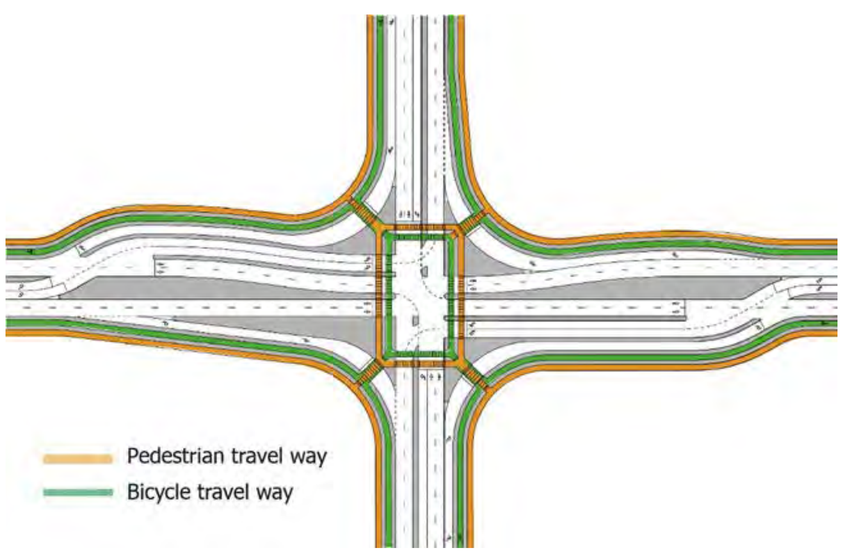


***Exhibit 8-17. DLT protected intersection concept.***

#### *8.4.2.1 Benefits*

- **Motor Vehicle Right-Turns design flag**: The design includes the protected intersection concept with corner refuge islands that tighten turn radii and extend physical protection for crossing pedestrians. The turn radius would need to be refined based on the intended design vehicle path but would control right-turning vehicle speeds. Crossing pedestrians are pulled back to enhance their visibility.
- **Crossing Yield- or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, providing safe crossing opportunities and eliminating the possible associated design flag.
- **Physical Separation for Bicyclists:** This concept moves all riding away from mixed traffic with physical (horizontal and vertical) separation. Bicyclists would cross motor vehicle paths using marked crossings; consult Chapter 5 for guidance on these crossings. The separated bicycle lane removes the bicycle and motor vehicle crossover conflict points throughout the intersection, relocating conflict to a controlled crossing of right-turn channelized turn lanes. The channelized lane crossings would be bidirectional for pedestrians and bicyclists, with sufficient width and marking to provide for these movements. This design eliminates the following design flags:
  - Riding in Mixed Traffic
  - Turning Motorists Crossing Bicycle Path
  - Riding between Travel Lanes, Lane Additions, or Lane Merges
- **Outside Crossing Provision:** The major-street pedestrian crossing would be made in a single stage, eliminating the extra delay that could be incurred waiting between two-stage crossings.

#### *8.4.2.2 Challenges*

The protected intersection concept leaves some design flags remaining, as presented in Exhibit 8-18.

### 8.4.3 DLT Pedestrian Walkway Between Vehicle Lefts and Throughs Concept

This DLT concept (presented in Exhibit 8-19) is distinguishable by the provision of the walking path between the displaced left-turn and through lanes, as well as the absence of bicycle facilities along the major street. Based on the bicycle facilities, this concept would be expected to be implemented where a bicycle route of importance suitable for on-street facilities (the minor street) crosses a major arterial route that is not a critical piece of a planned bike network. Consult Sections 3.1 and 3.3 to consider intended bicycle design users and guidance for matching a bicycle facility to speed and volume conditions.

This design introduces a new concept: pedestrians traveling between the vehicle left and through lanes (*4*). This includes the addition of a pedestrian facility between the DLT and the opposing through movement that travels away from the main intersection toward the crossover and bypass right lane end. This design places pedestrians in the median refuge island toward the crossover to cross the DLT there. The design, which functions similarly to the inside crossing option, creates a crossing opportunity across the DLT lanes at the crossover intersection because of the median positioning.

This concept allows the channelized right-turn and DLT crossings to operate on the same signal phase, minimizing the number of signal phases needed to cross quadrants at the intersection. Provided the two stages can be made within the provided clearance phase, the reduction in stages would reduce pedestrian delay at the main intersection.

**Exhibit 8-18. Summary of design flags remaining with DLT protected intersection concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | Channelized right-turn lanes can lead to high vehicle speeds. This flag can be eliminated by signalizing the movement or reducing speeds below 10 mph with raised crosswalks or other methods. | Pedestrians, all movements |
| Nonintuitive Motor Vehicle Movements (Section 4.4.3) | For pedestrians crossing the major street, crossing over the DLT is unintuitive. Although the conflict point is controlled, it may be unexpected and presents accessibility challenges. | Pedestrians, major-street crossings |
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | If not signalized or stop-controlled, the pedestrian crossing of the channelized right-turn lane would result in a flag. | Pedestrians and bicyclists, all movements |
| Multilane Crossings (Section 4.4.7) | The major and minor street pedestrian crossings include crossing over multiple lanes in a single stage and would be red or yellow flags, depending on subsequent design details. | Pedestrians, all main intersection crossings |
| Long Red Times (Section 4.4.8) | Pedestrians may require multiple phases or cycles to cross the intersection, given the separation of many crossings of conflicting phases. This is amplified if the channelized turn lanes are signalized. Because the design is a partial DLT, the signal phasing would likely include three phases, increasing the relative red share during which pedestrians must wait. | Pedestrians and Bicyclists, all crossings |
| Motor Vehicle Left-Turns (Section 4.4.10) | Users crossing the major street experience conflicts with the non-displaced left-turns from the minor street. | Pedestrians and Bicyclists, major-street crossings |
| Sight Distance for Gap Acceptance Movements (Section 4.4.12) | Adequate sight distance should be provided for any channelized turn movement not signalized. | Pedestrians and Bicyclists, all crossings |

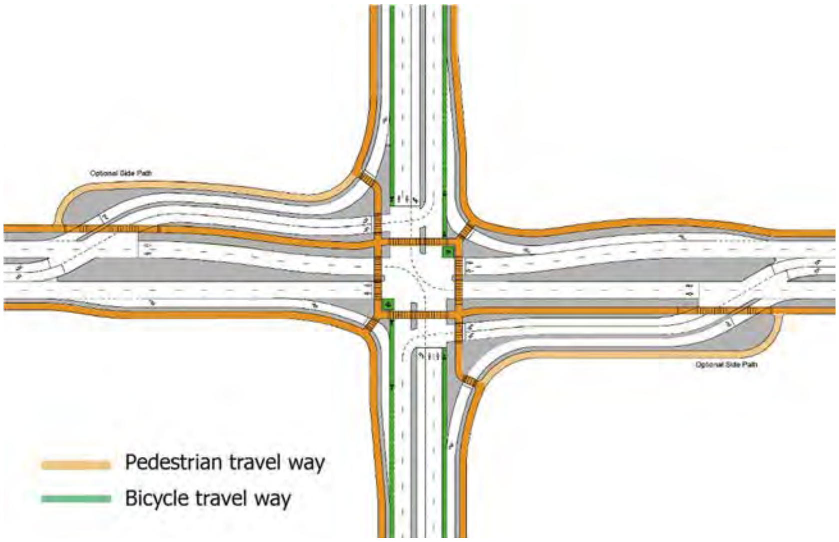


***Exhibit 8-19. DLT pedestrian walkway between vehicle left and through lanes concept.***

The core elements of the design are as follows:

- As with the inside crossing concept, the median walk provides a single crossing of mainline through vehicle movements. Limiting this crossing distance promotes a short clearance interval and cycle length, as well as reduced pedestrian crossing exposure.
- A separate stage is necessary for crossing displaced left-turns and right-turns. An option is provided to make this crossing at either Location 1 or Location 2 in Exhibit 8-20.
- Accessibility and pedestrian comfort are of concern for traversing the median between two opposing directions of traffic.
- An optional side path is shown. Absent the optional side path, the corner pedestrian path shown would require two crossings.

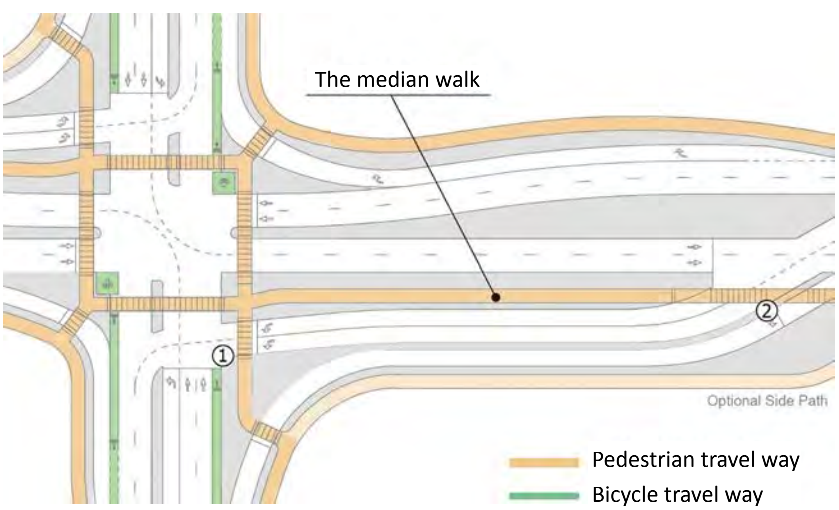


***Exhibit 8-20. Detailed view of median walkway.***

#### *8.4.3.1 Benefits*

This DLT intersection concept includes these benefits for bicyclists and pedestrians:

- **Multilane Crossings design flag:** An inside crossing pedestrian mainline crossing minimizes crossing distance and exposure to vehicular traffic. A tapered median also allows for a relatively narrow median at the mainline crossing, to shorten the crossing distance. The median walk concept also provides opportunities for pedestrians to avoid delay while crossing.
- **Crossing Yield- or Uncontrolled Vehicle Paths design flag:** All pedestrian crossings would be signal-controlled, providing safe crossing opportunities and eliminating the possible associated design flag.
- **Nonintuitive Motor Vehicle Movements design flag:** If pedestrians are crossing the intersection from west to east or east to west and are strictly using the median walk, they may avoid crossing over the displaced left-turns entirely. The use of the median walk would trigger the **Executing Unusual Movements design flag** (Section 4.4.6).
- The provision of bike lanes on the minor street provides facilities suitable for highly confident cyclists, possibly inviting lower-confidence cyclists if motor vehicle volumes and speeds are appropriate.
- The presence of the median walk would allow for the placement of a transit stop between the main and crossover intersections. The other DLT intersection designs would not allow for this because of the placement of the displaced left-turns between the through lane and walking paths.

#### *8.4.3.2 Challenges*

The median walk concept leaves some design flags remaining, as presented in Exhibit 8-21.

## 8.5 Detailed Design Techniques

The design flag procedure and corresponding flags are outlined in Chapter 4, and general design techniques are discussed in Chapter 5. Discussion in this section is limited to unique characteristics or design to assist in addressing flags at a DLT intersection. Specifically, the subsequent sections discuss the following:

- Crossover/left-turn design approach;
- Geometry and location of DLT;
- Channelized vs. non-channelized right-turns;
- Bypass lane design; and
- Three-legged intersection.

### 8.5.1 Crossover/Left-Turn Design Approach

The potential need for a bicyclist to cross through multiple lanes of concurrent through traffic to turn left is not a unique challenge for DLT intersections; however, the design of DLT intersections has rarely provided reasonable alternatives.

One reasonable alternative is to provide a two-stage turn box (as exemplified for all bicycle left-turns in Exhibit 8-15 and northbound and southbound left-turns in Exhibit 8-22) to facilitate left-turns made over two signal phases without a crossover. Alternatively, a DLT intersection can include a separated bicycle lane or shared-use path so cyclists can make the turn by crossing with pedestrians.

To accommodate the bicyclist turning left with motor vehicle traffic, a controlled crossing for bicyclists could be placed at the entrance of the DLT. This would change the crossover conflict for the movement into a crossing conflict; the crossing could be uncontrolled depending on

**Exhibit 8-21. Summary of design flags remaining with DLT median walk concept.**

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | Channelized right-turn lanes can lead to high vehicle speeds. This flag can be eliminated by signalizing the movement or reducing speeds below 10 mph with raised crosswalks or other methods. | Pedestrians, all movements |
| Uncomfortable/Tight Walking Environment (Section 4.4.2) | The careful design of the median walkway is necessary to mitigate the stress of walking between two sets of vehicle lanes. | Pedestrians, median crossings |
| Nonintuitive Motor Vehicle Movements (Section 4.4.3) | For pedestrians crossing the major street, crossing over the DLT is unintuitive. Although the conflict point is controlled, it may be unexpected and presents accessibility challenges. | Pedestrians, all origin-destination except crossing west to east or east to west using the median walks |
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | If not signalized or stop-controlled, the pedestrian crossing of the channelized right-turn lane would result in a flag. | Pedestrians, all movements |
| Multilane Crossings (Section 4.4.7) | The minor street would require crossing over three lanes without refuge. | Pedestrians, minor street crossings |
| Long Red Times (Section 4.4.8) | Pedestrians may require multiple phases or cycles to cross the intersection diagonally, given the separation of many crossings of conflicting phases. Because the design is a partial DLT, the signal phasing would likely include three phases, increasing the relative red share during which pedestrians must wait. | Pedestrians, all crossings |
| Motor Vehicle Left-Turns (Section 4.4.10) | Pedestrians crossing the major street experience conflicts with the non-displaced left-turns from the minor street. | Pedestrians, major-street crossings |
| Sight Distance for Gap Acceptance Movements (Section 4.4.12) | Adequate sight distance should be provided for any channelized turn movement not signalized. | Pedestrians, all crossings |
| Riding in Mixed Traffic (Section 4.4.14) | The provision of on-street bike lanes on the minor street requires a bicyclist to ride alongside motor vehicle traffic entering, traversing, and exiting the intersection. The major street includes no bicycle facilities. | Bicyclists, all approaches |

*(continued on next page)*

**Exhibit 8-21. *(Continued).***

| Flag Remaining | Description | Mode/Travel Path |
|---|---|---|
| Bicycle Clearance Times (Section 4.4.15) | Bicyclists may not clear the intersection with the yellow and all-red phases programmed to accommodate vehicle trajectories. | Bicyclists, through movements |
| Lane Change Across Motor Vehicle Travel Lane(s) (Section 4.4.16) | For any bicyclists who use the major street, there is no alternative left-turn provided other than using the DLT, which would require a crossover movement before the intersection to get into the left-turn lane. | Bicyclists, major-street approaches |
| Channelized Lanes (Section 4.4.17) | For any right-turning bicyclists and major-street left-turn bicyclists using the DLT, channelized lanes force cyclists into a confined curve with motor vehicles. | Bicyclists, right-turns and major-street left-turns |
| Turning Motorists Crossing Bicycle Path (Section 4.4.18) | Turning motorists cross the bike lane in this design with the development of the right-turn lanes. | Bicyclists, all approaches |
| Riding between Travel Lanes, Lane Additions, or Lane Merges (Section 4.4.19) | For through bicyclists, the right-turn lane add before the intersection presents a diverging conflict point with motor vehicles. Downstream of the intersection, the motor vehicle right-turn reentry downstream of the intersection presents a merging conflict point. | Bicyclists, through movements |

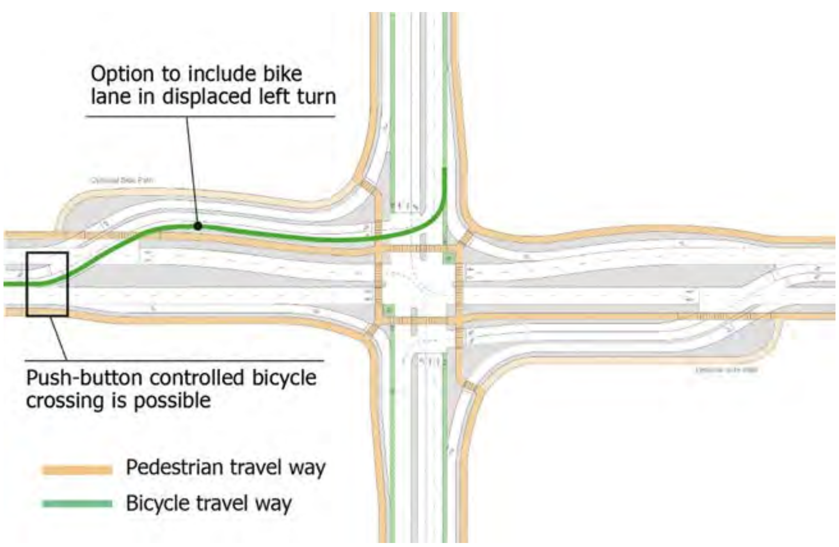


***Exhibit 8-22. Option for DLT crossing.***

speed, volumes, and number of lanes (though it is expected the crossing would be best served as a controlled movement). In some DLT intersection designs, this would be a single-lane crossing.

Speeds in the channelized left-turn and width of the lanes would be critical for bicyclist safety, with the possibility of adding a bike lane. This provision would improve access but might not satisfy the needs of risk-averse bicyclists. This concept is shown in Exhibit 8-22.

## 8.5.2 Geometry and Location of DLT

Depending on its location (inside crossing versus outside crossing), the DLT can create way-finding and operational issues for pedestrians and bicyclists. People crossing between through and DLT movements may not intuitively know which crossings operate concurrently or in which direction traffic will be approaching. Additional wayfinding elements are advisable.

## 8.5.3 Channelized Versus Non-Channelized Right-Turns

Most existing DLT intersections contain channelized right-turns either on some or all approaches, but some have been built without them. A general discussion of design flags and mitigation techniques for channelized right-turns is covered in Chapters 4 and 5. There are tradeoffs with either right-turn design approach.

Channelized right-turns spread out vehicle-vehicle and pedestrian-vehicle conflict points and provide more capacity for right-turning motorists. However, they require additional right-of-way, may create additional exposure for crossing movements, may encourage high speeds through a pedestrian conflict point through their design, and introduce accessibility challenges for pedestrians with vision disabilities.

A challenge particular to DLT intersections is that, with the displaced left-turn and associated medians, the inclusion of the right-turn lane without channelization may lengthen an already relatively long mainline crossing distance. This presents a challenge both for pedestrian exposure and for signal operations, given the required clearance interval.

Another challenge of the non-channelized right-turn lane for motorists is the possibility for drivers to turn right into the upstream DLT lane (see Exhibit 8-23). Turning paths may be designed and demarcated to clearly define paths and discourage wrong-way right-turns, but this risk is unique to DLT intersections. As such, the channelized right-turn lane is expected to continue as a common feature at DLT intersections. The design of this channelized right-turn lane should consider the guidance in this document.


***Exhibit 8-23. DLT intersection with non-channelized right-turn.***

### 8.5.4 Bypass Lane Design

If a bypass lane is used at a DLT intersection, there are two ways that DLT intersections have typically accommodated the geometry for the right-turn bypass lane to join back with the cross street through lanes. The choice between these two options will impact the pedestrian experience if pedestrians are walking along an inside path between travel lanes. The on-street bicyclist experience will differ depending on the design. The two design options are to

- Provide an add lane with a downstream lane merge. If an on-street bike facility is provided, then the corresponding through movement (shown as west to east in Exhibit 8-24) presents an accelerating, merging bicycle-vehicle conflict point. With an off-street facility or path as shown, the bicycle movement will have crossed over the right-turn closer to the main intersection.
- Signalize the movement and operate it as part of the crossover signal, as shown in Exhibit 8-25 and presented in all three design concepts in this chapter. A signalized right-turn approach as shown would provide a controlled vehicle-bicycle conflict point. RTOR movements could be allowed or restricted. With the provision of a separated bike facility, any ramp from the separated facility would be provided downstream of the signal to avoid a conflict with the right-turn in this location (This is shown for the minor street in Exhibit 8-15 previously in this chapter).

### 8.5.5 Three-Legged Intersection

A three-legged DLT can provide crossing benefits for pedestrians and bicyclists. Traditional three-leg intersections often result in conflicts between pedestrians and vehicles turning left from the stem. The three-leg DLT allows for protected left-turns from the minor street to the major street as well as a protected crossing for nonmotorized users across the major street with no additional signal phase.

Exhibit 8-25 shows an example of a three-leg DLT. Although access across the north-south roadway is not provided, it could be created between the northbound left and eastbound left. This would trigger the *Indirect Path* design flag.

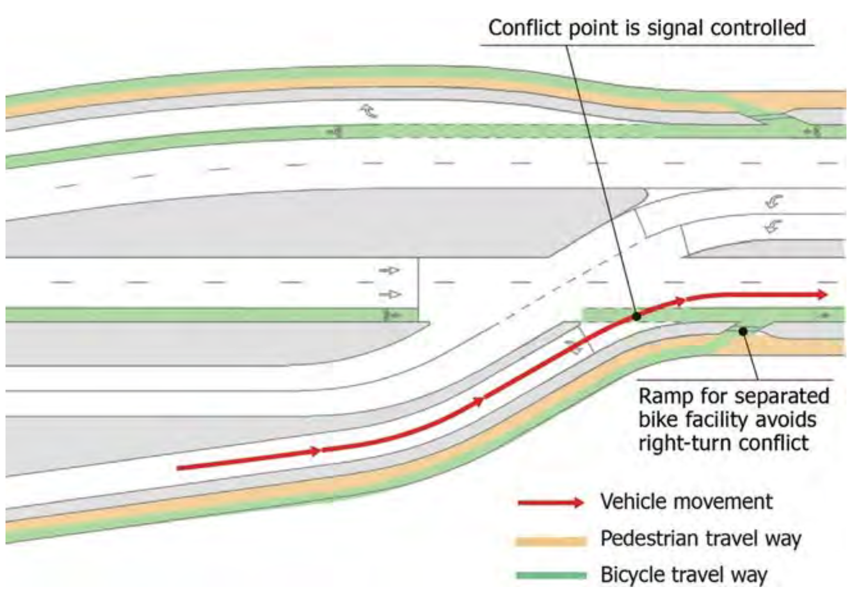


***Exhibit 8-24. DLT with signalized right-turn entry.***

***Exhibit 8-25. Median walk crossing option.***

## 8.6 References

1. Steyn, H., Z. Bugg, B. Ray, A. Daleiden, P. Jenior, and J. Knudsen. 2014. *Displaced Left Turn Informational Guide*. Report FHWA-SA-14-068. FHWA, Washington, DC.
2. Hughes, W. and R. Jagannathan. October 2009. "Displaced Left Turn Intersection" TechBrief FHWA-HRT-09-055. FHWA, Washington, DC.
3. Zlatkovic, M., and C. Kergaye. 2018. "Development of Crash Modification Factors for Continuous Flow Intersections." *Journal of Road and Traffic Engineering*. Vol 64, No 3, pp. 5-11.
4. Chlewicki, G. 2014. "Using the Concept of the Continuous Flow Intersection to Improve Pedestrian Movements at Intersections." Presented at Transportation Research Board Alternative Intersection and Interchange Symposium. Salt Lake City, UT.

CHAPTER 9

# Diverging Diamond Interchanges (DDIs)

## 9.1 Introduction

The diverging diamond interchange (DDI) is an alternative to the conventional diamond interchange or other alternative interchange forms. The primary difference between a DDI and a conventional diamond interchange is the design of directional crossovers on either side of the interchange. This eliminates the need for left-turning vehicles to cross the paths of approaching through vehicles. By shifting cross-street traffic to the left side of the street between the signalized crossover intersections, vehicles on the crossroad making a left-turn onto freeway on-ramps or from freeway off-ramps no longer conflict with opposing through vehicles.

The DDI design reduces the number of vehicle-to-vehicle conflict points. It has been shown to improve the operations of turning movements to and from the freeway facility and to reduce the number of vehicle-to-vehicle crashes compared to a conventional diamond interchange by 24% to 45% (*1, 2, 3, 4, 5*). The DDI also reduces the severity of such crashes, because conflicts between left-turning movements and the opposing through movement are eliminated. However, no quantitative factors have been developed for pedestrian- or bicycle-related safety.

Exhibit 9-1 provides an example of a DDI and highlights the key features of this interchange design (*1*).

The street segment between the crossovers can be designed as an underpass or overpass, depending on the site characteristics. The interchange design will be directly affected by whether the arterial passes over or under the limited access facility. The majority of DDIs evaluated have reconstructed existing diamond interchanges, and the decision to go over or under the limited access facility had already been determined.

Pedestrian movements at DDIs can either be on the inside of (between) travel lanes or the outside (perimeter), with crossings being signalized or uncontrolled. Bicycle movements traditionally have been accommodated with shared use of the travel lane or through a shared-use path facility, but DDI design features can pose safety challenges for nonmotorized modes and need to be evaluated carefully as part of the design process.

This chapter conveys the geometric, operations, and safety considerations, as well as design flags, specific to a DDI design. In light of these characteristics, this chapter also provides techniques and treatments at a DDI to help meet the design objectives presented in this guide: maximizing safety, providing access and accessibility, managing delay and travel time, and providing reasonable comfort.

## 9.2 Multimodal Operations

This section discusses the operational considerations at a DDI with relevance to the pedestrian and bicyclist experience, so the reader can understand tradeoffs associated with design decisions.

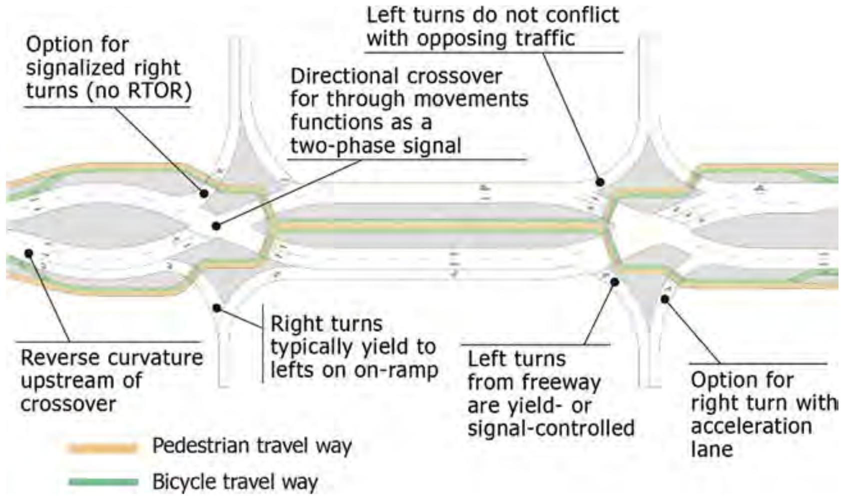


***Exhibit 9-1. Key characteristics of a DDI.***

### 9.2.1 Motor Vehicles

DDIs generally have a reduced number of signal phases relative to conventional diamond interchanges and provide greater vehicular capacity and throughput. The following general design features are commonplace at existing DDIs:

- Two-phase signals that reduce lost time at the interchange, allowing for shorter cycle lengths and increasing capacity relative to conventional diamond interchanges;
- Free-flowing left-turns (and right-turns) onto the freeway (on-ramps);
- Ability to coordinate through traffic or left-turns from the freeway; and
- Comparatively high capacity for the off-ramp movements from the freeway (particularly if right and left-turns on red are allowed).

The free-flowing on-ramps and permitted right and left-turns on red are design features common among existing designs that support improved vehicular capacity but are in tension with maximizing pedestrian and bicyclist safety, depending on the facility locations and design (the free-flowing left-turn does not conflict with inside crossings; see Section 9.2.2.1). The performance objectives for the intersection will help to decide which characteristics are part of a proposed design. These elements should be determined in Stage 2 of an ICE process. If a DDI's vehicular operational performance is tied to free-flowing turn movements that raise flags for pedestrian safety, resulting in the need for movements to be controlled, its selection as an alternative may not be realistic.

Because mainline through movements conflict at DDI crossovers, a decreased green time may be experienced by pedestrians and bicyclists traveling along the mainline. Shorter cycle lengths and geometric considerations can mitigate some delays.

### 9.2.2 Pedestrians

Pedestrian facilities at interchanges can be challenging due to high vehicular volumes and a focus on providing unimpeded capacity to vehicular flow. Nonetheless, interchanges can be safe and comfortable for pedestrians if the designer applies intersection-level design concepts that slow traffic flow, provide proper lines of sight for pedestrians and drivers, and manage conflict points to maximize pedestrian safety.

For pedestrians, the DDI allows for reduced signal phasing (shorter cycle lengths), channelization of movements (crossing of one direction of travel at a time), signalization, and right-of-way availability for pedestrian facilities. The DDI requires additional stages for pedestrian crossings, which can result in additional stops and delays (*6*). Several special considerations apply to the DDI, which are summarized below.

### *9.2.2.1 Inner Versus Outer Walkway*

A major consideration for pedestrian facilities at a DDI is whether to provide inner or outer walkways. Several design decisions flow from this choice. For an overpass DDI, pedestrian facilities in the center of the interchange (within the median) may be preferable so as to minimize conflicts with left-turning traffic to and from the freeway and allow crossing the interchange in all directions (i.e., travel along the arterial and crossing the arterial from one side to the other). For underpass DDIs, the inner versus outer options may not be a choice, depending on the placement of bridge columns.

Exhibits 9-2 and 9-3 give examples of a pedestrian facility in the center of a DDI, and of an outside pedestrian walkway, respectively. The exhibits further highlight which crossings are constrained in time by signal phasing, as well as which may not be. For pedestrian crossings without signals, geometric design or enhanced crossing treatment options may be incorporated to enhance pedestrian safety (discussed in Section 6.3.1).

With the overpass DDI having inner walkways, pedestrian facilities to cross into the center can be co-located with these vehicle signals at crossover movements, and a pedestrian crossing phase can be provided with the concurrent vehicle phase. The right-turns may be unsignalized

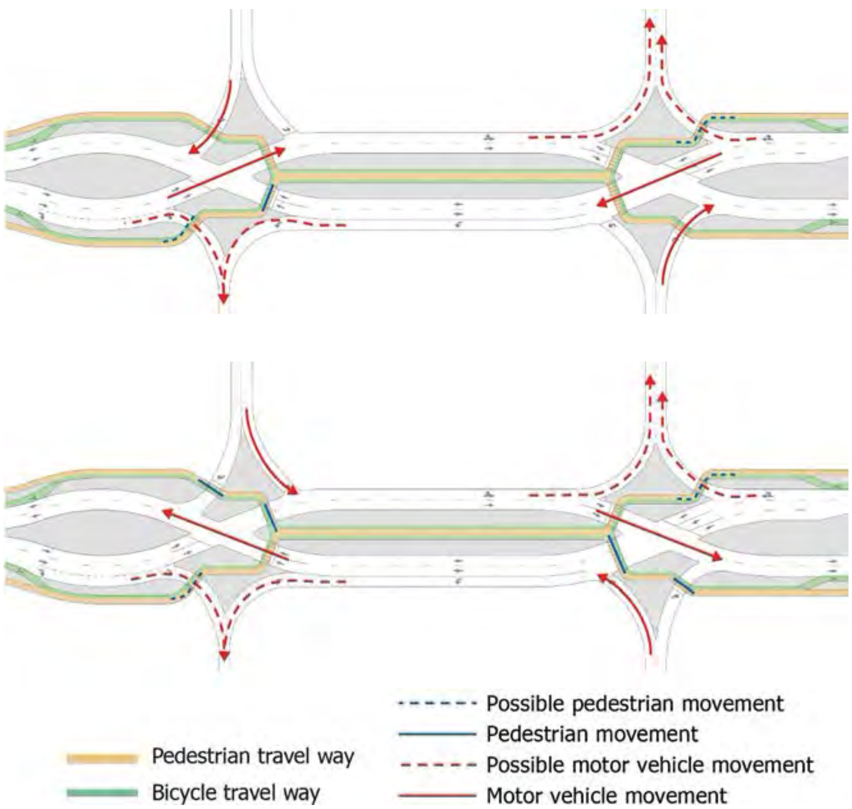


***Exhibit 9-2. Pedestrian movements given an inner walkway at a DDI. The top figure shows movements which run in the first phase. The bottom figure shows movements which run in the second phase.***

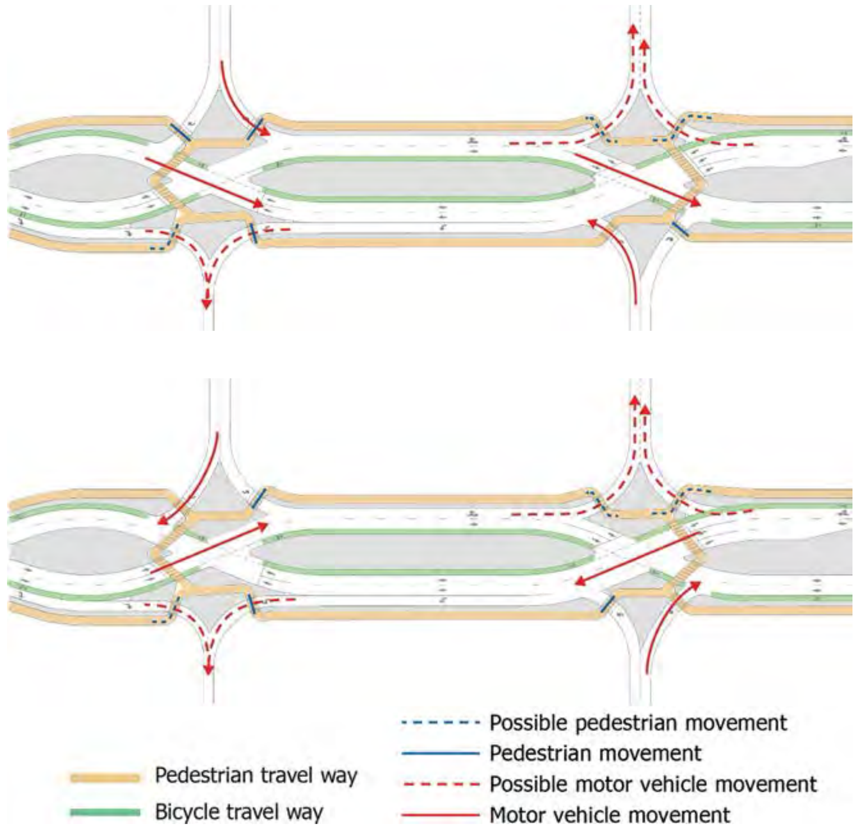


***Exhibit 9-3. Pedestrian facilities on the outside of DDI. The top figure shows movements that run in the first phase. The bottom figure shows movements that run in the second phase.***

or signalized crossings and, in either case, can be configured to promote low vehicle speeds and good sight distance to the crosswalks.

With outside walkways at DDIs, traversing pedestrians may cross four separate vehicle turning movements (the ramps). These may be free-flowing or controlled. In some existing DDIs with outer walkways, no pedestrian crossing of the arterial street is provided. This limits pedestrian access. As presented in Chapter 1, unless the intention is to restrict access for the life of the project, crossing opportunities should be provided. Otherwise, pedestrians will likely pursue their desired lines, often at considerable risk.

The advantages and challenges of inside and outside pedestrian facilities are summarized in Exhibits 9-4 and 9-5, respectively.

#### *9.2.2.2 Pedestrian Phase Coordination*

With an inner walkway between the crossovers, the designer can time pedestrian crossings to match crossing behavior. Because the right-turn onto a freeway on-ramp does not require coordination with any other phase at the DDI, the signal timing can progress the pedestrian movement across the right-turn on-ramp and then across the crossover movement, or vice versa.

The geometry of the freeway off-ramps affects pedestrian crossing delay, as well. Where an inner walkway is provided, the right-turn off-ramp and adjacent crossover crossing can operate concurrently (Exhibit 9-6). Depending on the distance between crossings and the phase length, a pedestrian may cross both movements in a single signal phase. A design that keeps these crossings close would promote that sequential crossing (*7*).

**Exhibit 9-4. Inner walkway pedestrian safety and comfort.**

| | Advantages | Challenges |
|---|---|---|
| **Street Crossings** | • Crossing of the arterial street naturally provided at DDI for full pedestrian access<br>• Crossing one direction of traffic at a time<br>• No exposure to left-turns to the freeway (typically free-flowing)<br>• Protected signalized crossing to the walkway<br>• Pedestrian clearance time generally provided in crossover signal phasing<br>• Pedestrian delay to center minimized by short cycles at two-phase signals | • The possible crossing of free-flow right-turn movements to/from the freeway<br>• Pedestrians may not know to look to the right when crossing from center<br>• Wait at center island dictated by the length of signal phase for through traffic<br>• Pedestrian signals can conflict with vehicle signals at crossovers<br>• Out-of-direction travel for pedestrians not desiring to cross the arterial |
| **Walkway Facility** | • Side walls provide a positive barrier between vehicular movements and pedestrians. (Walls low enough to avoid the “tunnel” effect could have a lesser impact on pedestrian comfort.)<br>• Need for only one facility inside the intersection footprint (inner walkway) can offer more enhanced features within the same right-of-way constraints. | • Design of side walls must be managed to avoid impeding sight distance<br>• Potential discomfort from moving vehicles on both sides of the walkway<br>• Potential challenge placing all necessary signs and signal control equipment while maintaining full pedestrian access |

**Exhibit 9-5. Outside path/sidewalk pedestrian safety and comfort.**

| | Advantages | Challenges |
|---|---|---|
| **Street Crossings** | • Crossing one direction of traffic at a time<br>• Ramp crossing distances are often shorter than through traffic crossing distances due to fewer travel lanes | • Crossing of free-flowing right-turn movements to/from the freeway<br>• Conflict with left-turns to the freeway (typically free-flowing), where high vehicle speeds are likely (acceleration to the freeway)<br>• Potential sight obstruction of pedestrian crossing left-turns from behind any structures<br>• Pedestrians may not know which direction to look when crossing turn lanes<br>• Unintuitive traffic directions to check when crossing out of the crossover<br>• Providing signalized crossings requires more complicated timing and potential safety risks associated with motor vehicle queuing |
| **Walkway Facility** | • Extension of the existing pedestrian network (natural placement on outside of lanes)<br>• Pedestrian typically has a view of the path ahead (depends on sightlines and obstructions)<br>• The walkway does not conflict with center bridge piers (at underpass)<br>• Opportunity to use right-of-way outside of bridge piers (at underpass)<br>• Does not create a potential tunnel effect that could make pedestrians feel “trapped” | • Need for widened structure on the outside for overpass<br>• Potential for additional right-of-way for underpass or construction of retaining wall under the bridge<br>• Need for additional lighting for the underpass |

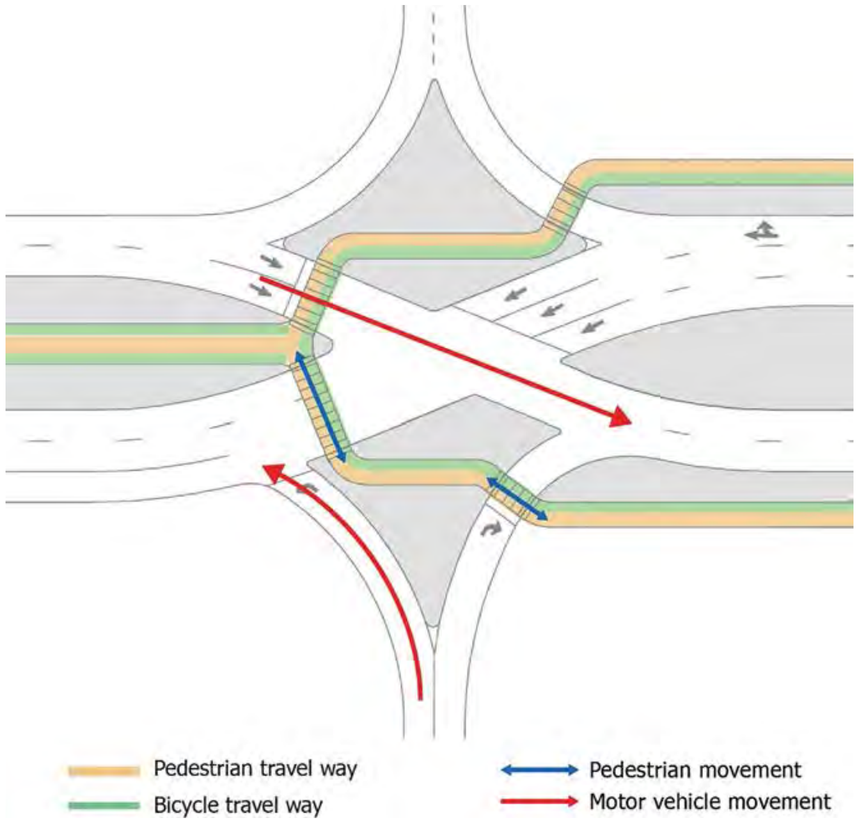


***Exhibit 9-6. Back-to-back off-ramp crossings during the same signal phase.***

Where an outer walkway is provided, the right-turn and left-turn off-ramp movements will not run concurrently (Exhibit 9-3). Thus, the distance of these crossings from one another is of less importance for pedestrian progression: pedestrians either walk slightly farther or are likely waiting for the signal phase to change (*6*).

#### *9.2.2.3 Left-Turn at Exit Ramp*

When pedestrian facilities are provided on the outside, signalization is a preferable control strategy for exit ramp left-turns because it provides a controlled crossing opportunity. For DDIs with inner walkways, and thus no pedestrian crossings at the left-turn exit ramp (see Exhibit 9-6), refer to the MUTCD for general guidance on choosing traffic control devices.

### 9.2.3 Bicycles

Three basic options exist for accommodating bicyclists at a DDI. These options are to provide the following:

- A marked bicycle lane through the DDI;
- A separated bicycle path or shared-use path; or
- Shared use of the travel lane.

One or more of these options may be viable for a project and would be determined in a Stage 1 ICE process (see Chapter 4). In all cases, the signal timing should accommodate a cyclist through all movements and phases and provide adequate time for bicyclists to clear the intersection before releasing conflicting traffic.

***Exhibit 9-7. Outer shared-use path at DDI in Lexington, Kentucky. Source: Google.***

### *9.2.3.1 Bicycle Lane Guidance*

Bicycle lanes at a DDI provide bicyclists with dedicated road space to travel across the interchange. Bicycle lanes should be located to the right of the travel lanes for motorized traffic, which is generally where bicyclists and motorists expect bicyclists to travel. Separated bicycle lanes are recommended where actual vehicle speeds exceed 35 mph or in high-volume situations, as explained in Chapter 3. Consistent with the guidance in Chapter 5, a wider bike shy distance is critical where the facility is next to a barrier.

The bicycle lane should continue through the off-ramps from the freeway where motorized traffic would generally be required to yield to arterial traffic, including cyclists (see Exhibit 9-16). Where bicycle lanes cross exit ramps, using colored pavement may increase bicyclist visibility to motorists.

When bicycle lanes are provided, it is generally preferred to locate them to the right of motorized vehicle traffic, consistent with generally expected bicyclist behavior. At a DDI with a center barrier wall adjacent to a bicycle lane, the lane should provide adequate width to avoid cyclists feeling "trapped." Exhibit 9-16 provides an example of bicycle lanes at a DDI.

### *9.2.3.2 Separated Bicycle Facilities*

An alternative to providing bicycle lanes through a DDI is to provide separated facilities. Where an inner path is possible, the "inner walkway" may instead be an inner shared-use path. Exhibits 9-14 and 9-18 provide examples of this design option. Bicyclists crossing at the signalized intersections would either share a crossing with pedestrians or cross in adjacent crossings; the progression concerns would be largely the same as those for pedestrians (discussed in Section 9.2.2.2).

If separated facilities are not provided on the approach to the DDI, a ramp can transition bicyclists from the roadway to the separated path. This can be accomplished in advance or with the development of vehicle right-turns to avoid a conflict. (This would be the turning motorists crossing bicycle path conflict, discussed in Section 4.4.18).

A shared-use path option can be provided as part of an outer path option, as depicted in Exhibit 9-7.

## 9.3 Safety and Comfort

Research has documented vehicular safety benefits for DDIs. The reduction in vehicular crashes relative to a traditional diamond interchange is attributable to the separation of conflict points and eliminating high-risk and high-severity crash patterns (e.g., angle crashes between left-turn and opposing through movements). For pedestrian and bicyclist safety, insufficient data are available to draw any conclusions regarding the crash performance of DDIs. Absent quantitative crash data, an investigation of conflict points provides insight into the expected safety of DDIs.

### 9.3.1 Conflict Points

A pedestrian-vehicle conflict point exists anywhere pedestrian walkways and vehicular travel lanes cross, and a bicycle-vehicle conflict point exists anywhere bicyclist paths and vehicular travel lanes cross. The pedestrian-vehicle conflict points for inside crossing DDIs and outside crossing DDIs are illustrated in Exhibits 9-8 and 9-9.

The key conflict points are denoted by asterisks (the freeway on-ramps). These conflict points may be accelerating conflict points and may be controlled or uncontrolled conflict points, depending on the design of the intersection.

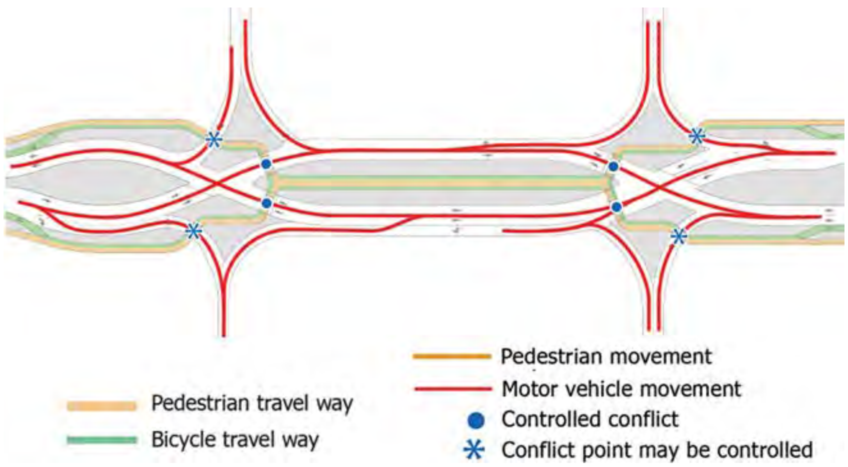


***Exhibit 9-8. Pedestrian-vehicle conflict point diagram for a DDI with an inside walkway.***

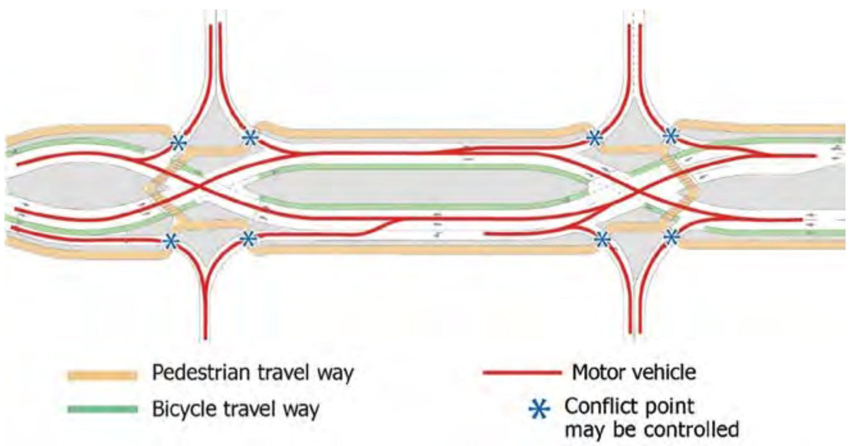


***Exhibit 9-9. Pedestrian-vehicle conflict point diagram for a DDI with an outside walkway.***

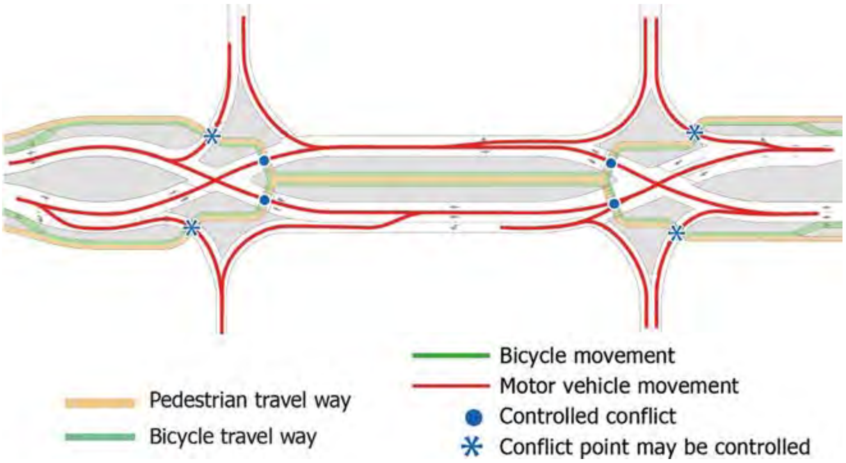


***Exhibit 9-10. Bicycle-vehicle conflict point diagram for a DDI with an inside bicycle path.***

Bicycle-vehicle conflict points for an inside bicycle path are presented in Exhibit 9-10. The asterisks represent conflict points that may be along accelerating vehicle paths, subject to the design of the intersection.

## 9.3.2 Pedestrians–Key Safety Challenges

The conflict points diagrams present a reduced number of conflict points for pedestrians at a DDI relative to a conventional intersection or interchange. Design factors inherent to a DDI that should be flagged in Stage 2 of the ICE process as the design is developed are as follows:

- A DDI often entails crossing traffic approaching from a potentially counterintuitive direction, which brings wayfinding challenges and risks for pedestrians. Although each crossing conflicts with only a single direction of vehicle traffic, pedestrians may not intuitively know in which direction to look for vehicles.
- The capacity benefits provided by free-flowing entrance ramps at a DDI degrade the crossing environment for pedestrians and bicyclists on separated paths. These crossings can be improved by ensuring geometry manages motor vehicle speeds and that sufficient sight distance is provided. Whether to control these vehicle movements should be weighed as part of Stage 2 of the ICE process.
- Assuming the left-turn entry ramp is unobstructed, the *right-turn entry ramp* has typically taken one of two basic designs: yield control with no acceleration lane or free turn with acceleration lane (see Exhibit 9-11). The acceleration, if provided, would allow motorists to achieve merge speeds *after* the pedestrian crossing.
  – **Yield control with no acceleration lane.** This choice of traffic control has often been made in consideration of conflicting traffic volumes, the downstream merge point onto the limited access facility, and right-of-way. It is most often used where low to moderate turning movements are present for the left- or right-turn. The left- and right-turn lane can be shared or exclusive. With the yield control option, the sight distance and the curve are important to encourage crossing pedestrians to yield, and the crossing point and vehicle yield point are separated in space to separate the decision points.
  – **Free turn with acceleration lane.** This form of traffic control is typically preferred if entry ramp volumes are high for turning movements or if queues from turning traffic spill back

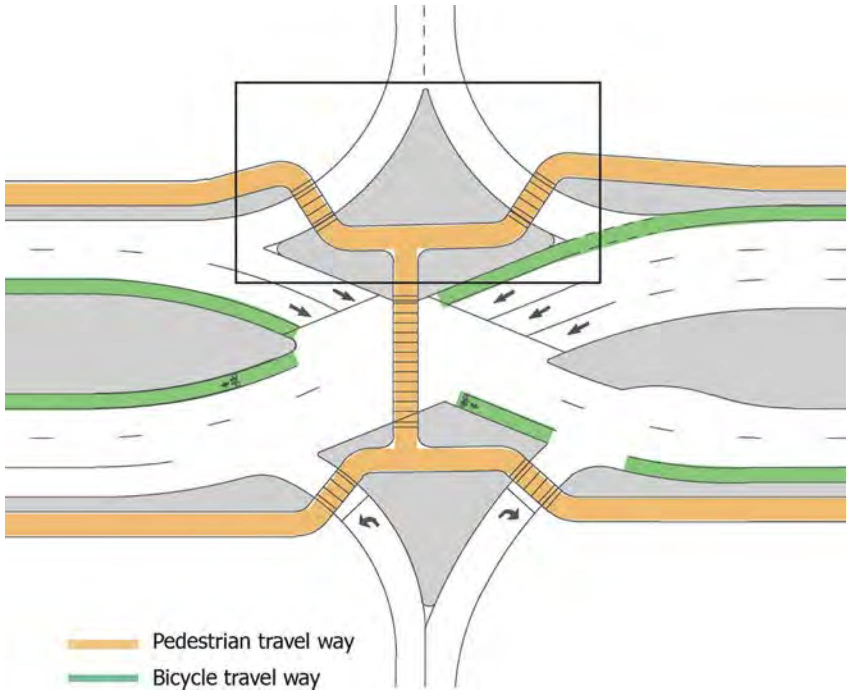


***Exhibit 9-11. Entry ramp free right and left-turns with acceleration lanes.***

to an arterial through lane. The downstream merge point onto the limited access facility would be designed no differently than other interchange designs. The left and right-turn lane can be shared or exclusive.

Both movements can be signalized, especially if an appropriate curve radius (intended to lower vehicular speeds) is difficult to obtain in design. Any potential queuing from signal control of these movements should be accounted for as part of the iterative design process in Stage 2 of an ICE process.

Exhibit 9-12 presents the design flags applicable to pedestrians, along with the location of their discussion and applicable treatments (design flags and treatments whose discussion applies across alternative intersection types are in Chapter 4).

### 9.3.3 Bicycles–Key Safety Challenges

Bicyclists at DDIs face challenges that either create safety risks or stress for riding through the intersection. Key challenges are as follows:

- **Provision of space.** The existing bicycle facilities at DDIs have consisted of traditional bike lanes to the right of motor vehicles, passing through the crossover and back. Recall that in Chapter 3 a design principle for bicyclists was to provide a relatively straight line of travel for bicyclists through an intersection (or at least to avoid abrupt turns). Given the speed difference between motorists and bicyclists through DDIs and the crossover section, as well as the curvature throughout the entire intersection, a bike lane width or buffer larger than the typical size would improve bicyclist safety and comfort. Separated facilities would address this issue.
- **On-ramp movements.** If free-flow movements are provided for motorists to access freeway on-ramps, then an uncontrolled diverging conflict point is introduced between bicyclists and motorists (essentially a “right hook” opportunity). This is closely related to safety

**Exhibit 9-12. Design flags applicable to pedestrians at DDIs.**

| Design Flag | Description | Mode / Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | This flag would apply if right-turn-on-red were permitted. | Pedestrians, all crossings |
| Uncomfortable/Tight Walking Environment (Section 4.4.2) | Pre-existing bridges, abutments, and piers may constrain the total facility width between the crossovers. | Pedestrians, all crossings |
| Nonintuitive Motor Vehicle Movements (Section 4.4.3) | Pedestrians crossing on the outside would confront consecutive crossings with vehicle traffic arriving from the same direction. | Pedestrians, outside crossing |
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | Movements to and from on- and off-ramps may be yield-controlled and therefore create additional stress and safety concerns for pedestrians. | Pedestrians, all crossings |
| Indirect Paths (Section 4.4.5) | Outside crossing designs should still allow for the pedestrian crossing of the mainline. | Pedestrians, outside crossings |
| Executing Unusual Movements (Section 4.4.6) | In most local contexts, pedestrians do not expect to cross into the mainline median to continue moving along the mainline road. | Pedestrians, inner crossing |
| Multilane Crossings (Section 4.4.7) | Depending on the lane configuration, pedestrians may cross multiple lanes either when crossing an on- or off-ramp or when crossing into the median. | Pedestrians, all crossings |
| Motor Vehicle Left-Turns (Section 4.4.10) | This flag would apply if left-turn-on-red were permitted. | Pedestrians, outside crossings |
| Sight distance for gap acceptance movements (Section 4.4.12) | At yield-controlled movements, vertical and horizontal alignments should allow for proper sight distance to pedestrian crossings. | Pedestrians, all crossings |
| Grade Change (Section 4.4.13) | Vertical curves on bridges may create challenges for pedestrians with mobility challenges or those carrying or pushing objects. | Pedestrians, all crossings |

concerns with the channelized turn-lane design and should be treated as such for bicyclists in the design flag assessment.

- **Bicycle clearance time.** An approaching bicyclist must judge if there is enough time to clear the intersection before a phase change. Usually, there are two options for cyclists to assist in this decision:
  1. If a pedestrian signal is present with a countdown, the bicyclist may get a better idea of when a signal phase is about to transition. This is *not* the design intent of countdown timers, but they may be useful to the bicyclists. The decision to cross may lead to a bicyclist still being in the intersection when the phase changes.
  2. At many signals, a bicyclist can only rely on the yellow clearance phase for vehicular traffic. This yellow clearance phase is designed just for drivers and rarely exceeds 5 seconds. This clearance time is usually too short for cyclists to clear the intersections. The disparity is exacerbated as clearance lengths increase.

When signal heads are placed at the entrance to the intersection, bicyclists have no indication of whether the signal phase has changed once they have passed the signal heads.

In consideration of the bicyclist conflict points at DDIs and the key safety challenges that accompany them, Exhibit 9-13 presents the design flags applicable to bicyclists, along with

**Exhibit 9-13. Design flags applicable to bicyclists at DDIs.**

| Design Flag | Description | Mode / Travel Path |
|---|---|---|
| Executing Unusual Movements (Section 4.4.6) | Similar to motor vehicles, bicyclists do not expect to cross to the left side of the road when crossing the DDI. | Bicyclists, all movements |
| Multilane Crossings (Section 4.4.7) | Large DDIs may tempt bicycles to cross many lanes at the crossover. | Bicyclists, all movements |
| Undefined Crossings at Intersections (Section 4.4.9) | Although not unique to DDIs, a lack of bicycle markings crossing ramp merge or diverge points may result in vehicles impeding on the bicycle lane. | Bicyclists, all movements |
| Grade Change (Section 4.4.13) | Vertical curves on bridges may create challenges for bicycles trying to maintain speed, resulting in a large speed differential with vehicles. | Bicyclists, all movements |
| Riding in Mixed Traffic (Section 4.4.14) | Although not unique to DDIs, vehicle speeds near interchanges may be significant, especially if curves have large design radii. | Bicyclists, all movements |
| Bicycle Clearance Time (Section 4.4.15) | Long distances between the crossover and right-turn off-ramp movement may result in conflict between bicyclists and right-turning vehicles. | Bicyclists, all movements |
| Turning Motorists Crossing Bicycle Paths (Section 4.4.18) | A high volume of turns onto the on-ramp may exacerbate vehicle-bicycle conflicts. | Bicyclists, all movements |
| Riding between Travel Lanes, Lane Additions, or Lane Merges (Section 4.4.19) | Off-ramp designs with lane additions or downstream merges create additional stress and safety concerns for bicyclists traveling along the mainline. | Bicyclists, all movements |
| Off-Tracking Trucks in Multilane Curves (Section 4.4.20) | Trucks moving through the crossover intersections may off-track into adjacent bicycle lanes. | Bicyclists, all movements |

the location of their discussion and applicable treatments (design flags and treatments whose discussion applies across alternative intersection types are in Chapter 4).

## 9.4 DDI Level Concepts

The three design concepts in this section were developed to present techniques for improving pedestrian and bicyclist safety and operational performance of DDIs. These concepts are *not* suggested as designs to be replicated as is; rather, they illustrate the DDI options possible in various contexts. These concepts mix design approaches. The designer must consider traffic volume and speed when matching designs and treatments to the appropriate context (discussion in Chapter 3, Section 3.3.2).

Following each concept is a discussion of the flags remaining with the design—the flags not obviated by the design that would still need to be addressed.

The designs are as follows:

- DDI Shared-Use Path/Inner Walkway Concept
- DDI On-Street Bike Lane/Outer Walkway Concept
- DDI Separated Bike Lane/Inner Walkway Concept

Section 9.3 presented other key design flags that would be subject to site-specific concerns and are not obviously presented or addressed with the concepts presented below.

### 9.4.1 DDI Shared-Use Path/Inner Walkway Concept

The first DDI concept, shown in Exhibit 9-14, includes a shared-use path inside the median. Bicycle access to the shared-use path is provided upstream of the DDI with bicycle ramps. Downstream of the DDI, ramps return bicyclists to the roadway. The concept would be appropriate for intersections where heavy vehicle movement through the crossover may result in truck off-tracking through the crossovers. The inside shared-use path allows for free-flowing left-turns onto the freeway without pedestrian or bicycle conflicts.

#### *9.4.1.1 Benefits*

This design addresses these key elements regarding safety and comfort:

- **Nonintuitive Motor Vehicle Movements design flag:** By providing an inner walkway, pedestrians cross motor vehicle movements in an alternating fashion. At the first crossing, vehicles arrive from the left, and at the next crossing, vehicles arrive from the right, and so on. This conforms to the typical expectation.

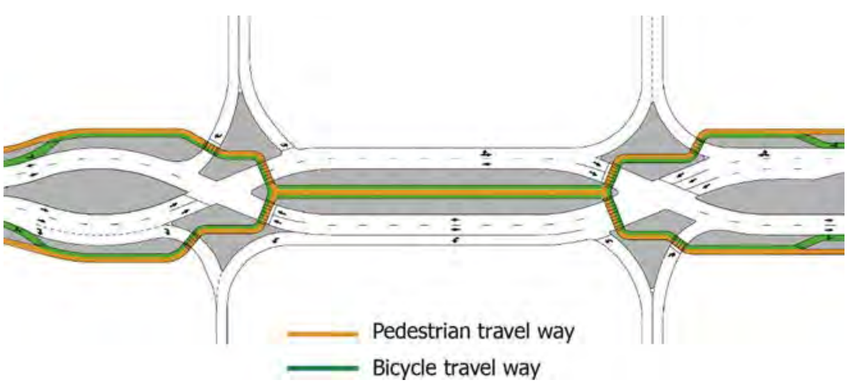


***Exhibit 9-14. DDI shared-use path/inner walkway design concept.***

- **Indirect Path design flag:** Pedestrians and bicyclists can cross the mainline by proceeding from one side of the roadway, onto the center island, and then to the opposing side of the roadway. This avoids the need for pedestrians to travel to an adjacent intersection to cross the mainline. This flag may still apply for other movements as described below.
- **Undefined Crossings at Intersections design flag:** All locations where pedestrians and bicyclists cross motor vehicles are marked. This will reduce the likelihood that vehicles will encroach on the crossing areas when stopped for a signal.
- **Motor Vehicle Left-Turns design flag:** The inner walkway design removes pedestrians from crossing the left-turn at the off-ramp.
- **Riding in Mixed Traffic design flag:** This design features a bike ramp off the roadway and onto the shared-use path. Bicyclists are provided a less stressful and safer path through the interchange.
- **Bicycle Clearance Time design flag:** By removing bicyclists from the roadway, the bicyclists no longer must travel between the crossover intersection and the right-turn from the off-ramp. This eliminates the need for additional clearance time for bicyclists to cover this distance.
- **Turning Motorists Crossing Bicycle Path design flag:** The bicycle ramp to the shared-use path is placed upstream of the development of the right-turn lane onto the on-ramp. This eliminates the conflict of motorists crossing the bicycle path.
- **Off-Tracking Trucks in Multilane Curves design flag:** Heavy vehicles may experience challenges maintaining their lane when traveling through the crossover intersections. By providing an off-street shared-use path for bicyclists, the users are separated in space, avoiding the potential conflict.

#### *9.4.1.2 Challenges*

Emphasizing again that the design is not intended to be "ready-made," this concept leaves several design flags as described in Exhibit 9-15.

### 9.4.2 DDI On-Street Bike Lane/Outer Walkway Concept

The next DDI concept, shown in Exhibit 9-16, features an outer walkway for pedestrians and on-street bicycle lanes. This concept could be implemented where bridge piers or other objects in the median make an inner walkway difficult, or where local preference is to remain on the outside of the interchange. As on-street bicycle lanes are present, the design is best suited where geometric elements create a low-speed environment.

#### *9.4.2.1 Benefits*

This design addresses these key elements regarding safety and comfort:

- **Indirect Path design flag:** Pedestrians can cross the mainline by proceeding from one side of the roadway, onto the center island, and then to the opposing side of the roadway. This avoids the need for pedestrians to travel to an adjacent intersection to cross the mainline.
- **Executing Unusual Movements design flag:** By providing an outer walkway, pedestrians wanting to continue along the mainline can do so without crossing any mainline movement. This flag still applies to bicyclists (see challenges below).
- **Undefined Crossings at Intersections design flag:** All locations where pedestrians and bicyclists cross motor vehicles are marked. This will reduce the likelihood that vehicles will encroach on the crossing areas when stopped for a signal.

#### *9.4.2.2 Challenges*

Emphasizing again that the design is not intended to be "ready-made," this concept leaves several design flags as described in Exhibit 9-17.

**Exhibit 9-15. Summary of design flags remaining with DDI shared-use path/inner walkway design concept.**

| Design Flag | Description | Mode / Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | DDIs tend to have high volumes of turns to and from the freeway. This design still requires pedestrians to cross the right-turn from the off-ramp. This flag can be mitigated by prohibiting right-turn-on-red or by designing the curve radii to keep speeds from exceeding 25 mph. Further, the pedestrian yield point and the merge point should be separated in space. | Pedestrians, all crossings |
| Uncomfortable/Tight Walking Environment (Section 4.4.2) | The careful design of the median walkway is necessary as the design progresses to ensure it provides adequate space for all users. | Pedestrians, center median crossing |
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | This design has a yield-controlled right-turn onto the on-ramp. Given the expected high volume of turns onto the on-ramp, the curve radii should be designed to keep vehicle speeds from exceeding 25 mph. This will mitigate the flag by increasing the likelihood of vehicles yielding to pedestrians. | Pedestrians and Bicyclists, all crossings |
| Indirect Path (Section 4.4.5) | Users wanting to continue along the mainline may experience enough out-of-direction travel crossing to the median and back that the indirect path flag would apply. | Pedestrians and Bicyclists, inner median crossing |
| Executing Unusual Movements (Section 4.4.6) | In most areas, DDIs are a relatively novel design. Users wanting to continue along the mainline likely do not expect to need to cross one direction of mainline traffic. Proper wayfinding design will be especially important for all users to understand how to execute their desired path. | Pedestrian and Bicyclists, inner crossing |
| Multilane Crossings (Section 4.4.7) | At the crossovers of this design, pedestrians must cross multiple lanes without refuge (the yellow flag threshold for pedestrians is 2-3 lanes). | Pedestrians, all crossings |
| Sight Distance for Gap Acceptance Movements (Section 4.4.12) | The motor vehicle right-turns to the on-ramp are yield-controlled and therefore require careful attention to sight distance requirements. In this design, the position of the crosswalk upstream of the center of the curve would likely provide adequate sight distance. | Pedestrians and Bicyclists, all crossings |
| Grade Change (Section 4.4.13) | While not able to be evaluated from the plan view provided, interchanges can experience grade changes. This should be evaluated during the flag assessment process. | Pedestrians and Bicyclists, inner median crossing |

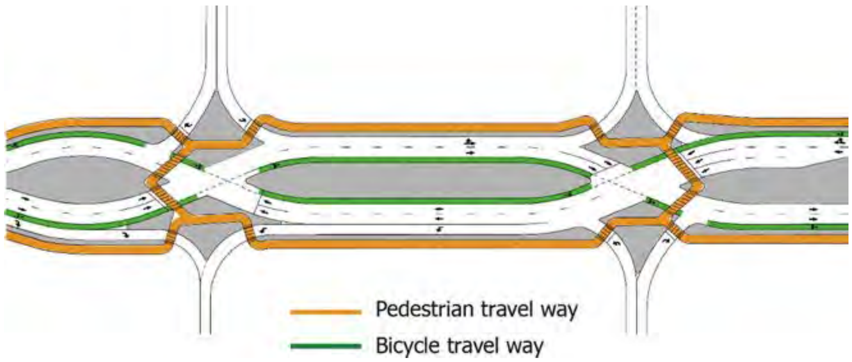


***Exhibit 9-16. DDI on-street bike lane/outer walkway design concept.***

**Exhibit 9-17. Summary of design flags remaining with DDI on-street bike lane/outer walkway design concept.**

| Design Flag | Description | Mode/Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | DDIs tend to have high volumes of turns to and from the freeway. This design still requires pedestrians to cross the right-turn from the off-ramp. This flag can be mitigated by prohibiting right-turn-on-red or by designing the curve radii to keep speeds from exceeding 25 mph. | Pedestrians, all crossings |
| Nonintuitive Motor Vehicle Movements (Section 4.4.3) | Shared-use path users following the outside walkway will encounter motor vehicles approaching from the same direction twice in a row. This deviates from the typical expectation of encountering vehicles from alternating directions. | Pedestrians, outside crossing |
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | This design has a yield-controlled right-turn onto the on-ramp. Given the expected high volume of turns onto the on-ramp, the curve radii should be designed to keep vehicle speeds from exceeding 25 mph. This will mitigate the flag by increasing the likelihood of vehicles yielding to pedestrians. | Pedestrians, all crossings |
| Executing Unusual Movements (Section 4.4.6) | In most areas, DDIs are a relatively novel design. Users wanting to continue along the mainline likely do not expect to need to cross one direction of mainline traffic. Proper wayfinding design will be especially important for all users to understand how to execute their desired path. | Bicyclists, all movements |
| Multilane Crossings (Section 4.4.7) | At the crossovers of this design, pedestrians must cross multiple lanes without refuge (the yellow flag threshold for pedestrians is 2-3 lanes). | Pedestrians, crossover crossing |

**Exhibit 9-17. *(Continued).***

| Design Flag | Description | Mode/Travel Path |
|---|---|---|
| Sight Distance for Gap Acceptance Movements (Section 4.4.12) | The motor vehicle right- and left-turns to the on-ramp are yield-controlled and therefore require careful attention to sight distance requirements. In this design, the position of the crosswalk upstream of the center of the curve would likely provide adequate sight distance. | Pedestrians and Bicyclists, all crossings |
| Grade Change (Section 4.4.13) | While not able to be evaluated from the plan view provided, interchanges can experience grade changes. This should be evaluated during the flag assessment process. | Pedestrians and Bicyclists, inner median crossing |
| Riding in Mixed Traffic (Section 4.4.14) | Given the expected high volume of vehicles on an interchange, this flag must be mitigated through vehicle speed control. The geometric design should be used to reduce speeds below 25 mph (yellow flag threshold). | Bicyclists, all movements |
| Bicycle Clearance Time (Section 4.4.15) | Bicyclists need sufficient time to travel through the crossover and continue through the right-turn from the off-ramp. Without signal timing details, it is not possible to determine the applicability of this flag to the design. | Bicyclists, all movements |
| Turning Motorists Crossing Bicycle Path (Section 4.4.18) | Vehicles turning right to the on-ramp must cross the bicycle lane resulting in a conflict. | Bicyclists, all movements |
| Riding between Travel Lanes, Lane Additions, or Lane Merges (Section 4.4.19) | Adding the right-turn pocket onto the on-ramp results in bicyclists riding between the through and right-turn lanes for an extended period. | Bicyclists, all movements |
| Off-Tracking Trucks in Multilane Curves (Section 4.4.20) | Bicycles moving through the crossover may be impeded by heavy vehicles off-tracking. Careful design of lane widths and curve radii may mitigate this issue. | Bicyclists, all movements |

## 9.4.3 DDI Separated Bike Lane/Inner Walkway Concept

The final DDI concept, shown in Exhibit 9-18, provides a separated bike lane through the intersection within the median between the crossovers as well as an inner walkway for pedestrians. The pedestrian walkway inside the separated bike lanes provides additional separation for pedestrians from motor vehicles while moving through the median. For less confident bicyclists, the separation from both pedestrians and motor vehicles reduces stress.

### *9.4.3.1 Benefits*

This design addresses these key elements regarding safety and comfort:

- **Uncomfortable/Tight Walking Environment design flag:** This design provides an exclusive path for pedestrians separate from both bicyclists and motor vehicles. By placing motor

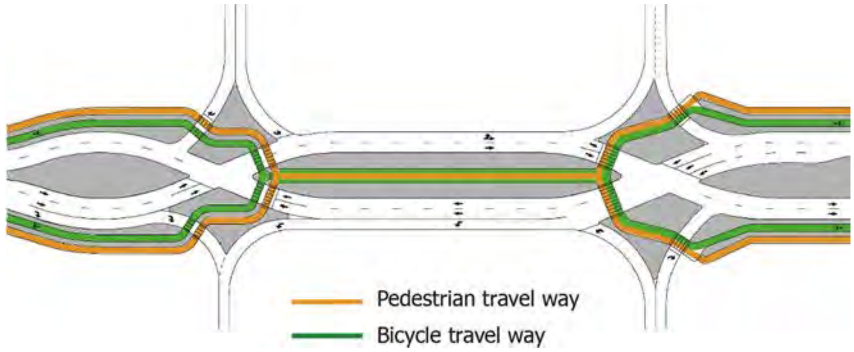


***Exhibit 9-18. DDI separated bike lane/inner walkway design concept.***

vehicles on either side of pedestrians in the inner walkway, pedestrians are further removed from motor vehicles. Care should be taken in the design to ensure proper space is provided for pedestrians to move past each other without encroaching on the bicycle lanes.

- **Nonintuitive Motor Vehicle Movements design flag:** By providing an inner walkway, pedestrians cross motor vehicle movements in an alternating fashion. At the first crossing, vehicles arrive from the left, and at the next crossing, vehicles arrive from the right, and so on. This conforms to the typical expectation.
- **Indirect Path design flag:** Pedestrians and bicyclists can cross the mainline by proceeding from one side of the roadway, onto the center island, and then to the opposing side of the roadway. This avoids the need for pedestrians to travel to an adjacent intersection to cross the mainline. This flag may still apply for other movements as described below.
- **Undefined Crossings at Intersections design flag:** All locations where pedestrians and bicyclists cross motor vehicles are marked. This will reduce the likelihood that vehicles will encroach on the crossing areas when stopped for a signal.
- **Motor Vehicle Left-Turns design flag:** The inner walkway design removes pedestrians from crossing the left-turn at the off-ramp.
- **Riding in Mixed Traffic design flag:** This design features a bike ramp off the roadway and onto the shared-use path. Bicyclists are provided a less stressful and safer path through the interchange.
- **Bicycle Clearance Time design flag:** By removing bicyclists from the roadway, the bicyclists no longer must travel between the crossover intersection and the right-turn from the off-ramp. This eliminates the need for additional clearance time for bicyclists to cover this distance.
- **Turning Motorists Crossing Bicycle Path design flag:** The bicycle ramp to the shared-use path is placed upstream of the development of the right-turn lane onto the on-ramp. This eliminates the conflict of motorists crossing the bicycle path.
- **Off-Tracking Trucks in Multilane Curves design flag:** Heavy vehicles may experience challenges maintaining their lane when traveling through the crossover intersections. By providing an off-street shared-use path for bicyclists, the users are separated in space, avoiding the potential conflict.

### *9.4.3.2 Challenges*

Emphasizing again that the design is not intended to be “ready-made,” this concept leaves several design flags as described in Exhibit 9-19.

**Exhibit 9-19. Summary of design flags remaining with DDI separated bike lane/inner walkway design concept.**

| Design Flag | Description | Mode / Travel Path |
|---|---|---|
| Motor Vehicle Right-Turns (Section 4.4.1) | DDIs tend to have high volumes of turns to and from the freeway. This design still requires pedestrians to cross the right-turn from the off-ramp. This flag can be mitigated by prohibiting right-turn-on-red or by designing the curve radii to keep speeds from exceeding 25 mph. | Pedestrians and Bicyclists, all crossings |
| Crossing Yield-Controlled or Uncontrolled Vehicle Paths (Section 4.4.4) | This design has a yield-controlled right-turn onto the on-ramp. Given the expected high volume of turns onto the on-ramp, the curve radii should be designed to keep vehicle speeds from exceeding 25 mph. This will mitigate the flag by increasing the likelihood of vehicles yielding to pedestrians. | Pedestrians, all crossings |
| Indirect Path (Section 4.4.5) | Users wanting to continue along the mainline may experience enough out-of-direction travel crossing to the median and back that the indirect path flag would apply. | Pedestrians and Bicyclists, inner median crossing |
| Executing Unusual Movements (Section 4.4.6) | In most areas, DDIs are a relatively novel design. Users wanting to continue along the mainline likely do not expect to need to cross one direction of mainline traffic. Proper wayfinding design will be especially important for all users to understand how to execute their desired path. | Pedestrians, inner crossing |
| Multilane Crossings (Section 4.4.7) | At the crossovers of this design, pedestrians must cross multiple lanes without refuge (the yellow flag threshold for pedestrians is 2-3 lanes). | Pedestrians and Bicyclists, all crossings |
| Sight Distance for Gap Acceptance Movements (Section 4.4.12) | The motor vehicle right-turns to the on-ramp are yield-controlled and therefore require careful attention to sight distance requirements. In this design, the position of the crosswalk upstream of the center of the curve would likely provide adequate sight distance. | Pedestrians and Bicyclists, all crossings |
| Grade Change (Section 4.4.13) | While not able to be evaluated from the plan view provided, interchanges can experience grade changes. This should be evaluated during the flag assessment process. | Pedestrians and Bicyclists, inner median crossing |

## 9.5 Detailed Design Techniques

The design flag procedure and corresponding flags are outlined in Chapter 4, and techniques are discussed in Chapter 5. Because many flags and techniques appear in the same fashion at many A.I.I.s, those common flags and design treatments/techniques are discussed solely in Chapter 5. Discussion in this section is limited to unique characteristics or design responses to assist in addressing flags *in a DDI*. This includes:

- ADA and accessibility;
- Channelized turn lanes;
- Sight distance; and
- Indirect paths.

### 9.5.1 ADA and Accessibility

Because the DDI crossover may be novel for drivers, human factors considerations are emphasized throughout the design process. Human factors considerations also apply to the pedestrian environment, because the DDI environment differs from what pedestrians are accustomed to using at conventional interchanges.

At the DDI, the provision of an accessible pedestrian signal (APS) may pose a challenge on the median island for pedestrian facilities in the center. Exhibit 9-20 shows an example of an undesirable pedestrian pushbutton installation with the pushbutton for the two directions on the same pole. The lack of separation may make it difficult for pedestrians (especially those with vision disabilities) to distinguish which pushbutton is intended for which crossing. Further, the example shown does not provide APS devices or any audible information about the crossing.

Given that the nose of the median island does not provide adequate room to allow the pedestrian pushbuttons to be on separate poles and sufficiently separated, it is recommended that the pedestrian pushbuttons be separated diagonally, with the pushbuttons consistently on the

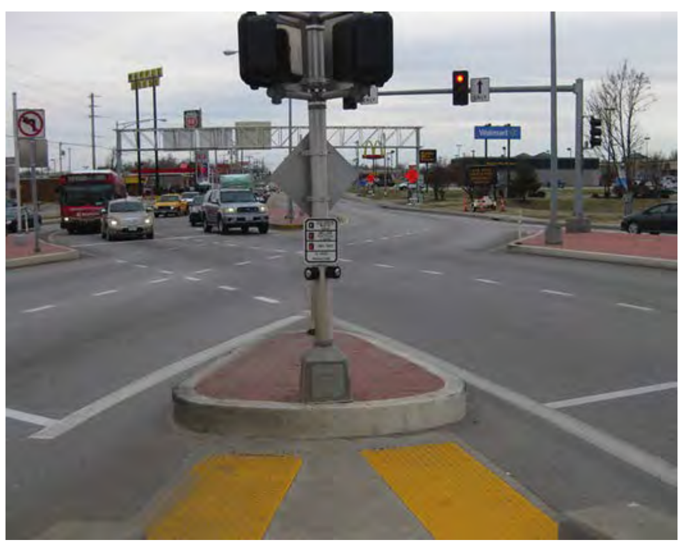

***Exhibit 9-20. Undesirable use of single pole with two pedestrian pushbuttons, no APS, and insufficient separation of the two detectable warning surfaces. Source: Google.***

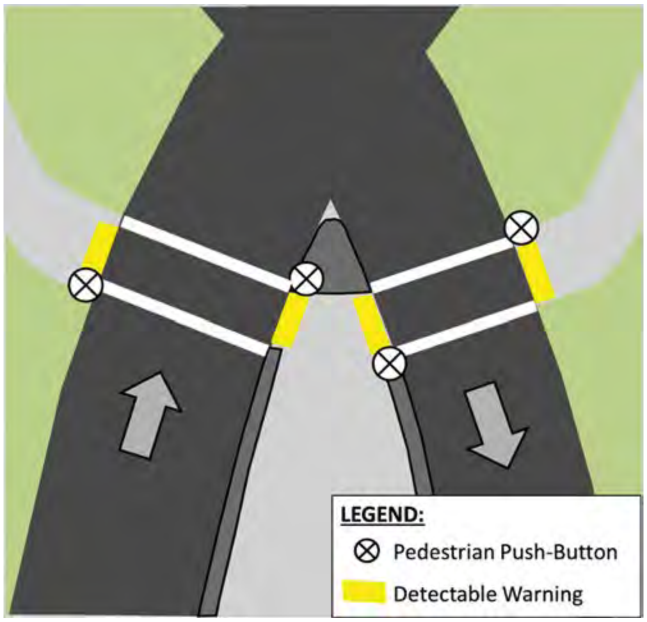


***Exhibit 9-21. DDI splitter island with diagonal pedestrian signals.***

downstream side of the crossing to provide audible separation between the APS messages and oncoming traffic, as shown in Exhibit 9-21.

Wider islands are strongly recommended to provide a true refuge area of at least 6 feet in the direction of pedestrian travel. This ensures at least 2 feet between the detectable warning surfaces, as well as adequate storage for wheelchair users.

If the two APS devices are less than 10 feet apart, speech messages with customized wording specific to the DDI are required. One potential for such wording after activating the push-button (the pushbutton information message, see MUTCD 4E.13, par 9 & 10) may be: "Wait to cross eastbound lanes Airport Rd. at Highway 26. Traffic coming from your left." (*8*) During the Walk interval, the message would be: "Eastbound lanes Airport Rd, walk sign is on to cross eastbound lanes Airport Rd." An expert in accessibility installations may need to be consulted for specialized applications and signal installations at a DDI to ensure that the crossings are accessible to and usable by all pedestrians, as required by the ADA.

## 9.5.2 Channelized Turn Lanes

Channelization of all turns to and from the freeway is used to discourage wrong-way maneuvers and to move ramp terminal intersections away from the crossover intersection. Channelization, especially for unsignalized turns, could create pedestrian safety concerns due to the potential for high speeds and sight distance limitations.

Many DDI designs have been associated with upgrades to pedestrian facilities and/or shared-use paths, and best practices for the design of these facilities are still developing. Considerations include the location of the pedestrian facilities (outside versus inside), unintuitive traffic directions for crossing, radius and speed of turning movements, and whether to signalize turns at on-ramps–especially left-turns onto on-ramps with walkways along the outside of the DDI where speeds are higher and there may be limited sight distance.

***Exhibit 9-22. Example of a pedestrian crossing at free-flow left onto the freeway.***

If pedestrian facilities are placed on the outside, attention is needed regarding the placement, visibility, and vehicular speeds for the pedestrian crossing at the left-turn to the on-ramp. Exhibit 9-22 shows one example of such a left-turn crossing, viewed from the middle of the DDI. The image shows an exclusive left-turn lane approaching the crosswalk, with motor vehicles accelerating toward the freeway entrance ramp. The exhibit further shows potential visibility limitations for pedestrians crossing from the middle of the DDI. The waiting area is obscured by a shadow in the photo, but even at other times of day, the line of sight between the waiting position and the approaching truck in the left-turn lane is partially obstructed by the barrier wall on the bridge structure. Free-flowing vehicle movements, elevated speeds, acceleration, and insufficient sight distance can contribute to low yielding, as well as an increased chance of conflicts at these crossing locations.

To overcome visibility and sight distance challenges, several potential treatments could be considered, including the following:

- Revising the left-turn geometry toward a pedestrian-focused DDI design with reduced turn radii, reduced vehicle speeds, and improved sight distances, as described above;
- Relocating the crosswalk to farther upstream in the turn lane for improved sight distances, which might require a slightly longer crossing;
- Adding raised crosswalks or other geometric modifications to control vehicular speeds near the crosswalk;
- Installing rectangular rapid-flashing beacons (RRFBs) or other pedestrian-activated devices to alert drivers of the presence and crossing intent of a pedestrian;
- Providing a pedestrian-activated signal to supply a crossing opportunity with a steady red phase for vehicular traffic; and
- Moving pedestrian facilities to inside the median (resolves left-turn movements, but right-turn movements may still need additional treatment).

Although this discussion has focused on the channelized left-turn to the freeway, similar considerations should be applied to channelized right-turn lanes to and from the freeway, as well as to the channelized left-turn from the freeway (if yield-controlled). Relative to other intersection forms, sight distance is a challenge at DDIs.

### 9.5.3 Sight Distance

Sight distance is discussed in Chapters 4 and 5 but has a special application at DDIs due to traffic from potentially counterintuitive directions at pedestrian crossings.

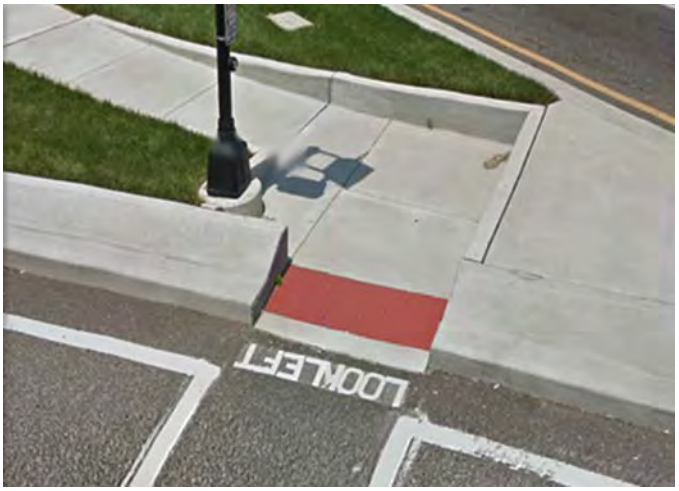


***Exhibit 9-23. Engraved pedestrian pavement marking – "Look Left." Source: Google.***

Whether or not pedestrian facilities are provided along the outside or in the center median, a unique issue with pedestrian crossings at DDIs is the propensity to look the wrong direction for gaps in traffic. One treatment that could be considered, in addition to supplemental signing and/or speech messages used with APS devices, is an embedded pavement marking, such as the one in Exhibit 9-23. Other marking possibilities that would be more accessible to pedestrians who cannot read English could also be explored. This treatment could help pedestrians and is relatively inexpensive to install and maintain. The installation process may require that a small section of pavement be removed before marking installation. This protects snowplows and wheel friction, which reduces the marking's maintenance needs.

### 9.5.4 Visibility of Traffic Control Devices

Pedestrian crossings at a DDI can be signalized or unsignalized. For inner walkways, the crossings from the channelization island to the inner walkway are signalized, while the crossings from the island across the on-ramps are often unsignalized. Visibility of any traffic control devices is critical (and required), per MUTCD, but DDIs call for special attention to this specific element.

The visibility of the pedestrian signals should be explored in the early stages of the design phase of the DDI, especially with the narrow "noses" at the ends of the inner walkway. Sightlines to and from the inner walkway can be further obstructed by vehicles using the crossovers, as well as by poles and signage in the median. The actual pedestrian signal may not be visible when approaching the crossing in the inner walkway, and it may be unclear what the intended crossing direction is. Signal pole placement and orientation should be screened and carefully selected to ensure that pedestrians can find and understand the intention of these traffic control devices intuitively. Supplemental signs specifically for pedestrians and cyclists may be necessary when signs for drivers are not adequate for other roadway users. An APS with a locator tone is required to help pedestrians with vision disabilities locate the pushbutton.

### 9.5.5 Indirect Paths

DDI design and signal phasing provide a natural time and location for pedestrian access across the mainline. Yet, some existing DDIs with outer walkways do not include provisions

***Exhibit 9-24. DDI with an outer walkway and no arterial crossing opportunities.***

for pedestrians to cross the arterial roadway at a DDI (Exhibit 9-24)–if a pedestrian needs to cross the arterial, they are expected to travel to the next intersection to do so. This contradicts the design objectives to provide access, reasonable comfort, and acceptable travel time to all pedestrians. It can be expected that a person will find a desire line to cross, even if it is at the expense of safety, rather than detour to the next intersection and back for a street crossing. Crossings should be provided and can be accomplished with outer walkways–concepts in Section 9.4 demonstrate how this can be reasonably achieved.

## 9.6 References

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*Abbreviations and acronyms used without definitions in TRB publications:*

| | |
|---|---|
| A4A | Airlines for America |
| AAAE | American Association of Airport Executives |
| AASHO | American Association of State Highway Officials |
| AASHTO | American Association of State Highway and Transportation Officials |
| ACI–NA | Airports Council International–North America |
| ACRP | Airport Cooperative Research Program |
| ADA | Americans with Disabilities Act |
| APTA | American Public Transportation Association |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| ATA | American Trucking Associations |
| CTAA | Community Transportation Association of America |
| CTBSSP | Commercial Truck and Bus Safety Synthesis Program |
| DHS | Department of Homeland Security |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| FAA | Federal Aviation Administration |
| FAST | Fixing America's Surface Transportation Act (2015) |
| FHWA | Federal Highway Administration |
| FMCSA | Federal Motor Carrier Safety Administration |
| FRA | Federal Railroad Administration |
| FTA | Federal Transit Administration |
| HMCRP | Hazardous Materials Cooperative Research Program |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISTEA | Intermodal Surface Transportation Efficiency Act of 1991 |
| ITE | Institute of Transportation Engineers |
| MAP-21 | Moving Ahead for Progress in the 21st Century Act (2012) |
| NASA | National Aeronautics and Space Administration |
| NASAO | National Association of State Aviation Officials |
| NCFRP | National Cooperative Freight Research Program |
| NCHRP | National Cooperative Highway Research Program |
| NHTSA | National Highway Traffic Safety Administration |
| NTSB | National Transportation Safety Board |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| RITA | Research and Innovative Technology Administration |
| SAE | Society of Automotive Engineers |
| SAFETEA-LU | Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005) |
| TCRP | Transit Cooperative Research Program |
| TDC | Transit Development Corporation |
| TEA-21 | Transportation Equity Act for the 21st Century (1998) |
| TRB | Transportation Research Board |
| TSA | Transportation Security Administration |
| U.S. DOT | United States Department of Transportation |

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