OS-299 (5-21)

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DEPARTMENT OF TRANSPORTATION
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# TRANSMITTAL LETTER

PUBLICATION:

Publication 13

DATE:

6/15/2022

SUBJECT:

**Revisions to**
**Design Manual, Part 2**
**Contextual Roadway Design**
**April 2021 Edition, Change No. 1**

INFORMATION AND SPECIAL INSTRUCTIONS:

Revisions to Publication 13, Design Manual Part 2, Contextual Roadway Design are to be issued with this letter.

Change No. 1 includes revisions to the "About Design Manual 2" chapter and the addition of four chapters (Chapter 8, Road Diet, Chapter 21, Wildlife Crossings, Chapter 22, Landscape Planting Design, and Chapter 23, Emergency Escape Ramps).

These new guidelines should be adopted on all new and existing designs as soon as practical without affecting any letting schedules, but no later than January 1, 2023.

Publication 13 is anticipated to ultimately include a total of twenty-four chapters. As chapters for Publication 13 are circulated and approved through the Clearance Transmittal (CT) review process, an update for Publication 13 will be issued. If a chapter in Publication 13 replaces an existing chapter in Publication 13M, an update for Publication 13M will also be issued.

ABOUT DESIGN MANUAL 2

*Removed physical address for comment submissions and replaced with e-mail address.

CHAPTER 8 – Road Diet

*New chapter not previously found in Publication 13M, Design Manual Part 2, Highway Design.

CHAPTER 21 – Wildlife Crossings

*Issued design guidance to replace the guidance found previously in Publication 13M, Design Manual Part 2, Highway Design, Chapter 20, Wildlife Crossings.

CHAPTER 22 – Landscape Planting Design

*Issued design guidance to replace the guidance found previously in Publication 13M, Design Manual Part 2, Highway Design, Chapter 8, Landscape Planting Design (Roadside Development).

CHAPTER 23 – Emergency Escape Ramps

*Issued design guidance to replace the guidance found previously in Publication 13M, Design Manual Part 2, Highway Design, Chapter 17, Emergency Escape Ramps.

CANCEL AND DESTROY THE FOLLOWING:

Cover Page – all pages
Table of Contents – all pages
About Design Manual 2 – all pages
Chapter 8 placeholder – all pages
Chapter 21 placeholder – all pages
Chapter 22 placeholder – all pages
Chapter 23 placeholder – all pages

ADDITIONAL COPIES ARE AVAILABLE FROM:

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APPROVED FOR ISSUANCE BY:

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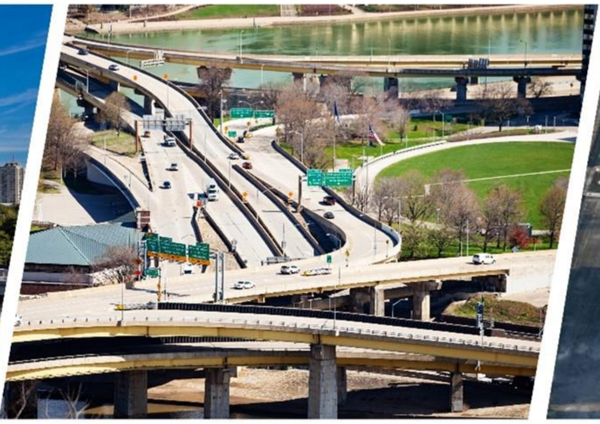
Chief Executive, Highway Administration

# DESIGN MANUAL PART 2

## CONTEXTUAL ROADWAY DESIGN

## PUBLICATION 13



pennsylvania
DEPARTMENT OF TRANSPORTATION

Pub 13 (6-22)

# Table of Contents

# About Design Manual 2

This manual provides basic design guidance for the development of transportation projects in Pennsylvania. The purpose of this manual is not to reiterate design guidelines described in the American Association of State Highway and Transportation Officials' (AASHTO) manuals. Instead, it provides Pennsylvania-specific design guidance. Therefore, when design criteria presented in this manual differ from criteria presented in other sources, this manual will take precedence (with the exception of National Highway System (NHS) routes, where the AASHTO *A Policy on Geometric Design of Highways and Streets*, i.e., the Green Book, takes precedence if more conservative than DM-2).

Further, this manual does not attempt to incorporate the entire scope of other published literature relating to the formulation of highway design criteria, policies, and procedures. Some of the other resources that may complement the concepts contained within this manual include:

- AASHTO, *A Policy on Geometric Design of Highways and Streets, 6th Edition* commonly referred to as the "The Green Book", 2011.
- AASHTO, *Highway Safety Manual* (HSM*)* (edition defined in Publication 638A).
- AASHTO, *Guide for the Planning, Design, and Operation of Pedestrian Facilities*, 2021.
- AASHTO, *Guide for the Development of Bicycle Facilities,* 2012.
- AASHTO, *Policy on Design Standards Interstate System,* 2016.
- AASHTO, *Roadside Design Guide, 4th Edition*, 2011.
- PennDOT, Publication 408, *Specifications*.
- The Federal Highway Administration (FHWA), *Manual on Uniform Traffic Control Devices* (MUTCD), (edition defined in Publication 46).
- The Transportation Research Board, *Highway Capacity Manual* (HCM*),* (edition defined in Publication 46).

A topic-specific list of references is included in each chapter.

## Updating this Manual

To uphold PennDOT's mission to provide a sustainable transportation system and quality services that are embraced by our communities and add value to our customers, it is important that design processes and procedures include state-of-the-art best practices. As practitioners, PennDOT's employees are the best resources for providing these updates.

PennDOT encourages staff and consultants to submit comments and suggestions for changes to the manual to the e-mail resource account: RA-PDPUB13-DM-2RA@pa.gov

To assist in effectively coordinating comments and suggestions, please include the form on the following page with each submission.


Also, employees' ideas that have not been tried on a project can be submitted through IdeaLink. IdeaLink, PennDOT's web-based suggestion box, gathers employee feedback on how to improve efficiency and safety. All submittals to IdeaLink follow a comprehensive review process to determine their applicability.


Employees can also share design process modifications or best practices through PennDOT WorkSmart, an online bulletin board. PennDOT WorkSmart provides the opportunity for PennDOT employees to find common ground and collaborate with one another to help make the Department a safer, more efficient, and more cost-effective organization.

Highway Design and Technology Division staff review comments and suggestions in a timely manner. Their review is also coordinated with other PennDOT sections, as appropriate.

**Pennsylvania Department of Transportation**
**Suggestions and Comments for Incorporation into Design Manual 2**

Name of firm: ______________________________

Firm address: ______________________________

______________________________

Person responsible for suggestion: ______________________________

Email and phone number: ______________________________

Suggestions and comments: ______________________________

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(Comments or suggestions may be attached as marked-up copies of pages from this manual.)

Please complete the requested information on a copy of the sheet and e-mail it to the Highway Design and Technology Division at: RA-PDPUB13-DM-2RA@pa.gov

# Preface

Transportation professionals in the 21st century must be cognizant of the public's travel needs and an area's livability as projects progress from conception through construction. In the past decade, the term "complete streets" has become synonymous with the incorporation of multimodal principles into the physical configuration of roadways and associated facilities. Streets are made complete by addressing the needs of all system users and accommodating these unique needs through design, appearance, and the modes of travel. Depending upon local context and environmental conditions, different streets will require distinct physical design features to best address users' needs.

**PennDOT's Mission**

To provide a sustainable transportation system and quality services that are embraced by our communities and add value to our customers.

In addition to being complete, streets need to be livable, providing improved quality of life for the people using the space. Livable neighborhoods require that streets function as transportation facilities as well as viable public places. In addition, communities may wish to preserve historic or unique elements along main streets, invite new businesses and development, and energize public spaces for civic activities, community celebrations, and special events.

Preserving a community's sense of place allows PennDOT the opportunity to support and enhance elements that make a community livable, unique, and economically viable. Within the context of transportation projects, placemaking (the multi-faceted approach to planning, designing and management of public spaces) improves practical aspects of civic life, such as providing connections between homes and neighborhood centers. It also addresses harder-to-quantify livability issues, such as establishing socially cohesive neighborhoods and community identity. Transportation improvements alone cannot address every component of placemaking, but they can significantly bolster community efforts to create and preserve a rich and unique sense of place.

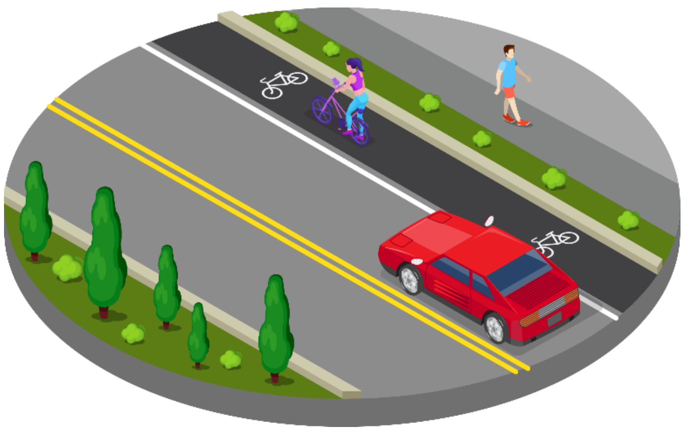
Complete livable streets are planned, designed, constructed, operated, and maintained to provide mobility for all users, appropriate to the function and context of the facility. Transportation professionals are responsible for designing with flexibility and employing context-sensitive approaches that consider the communities in which they are working, because construction today may be in place for decades to come.

## Framework for the Development of Projects

Over the past twenty years, transportation professionals have made great strides in developing sophisticated components within the transportation network. However, as the priority had been investment in personal vehicle transport, some fragmentation of the transportation network has occurred. As funding for developing transportation projects becomes increasingly difficult to obtain, it is critical to integrate existing systems to realize the full potential of the transportation network.

Further, the development of a project today should not become the limiting factor for additional modes to be accommodated through the same project area in the future. The framework presented in this section addresses the concepts of complete streets, context sensitive solutions, flexibility in design, and risk management. These concepts should be considered in the development of projects so that opportunities for today and in the future are not compromised.

## Complete Streets

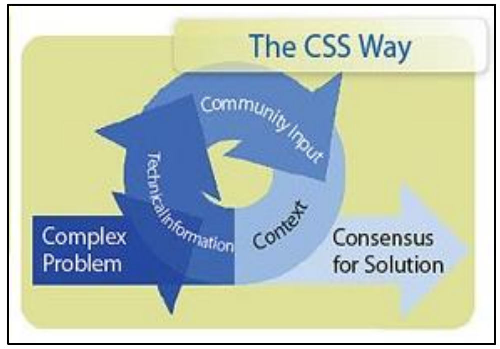


A complete streets approach challenges transportation professionals to routinely design and operate the entire right-of-way to enable safe access for all users, regardless of age, ability, or mode of transportation. This means that every transportation project should promote a street network better operationally and safer for drivers, transit users, pedestrians, and bicyclists, ultimately making each location a better place to live.

There is no singular design prescription for complete streets; each one is unique and responds to its community context. In a city, a complete street may include sidewalks, bike lanes or wide paved shoulders, special bus lanes, comfortable and accessible public transportation stops, frequent and safe crossing opportunities, median islands, accessible pedestrian signals, curb extensions, narrower travel lanes, and roundabouts. By contrast, a complete street in a rural area may look quite different yet share the same goal of balancing safety and convenience for everyone using the road. Additional information on complete streets is provided in Chapter 1.

## Context Sensitive Solutions

The Context Sensitive Solutions (CSS) approach to project development assumes that all projects have a context that informs the development of solutions. The CSS process involves stakeholders, such as community members, elected officials, interest groups, as well as local, state, and federal agencies, in a collaborative, interdisciplinary, and holistic approach to developing transportation projects.



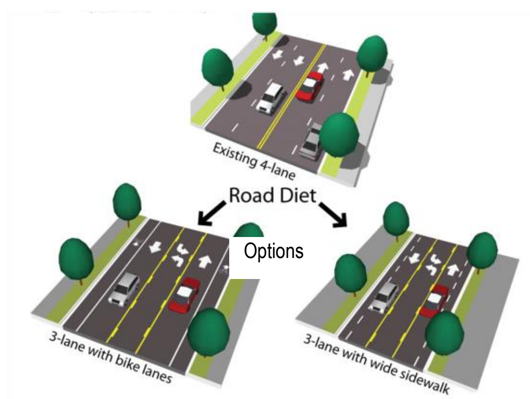

(Source: FHWA contextsensitivesolutions.org)

The process differs from traditional processes in that it considers a range of goals that extend beyond the transportation problem. It includes goals related to community livability and sustainability and seeks to identify and evaluate diverse objectives earlier in the process and with greater participation by those affected.

The CSS approach plans for and responds to the unique needs and qualities of individual communities. At each step, inclusiveness, flexibility, and creativity fuel development of fresh solutions and increase the prospects for success. Additional information on CSS is provided in Chapter 1.

## Design Flexibility

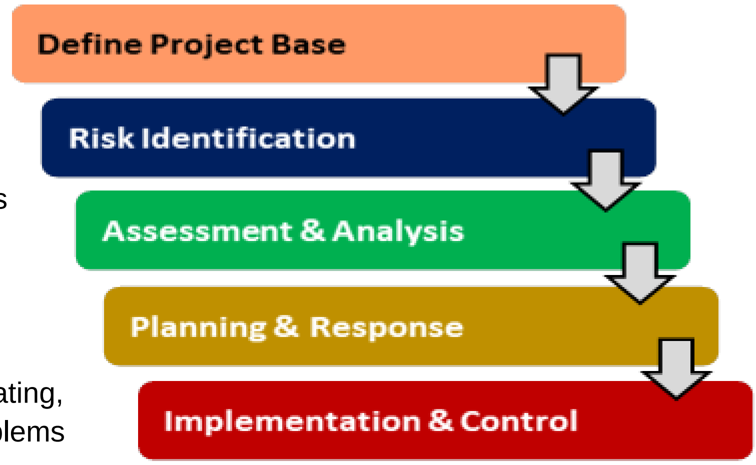
Flexibility in design is a context sensitive concept that encourages transportation professionals to expand their consideration in applying the AASHTO Green Book and other design criteria.




(Source: LSL Planning / Michigan Association of Planning)

Flexible thinking is about making informed choices. Simply applying the highest or lowest value within a range of design values without explicit consideration of context might not always lead to the most informed choices that best meet a project's objectives. Applying flexibility in design encourages transportation professionals to consider the roadway context, implications for the safety and comfort of pedestrians and bicyclists, and implications for regional mobility. Additional information on design flexibility is provided in Chapter 1.

## Risk Management




Transportation projects come in a variety of sizes and use various financing and delivery methods. Work on such projects often involves the potential for schedule delays, budget overruns, and other unexpected problems or risks that affect project performance. Risk management, in the context of the planning and design of a transportation project, affords better understanding and optimized project performance by anticipating, planning for, and mitigating potential problems or risks and potential improvements or opportunities.

Complex relationships among entities such as PennDOT, project stakeholders, local governments, review agencies, and others are often inherent within projects. Therefore, flexibility in roadway design and managing related risks becomes paramount to the project development process. Additional information on Risk management for Project Development is provided in Publication 10X, Design Manual Part 1X, Appendix AH.

## Glossary

| | |
|---|---|
| Average Daily Traffic (ADT) | The total volume of traffic during a number of whole days, more than one day and less than one year, divided by the number of days in that period. |
| Auxiliary lane | A portion of the roadway adjoining the through lanes for speed change, turning, storage for turning, weaving, truck climbing, and other purposes that supplement through-traffic movement. |
| Bicycle lane / Bike lane | A portion of a roadway (typically four to five feet) designated for preferential use by bicyclists, delineated by pavement markings and signs. Bicycle lanes are one-way facilities that typically carry bicycles in the same direction as adjacent motor vehicle traffic. |
| Clear zone | The total roadside border area, starting at the edge of the motor vehicle travel lane, available for use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear runout area. The desired width is dependent upon the traffic volumes and speeds, and on the roadside geometry. |

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| Control Vehicle | A vehicle that uses a facility infrequently but must be accommodated. When using a Control Vehicle, encroachment into the opposing traffic lanes, multiple-point turns, or minor encroachment into the street side is acceptable |
| Crosswalk | Marked or unmarked portion of the roadway at an intersection included within the connections of lateral lines of the sidewalks on opposite sides of the highway, measured from the curbs or (in the absence of curbs) from the traversable roadway. Crosswalks may also occur at an intersection or elsewhere in the traveled way and travel lane (including bike lanes), such as mid-block crossings, distinctly indicated for pedestrian crossing. |
| Design Hourly Volume (DHV) | The Design Hourly Volume (DHV) is usually the 30th highest hourly volume for the design year, commonly 20 years from the time of construction completion. For situations involving high seasonal fluctuations in ADT, some adjustment of DHV may be appropriate. |
| Design speed | A selected rate of travel used to determine the various geometric features of the roadway. |
| Design vehicle | A vehicle that must be regularly accommodated without encroachment into the opposing traffic lanes or into the street side. |
| Divided highway | A highway divided into two or more roadways. Divided highways impede vehicular traffic between the roadways by providing an intervening space, physical barrier, or clearly indicated dividing section. |
| Expressway | A divided arterial highway for through traffic, with partial control of access and generally with grade separations at major intersections. |
| Freeway | A fully limited access highway for which the only means of ingress and egress is by interchange ramps. |
| Frontage road | A street or highway constructed adjacent to a higher classification street or other roadway network serving adjacent property to provide access. |
| Grade separated crossing | A crossing of two roadways, or a crossing of a roadway and a railroad or pedestrian pathway, at different elevations or levels. |
| High speed | Speeds of 50 mph or greater. |
| Horizontal clearance | Lateral distance from edge of the traveled way, shoulder or other designated point to a vertical roadside element. |
| Intersection | The general area where two or more streets or highways join or cross. |

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| May | A permissive condition. The verb “may" is used to denote permissive usage. |
| Maintenance | A strategy of treatments to an existing roadway system that preserves the system, retards future deterioration, and maintains or improves its functional condition. Typically, maintenance projects do not include geometric enhancements or require right-of-way acquisition. Pavement repairs, such as seal coats, full width patching, crack sealing, or correcting minor irregularities, are generally considered maintenance activities. |
| New construction | A new transportation facility where one did not previously exist. The addition of new appurtenances to an existing facility, such as striping, signs, signals, or noise barrier, are not considered new construction. |
| Operating speed | The rate of travel at which vehicles are observed traveling during free-flow conditions. |
| Public transit | Passenger transportation service, local or regional in nature, that is available to any person. Public transit includes bus, light rail, and rapid transit. |
| Reconstruction | Reconstruction projects are projects that utilize an existing roadway alignment (or make only minor changes to an existing alignment), but involve a change in the basic roadway type. Changes in the basic roadway type include widening a road to provide additional through lanes or adding a raised or depressed median where none currently exists, and where these changes cannot be accomplished within the existing roadway width (including shoulders). The change in basic roadway type means that performance measures for the existing roadway may not be relevant to forecasting the performance of the future constructed roadway. However, retaining the existing alignment mean that the existing constraints in the current roadway environment will influence design decisions. |
| Rehabilitation | Improvements to remove and replace major structural elements of a highway or bridge to restore the structure to an acceptable condition. |
| Restoration | Improvements that restore pavement, shoulders, and bridges to an acceptable condition that ensures safe operations for a substantial period. |
| Resurfacing | Application of a new or recycled layer(s) of pavement material to existing pavements, shoulders, and bridge decks. |

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| Resurfacing, Restoration and Rehabilitation (3R) | A 3R project is the improvement of an existing facility on similar alignment to extend the service life of the facility and/or improve the pavement structural and functional capacity. A 3R project typically does not address operational capacity improvements, major realignment, or major upgrading of geometric features. It may include selective improvements to highway geometry and other roadway features to address safety concerns and reconstruction of limited portions of the project's length. |
| Right-of-way (ROW) | A general term denoting land, property, or interest therein acquired or donated for transportation purposes. More specifically, land in which the state, a county, a transit authority, or a municipality owns the fee or has an easement devoted to, or required for, use as a public road. |
| Roadway | The portion of a street or highway including shoulders and bike lanes, for vehicular, and transportation uses. A divided highway has two or more roadways. |
| Shall | A mandatory condition. The verb “shall” is used when mandatory requirements must be met. |
| Shared use path | Paved facilities physically separated from motorized vehicular traffic by an open space or barrier. A shared use path may be within the highway right-of-way or within an independent right-of-way with minimal cross flow by motor vehicles. Users are non-motorized and may include pedestrians, bicyclists, skaters, and people with disabilities. |
| Should | An advisory condition. The verb “should” is used when a condition is recommended but not mandatory. |
| Slopes | A surface of which one end or side is at a higher elevation than another. Slopes are expressed as a ratio of vertical to horizontal (V:H). It can also be shown as a percentage. |
| State Transportation Improvement Plan (STIP) | Pennsylvania’s official four-year listing of transportation projects mandated under federal law. The STIP comprises all of the TIPs. |
| Temporary Traffic Control (or Work Zone) | The area of a highway where construction, maintenance, or utility work activities are conducted and in which traffic control devices are required. |
| Transportation Improvement Program (TIP) | Four-year listing of transportation projects within the geographic boundary of each planning region in Pennsylvania. Interstate Highway System projects are managed in a separate Interstate Management TIP but are included in regional TIPs for public review and comment. |

| | |
|---|---|
| | Fund reserves for statewide programs, as well as line items for ongoing planning and administration projects, are managed in a separate Statewide Items TIP. |
| Traffic | Pedestrians, bicyclists, motor vehicles, streetcars, horse and buggies, and other conveyances (either singularly or combined) traveling any road open to public travel. |
| Traveled way | The portion of the roadway dedicated to the movement of vehicles, exclusive of shoulders, berms, sidewalks, bike lanes and parking lanes. |
| Travel lane | A designated portion of roadway marked to carry through-traffic and to separate it from opposing traffic or traffic occupying other traffic lanes. Generally, travel lanes equate to the basic number of lanes for a facility. |
| Twelve Year Transportation Program (TYP) | Pennsylvania's official 12-year listing of transportation projects mandated under state law. The first four years of the TYP are the STIP. |
| Vehicle | Every device upon, or by which any person or property is or may be transported or drawn upon, a traveled way, excepting devices used exclusively upon stationary rails or tracks. Vehicle examples include automobiles, bicycles and horse and buggies. |
| Work zone (or Temporary Traffic Control) | The area of a highway where construction, maintenance, or utility work activities are conducted and in which traffic control devices are required. |

# Chapter 1 – Context Based Design (To be Added Later)

This chapter will be published in the future.  Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 2 – Design Controls (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 3 – New Construction and Reconstruction - Change In Road Type (To be Added Later)

This chapter will be published in the future.  Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 4 – Reconstruction - No Change In Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 5 – Bridge Projects (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 6 – Intersections and Driveways (To be Added Later)

This chapter will be published in the future.  Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 7 – Interchanges (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 8 – Road Diet

In this chapter there are references to future chapter that are currently not included in this Publication 13.

Until they are included in this Publication, please refer to relevant topics in Publication 13M.

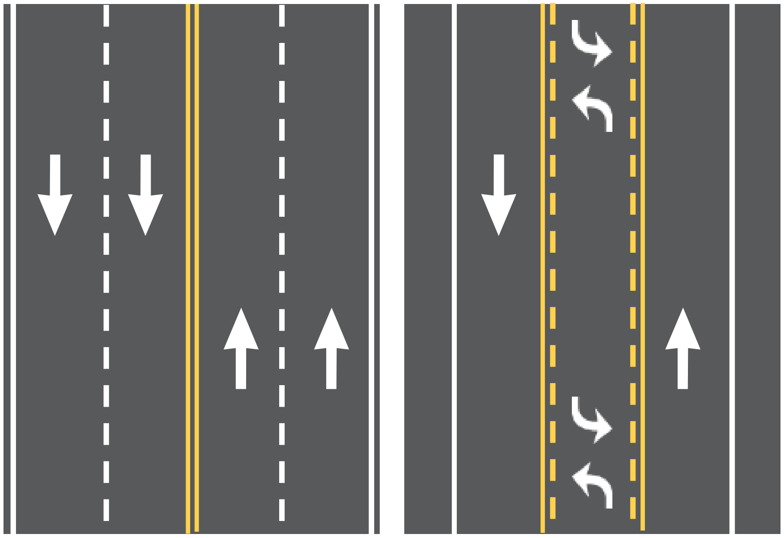
# Chapter 8 – Road Diet

## 8.0 – Introduction

A road diet is generally described as the removal of travel lanes from a roadway or the reduction of travel lane widths to create space for other uses (such as parking or pedestrian and bicycle facilities).

Most, but not all, road diets utilize a center two-way left-turn lane (TWLTL). The most common road diet, as depicted in **Exhibit 8.0.1**, involves converting an existing four-lane, undivided roadway segment to a three-lane segment consisting of two through-lanes and a center TWLTL.

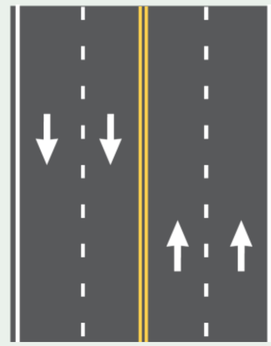
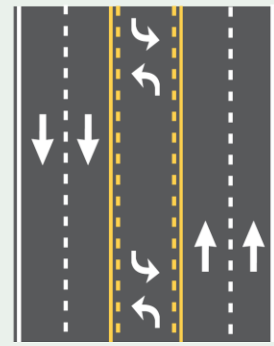
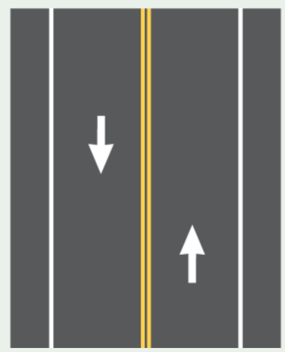
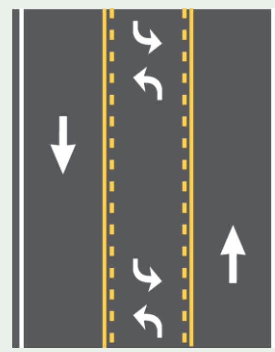
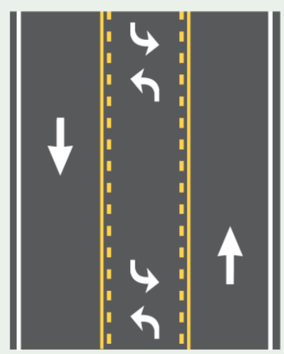
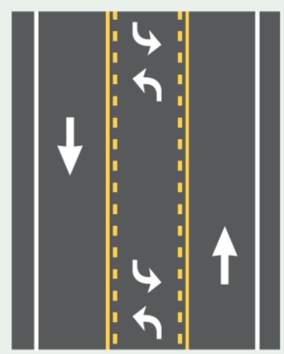
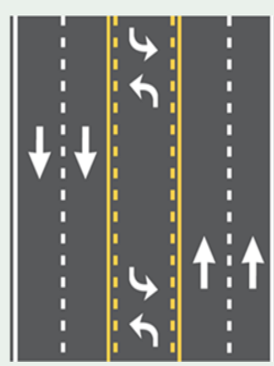
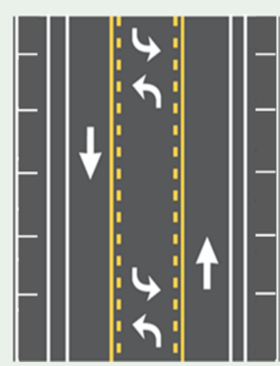
**Exhibit 8.0.1 Four-Lane to Three-Lane Road Diet**



Road diets can be used to address safety concerns. For example, a four-lane, undivided highway can have a relatively high crash rate, as the inside lanes are shared by high-speed traffic and left-turning vehicles. A new lane reconfiguration with a TWLTL separates the through-traffic and turning-traffic conflicts. In addition to improved safety, other road diet benefits include traffic calming and the opportunity to repurpose segments of the roadway to create on-street parking, bike lanes, or transit stops.

Other road diet configurations, such as those depicted in **Exhibit 8.0.2**, can also provide safety benefits.

### Exhibit 8.0.2 Additional Potential Road Diet Configurations

| | Before | After |
|---|---|---|
| **Four-lane to five-lane:** In some cases, it is necessary to keep two lanes in each direction for capacity. Narrowing lane width to provide a TWLTL introduces the benefits of separating turning vehicles and reducing operating speeds. |  |  |
| **Two-lane to three-lane:** If capacity expansion of an existing two-lane road is desired, a three-lane cross section may provide similar operational benefits as a four-lane cross section, while maintaining the safety benefits of the three-lane configuration. |  |  |
| **Three-lane to three-lane:** In some cases, designers reduce the width of each lane, instead of reducing the number of lanes. Converting an existing three-lane roadway to a three-lane cross section with narrowed lanes can accommodate bicycle lanes or parking and provide some traffic-calming benefit. |  |  |
| **Five-lane to three-lane:** In some cases, jurisdictions have reconfigured five-lane sections to three lanes, adding features such as parking and protected bicycle lanes with the extra cross section width. |  |  |

Some situations may require allocating the cross section differently through unbalanced lane splits (e.g., two in one direction, one in the other), separated left-turn lanes for opposite directions, or shoulders for other uses (e.g., parking, bicycle lanes, sidewalks). In these situations, the basic concepts of road diets still apply, although in some cases there may be different safety and operational effects than with a classic four-lane to three-lane road diet.

The designer should ask these important context questions:

- How will a road diet impact the mobility, safety, and access of all road users?
- On an existing four-lane roadway, is the roadway functioning operationally as a de facto three-lane roadway, where left-turning vehicles along the existing four-lane undivided roadway cause the majority of through traffic to use the outside lanes?
- On an existing six-lane roadway, is the roadway functioning operationally as a de facto five-lane roadway as described above?
- Is vehicle speed greater than what the context supports?
- Is public perception of the corridor's level of safety and comfort below what the context supports?
- Do the traffic volume, composition, crash history, and directional distribution support a change in lane assignments?

Key design components include:

- **Sight Distance**. Changes in vehicle position due to the cross section changes may impact horizontal sight.
- **Access Management**. Given the operational change that can occur through a travel-lane reduction and the addition of a TWLTL, designers should analyze access management during the road diet conversion.
- **Intersection/Driveway Design and Offset Intersections**. Given the cross section change during road diet implementation, designers should perform a new operational analysis at each intersection. Driveways are, in effect, low-volume intersections.
- **Bicycle and Pedestrian Facilities.** The reduction of lanes in a road diet can provide for the possible addition or expansion of bike facilities or sidewalks with little or no additional right-of-way.

## 8.0.1 – Resources and References

- AASHTO, *A Guide for Achieving Flexibility in Highway Design*, 2004.
- Institute of Transportation Engineers*, Designing Walkable Urban Thoroughfares*, 2010.
- FHWA, *Evaluation of Lane Reduction 'Road Diet' Measures on Crashes*, 2010.
- FHWA, *Flexibility in Highway Design*, 1997.
- FHWA, *Functional Classification Guidelines and Updated Guidance for the Functional Classification of Highways*, 2008.
- Delaware Valley Regional Planning Commission, *Regional Road Diet Analysis Feasibility Assessment*, 2008.
- FHWA, *Road Diet Informational Guide*, 2014.
- FHWA, *Signalized Intersections Informational Guide*, 2013.

## 8.1 – Appropriately Implementing a Road Diet


When planning for or designing a road diet, it is important to be aware of the opportunities and potential drawbacks that this treatment may have on other travel modes.

When deciding whether a particular element is appropriate for an individual street, or whether a road diet in general is appropriate, the surrounding context should be taken into consideration (including the extended roadway network). Each decision must be made on a case-by-case basis and will depend on the desired operation of the street in question. The designer should consult with non-motorized advocacy groups, transit agencies, freight stakeholders, and emergency responders to understand their needs throughout the planning and design of a road diet.

Factors for consideration include the following:

- Improving safety for all road users.
- Incorporating context-sensitive features and solutions.
- Improving or minimally impacting operational efficiency, taking into account:
  - Whether the existing four-lane or six-lane roadway operates as a de facto three-lane or five-lane roadway, respectively.
  - The need for reduced speed or traffic calming.
  - Average daily traffic.
  - Multimodal level of service.
  - Peak-hour volumes and peak direction.
  - Turning volumes and patterns.
  - The presence of slow-moving or frequently stopping vehicles, such as transit, curbside mail delivery, and others.
- Accommodating bicycles, pedestrians, parking, and transit service.
- Addressing right-of-way constraints.
- Addressing the existence of parallel roadways.
- Incorporating public input.

In addition, design professionals must make a number of geometric and operational decisions, including cross section allocation, signalization changes, transition points, and pavement marking and signing. As with any roadway treatment, data analysis and engineering judgment are required to determine whether a road diet is appropriate.

### 8.1.1 – Benefits of Road Diets

Road diets have the potential to improve safety, operations, access, and quality of life for all road users. Road diets can be of relatively low cost if planned in conjunction with reconstruction or simple overlay projects since their application consists primarily of restriping.

For roads with appropriate traffic volumes, there is strong research support for achieving safety benefits through converting four-lane undivided roads to three-lane cross sections with TWLTLs. Operational and design changes associated with road diets that promote safety include reduced vehicle speeds and reduced vehicle-pedestrian, vehicle-bicycle, and vehicle-vehicle conflicts.

In addition to providing direct safety benefits, a road diet can improve the quality of life in a corridor through a combination of bicycle lanes, pedestrian improvements, and reduced speed differentials, all of which can also improve the comfort level for all users.

### 8.1.1.a – Improved Safety Benefits

Road diets typically improve safety by reducing the number of conflict points, overall speeds, and speed differentials. Data has shown that four-lane undivided roads have high crash rates in urban and suburban areas, especially where there are a significant number of driveway access points. A three-lane cross section typically provides a safer alternative. Converting four-lane roads to three lanes, or six-lane roads to five lanes, may reduce the amount of rear-end and right-angle crashes, especially those involving left turn movements made by vehicles attempting to access businesses or residences.
Safety improvements that can be achieved through road diets include reducing:

- Vehicle-to-vehicle conflicts that contribute to rear-end, left-turn, and sideswipe crashes by removing the inside lanes serving both through and turning traffic.
- The speed differential along a corridor by shifting turning vehicles to the turning lane in a TWLTL.
- The amount of weave-in/weave-out traffic caused by left-turn traffic on through lanes.
- The severity of crashes, particularly rear-end and angle crashes due to left-turn traffic.

**Exhibits 8.1.1, 8.1.2,** and **8.1.3** illustrate conflict points and safety issues related to turning movements on four-lane undivided roadways and three-lane cross sections.

**Exhibit 8.1.1 Mid-Block Conflict Points for Four-Lane Undivided Roadway and Three-Lane Cross Section**

Four-Lane Undivided    Three-Lane

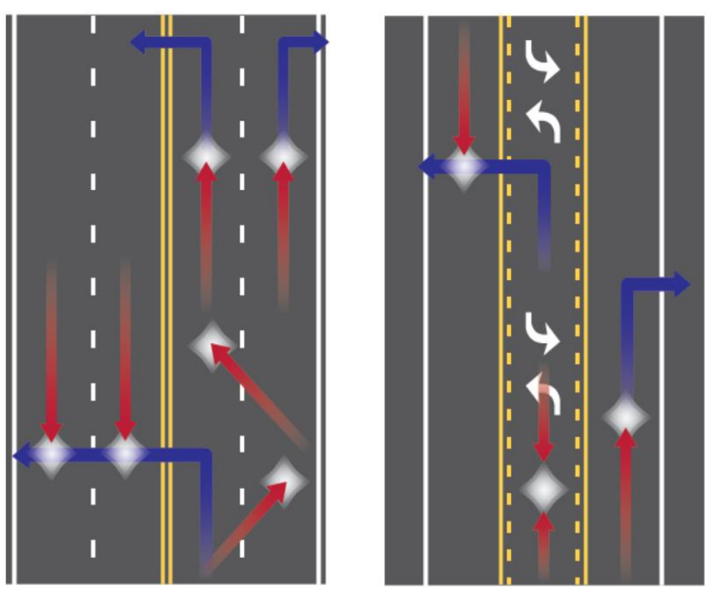


**Exhibit 8.1.2 Crossing and Through Traffic Conflict Points at Intersections for a Four-Lane Undivided Roadway and Three-Lane Cross Section**

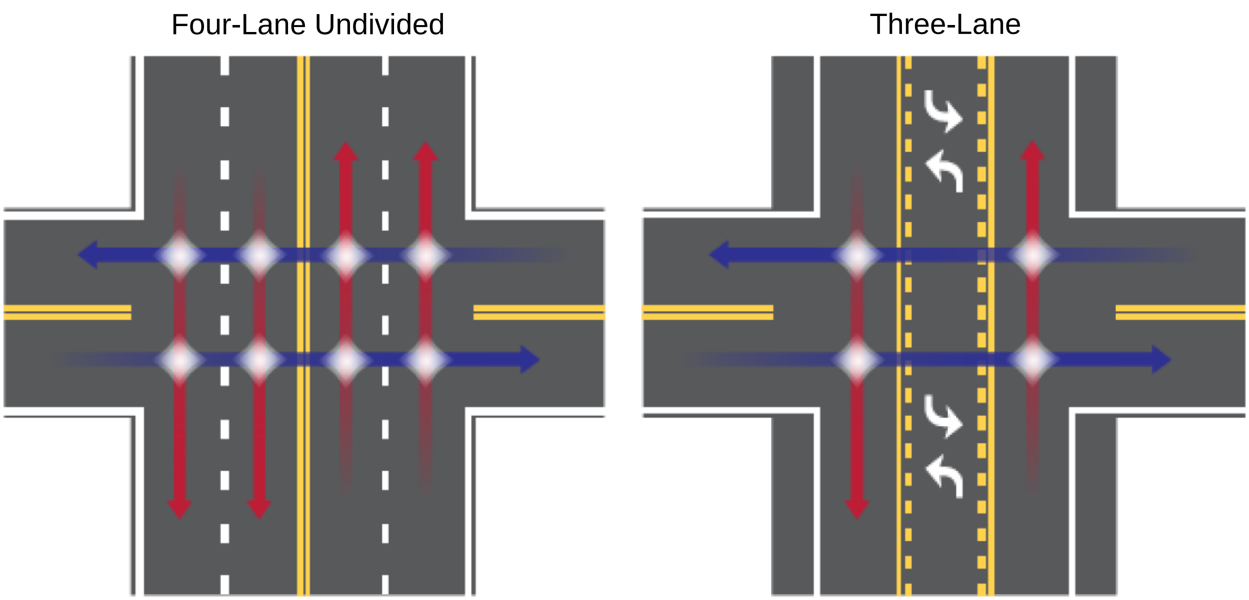
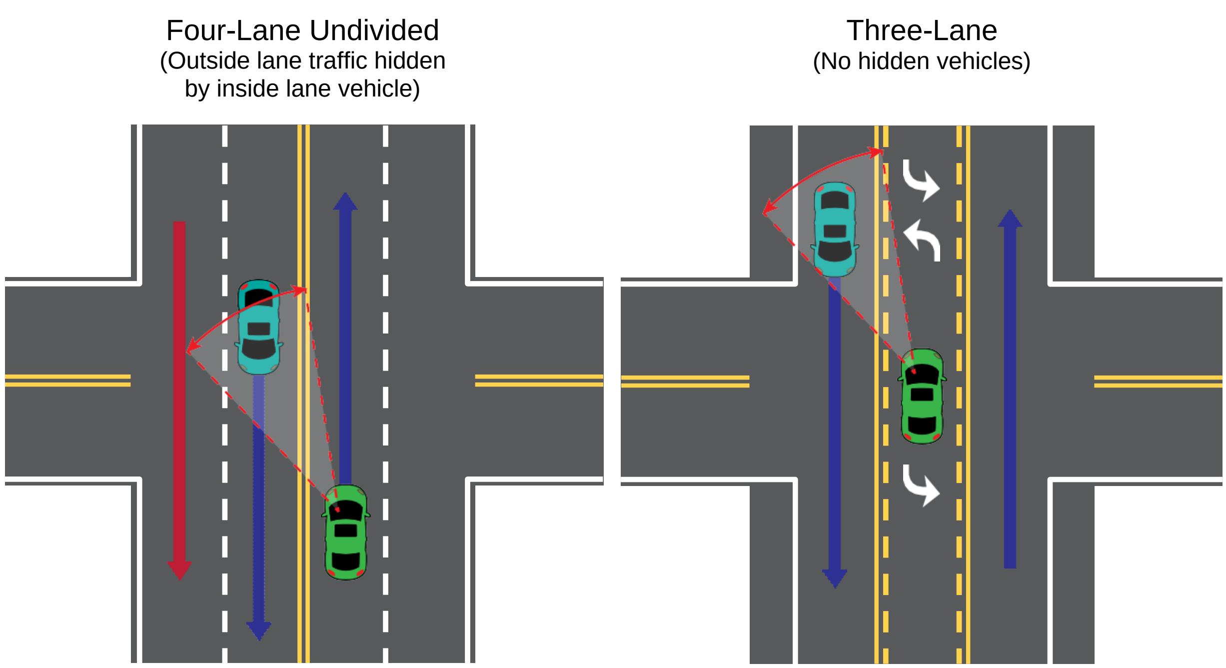



**Exhibit 8.1.3 Primary-Street Left-Turn Sight Distance for Four-Lane Undivided Roadway and Three-Lane Cross Section**



### 8.1.1.b – Operational Benefits

Typically, road diets provide the following operational benefits:

- **Separating Left-turns** – Separating left-turning traffic has been shown to reduce delays by removing turning vehicles from the through travel.
- **Improved Side-Street Traffic Crossing** – Side-street and driveway traffic can more comfortably cross the mainline roadway because there are fewer lanes to cross. By moving traffic into the TWLTL, side-street and driveway delays are reduced.
- **Speed Differential Reductions** – The reduction of speed differential provides more-consistent traffic flow and less "accordion-style" slow-and-go operations along the corridor.

On some corridors, a high number of turning movements result from the number and spacing of driveways and intersections. In these cases, four-lane undivided roads operate as de facto three-lane roadways. The majority of through traffic uses the outside lanes, due to the high volume of left-turning traffic on the inside shared through- and left-turn lanes. In these cases, a conversion to a three-lane cross section may have minimal hinderance on operational efficiency despite a reduction in the overall number of lanes.

### 8.1.1.c – Pedestrian and Bicycle Benefits

Road diets can benefit non-motorized road users. They often reallocate space from travel lanes to bike lanes (or in some cases sidewalks), where these facilities were previously lacking. Most road diets benefit pedestrians and bicyclists, regardless of whether specific facilities are provided for these modes. For example, speed reductions associated with road diets lead to fewer and less-severe crashes. Also, a reduced cross section makes it easier for pedestrians to cross a roadway, as they may have fewer travel lanes to cross and are exposed to moving traffic for a shorter period of time.

**Exhibit 8.1.4 Pedestrian/Bicycle Refuge Island**

Uncontrolled and mid-block pedestrian crossing locations tend to experience higher vehicle travel speeds, contributing to increased injury and fatality rates when pedestrian crashes occur. To increase safety, road diet design may include the addition of a raised pedestrian refuge island, placed on a street to separate crossing pedestrians from motor vehicles (as illustrated in **Exhibit 8.1.4**). With refuge islands, the crossing becomes shorter and less complicated because pedestrians have to be concerned with only one direction of travel at a time.

Road diets often include on-street parking or a bike lane, which creates a buffer between pedestrians and moving vehicles. This improvement is especially beneficial in central business districts.

For bicyclists, a major benefit of road diets is the addition of bicycle facilities. A road diet can transform a street that was formerly difficult to travel into a comfortable route that attracts bicyclists. When bicycle lanes are striped, bicyclists are made more visible, motorists know where to look for them, speeds are reduced, and bicycle safety can be improved.

Buffered bike lanes can enhance the comfort of the route and encourage increased usage. These are conventional bicycle lanes paired with a designated buffer space via lane markings. Additionally, physically separated bike lanes provide physical barrier buffer space. See Chapter 14, *Bicycle Facilities*, for more information.

Even without a dedicated bicycle lane or buffer, motorists on a three-lane roadway are able to move closer to the center lane when approaching a bicycle. In contrast, motorists on a four-lane undivided roadway have less opportunity to move to the left, as all lanes are active travel lanes.

## 8.2 – Operational Considerations

Since road diets typically reduce the number of lanes, the traffic operations must be evaluated. When developing a road diet, the designer should consider the following traffic operational factors:

- De facto three-lane or five-lane roadway operation
- Speed
- Level of service
- Quality of service
- Average daily traffic
- Peak hour and peak direction
- Turning volumes and patterns
- Frequently stopping and slow-moving vehicles

### 8.2.1 – De Facto Three-Lane or Five-Lane Roadway Operation

A road diet is likely to succeed operationally if the inside lanes are already functioning as turning lanes, where much of the through traffic avoids these lanes because of stopped vehicles waiting to turn. In these cases, an existing four-lane roadway operates as a de facto three-lane roadway and a six-lane roadway operates as a de facto five-lane roadway. In other words, a de facto roadway is one in which left-turning vehicles along the existing undivided roadway cause the majority of through traffic to use the outside lanes.

### 8.2.2 – Speed

When developing a road diet, it is important to match the posted and design speeds to the corridor's context, considering all users. Typically, potential road diet areas have higher pedestrian and bicycle volumes, with possibly younger pedestrians and bicyclists. Often, this means that lower vehicle speeds are desirable to provide a calmer traffic flow.

Road diets can reduce speed and speed differential, particularly in areas where speeding has been documented in an existing configuration. Case studies presented in FHWA's *Road Diet Informational Guide* indicate that the 85th percentile and average speeds are likely to decrease 3 mph to 5 mph through a road diet. Further, anecdotal evidence from several case studies has shown that road diets can result in lower vehicle speed variability.

### 8.2.3 – Level of Service (LOS)

Both intersections and roadway segments should be considered when looking at LOS for a road diet. Corridors with closely spaced signalized intersections may have a larger impact on the road diet operation, due to the queuing at adjacent signalized intersections. This impact can be mitigated by signal timing and coordination between adjacent signals, allowing the corridor to be "flushed" with each green cycle, or by changing the traffic-control elements (such as signal removal or roundabout installation).

The differences in delays and queues should also be considered when determining the feasibility of a road diet conversion. After the conversion, through-vehicle delay due to turning traffic typically decreases. Delays for left-turning vehicles, however, may increase because a similar through volume will use one through-lane rather than two. Through-vehicle delay and queuing along the main line and minor street approaches may also increase and should be considered in a detailed analysis.

The difference in these measures can be small if an existing four-lane undivided roadway is generally operating at a level close to that of a three-lane roadway. Several measures that also can be used to mitigate and minimize these operational impacts include, but are not limited to, signal optimization and coordination, turn-lane additions, and driveway consolidation.

Particular focus should be placed on minor street delays and queues at signalized intersections and available gaps at unsignalized intersections or driveways. The designer should consider the mitigation of any negative impacts through detailed alternative analysis and evaluation and weigh them against the benefits for non-motorized road users and other advantages of the road diet.

## 8.2.4 – Quality of Service

Quality of service is a quantitative indicator of the operational conditions of a facility or service and users' perception of these conditions. Designers should consider using quality of service for individual intersections, roadway segments, and the overall facility. Methodologies for urban street facilities in the Transportation Research Board's *Highway Capacity Manual* allow analysts to determine quality-of-service measures for automobiles, pedestrians, bicyclists, and transit.

Some general trends are expected for a road diet:

- Pedestrian LOS scores are likely to improve, due to lane reduction, speed reduction, and reallocation of traveled-way width to bicycle lanes and on-street parking.
- Bicycle LOS scores will improve as a result of some of the factors noted above, as well as with the addition of a bicycle lane.
- A corridor with frequent signalized intersections will have a larger impact on motor vehicle operations than on a corridor with more infrequent signal spacing. Frequently spaced signals are more likely to have queued traffic back-up into adjacent signals' effective areas, causing congestion issues. The vehicular LOS provides a more accurate view of conditions when there are longer distances between signalized intersections or only unsignalized intersections in the corridor.

## 8.2.5 – Average Daily Traffic (ADT)

The ADT provides a good first approximation on whether to consider a road diet. The FHWA advises that roadways with ADT of 15,000 vehicles per day (vpd) or less may be good candidates for a four-lane to three-lane road diet. However, if the ADT is near 20,000 vpd, designers should conduct further analysis to determine its operational feasibility. This includes looking at peak-hour volumes by direction and considering other factors, such as signal spacing, turning volumes at intersections, truck percentages and grades, and other access points.

**Guidance**

FHWA advises that roadways with ADT of 15,000 vpd or less may be good candidates for a four-lane to three-lane road diet and should be evaluated for feasibility.

### 8.2.6 – Peak Hour and Peak Direction

The peak-hour volume in the peak direction is the measure driving the analysis and can determine whether a road diet is prudent. This is the traffic volume used in calculating LOS for intersections or the roadway corridor.

Peak-hour volumes along urban roadways typically represent 8% to 12% of the ADT along a roadway. From an operational point of view, the designer should consider the following volume-based road diet guidelines for a four- to three-lane road diet:

- Typically acceptable at or below 750 vehicles per hour per direction (vphpd) during the peak hour.
- Cautiously considered between 750 and 875 vphpd during the peak hour.
- Typically not advisable above 875 vphpd during the peak hour, due to expected reduced roadway LOS during the peak period.

### 8.2.7 – Turning Volumes and Patterns

The volume and pattern of turning vehicles influence roadway safety and operation. In general, four-lane or six-lane undivided roadways begin to operate in a manner similar to three-lane or five-lane roadways as the number of access points and left-turn volumes increases.

A road diet may be prudent if these situations are expected during the entire design period. However, a more-detailed operational analysis of the existing and expected through and turning volumes is necessary.

It is important to understand the interaction between vehicles entering and exiting all points along a proposed road diet corridor. For example, as motorists try to turn in to driveways opposite each other, opposite-direction vehicles could end up in the TWLTL, resulting in potential conflicts.

Offset intersections can also cause problems, as left-turning vehicles entering the TWLTL from opposite directions desire the same space from which to make their turn.

**Example**

If a major driveway exists along the corridor, it could change the potential impact of a road diet by introducing another (often closely-spaced) opportunity for additional vehicular turning movements. As motorists try to turn into driveways opposite each other, opposite-direction vehicles could end up in the TWLTL, resulting in potential conflicts.

Recognizing that the design of intersections and driveways, along with the volume of left-turning traffic, can result in potential conflicts, the designer should identify and mitigate these conflicts through design.

### 8.2.8 – Frequently-Stopping and Slow-Moving Vehicles

The number and frequency of slow-moving and frequently stopping vehicles using a roadway corridor should be considered when evaluating a potential road diet. Examples of these vehicles include agricultural equipment, transit buses, curbside mail-delivery vehicles, trash pick-up trucks, and horse-drawn vehicles. These vehicles have a greater impact on the operation of a three-lane roadway than on a four-lane undivided roadway, with the primary reason being the inability of other vehicles to legally pass.  Please see Chapter 17, *Plain People Community Considerations*, for additional guidance related to transportation design in these areas.

When determining the prudence of a road diet, designers should consider the number and duration of vehicle stops along the corridor (particularly during peak hours), as well as the enforcement levels needed to deter illegal passing. One potential mitigation measure to minimize the impact of frequently stopping vehicles is to provide pull-out areas at specific locations along the corridor. Another potential mitigation measure is using some of the existing cross section for these vehicles (e.g., a transit lane). Improvements to intersection and driveway radii or pavement markings should also be considered if a road diet is selected.

## 8.3 – Bicycles, Pedestrians, Transit, and Freight Considerations

A road diet may present an opportunity to dedicate more space to other roadway users and create a more balanced transportation system. The following sections present considerations and examples of how road diets may be implemented with pedestrians, bicycles, transit, and freight operations in mind.

### 8.3.1 – Bicycle Considerations

For bicyclists, road diets often include adding bicycle lanes or wider shoulders to a street with little or no bicycle accommodation. The bicycle lane or wider shoulders make that route an option for many who would have been too intimidated to use the street previously.

Since bicycle routes are part of an integrated transportation network, one item to consider when determining whether a street is appropriate for a road diet is whether it fills a gap in the overall bicycle network or is part of a planned bicycle network.

If a formal bicycle network has not been identified, the roadway may still benefit from bicycle facilities. The street should first be studied to determine if there is any existing bicycle activity. If bicyclists are already using the roadway without a facility, significantly more bicyclists will likely use the route after a bike lane or shoulder is provided. Whether or not there is existing activity, demand for a bicycle facility should be estimated.


In cases where bicycle facilities already exist, a road diet may help to further enhance the comfort of bicyclists by adding buffer space or converting a standard bicycle lane to a protected bicycle lane. Adding buffers may have additional benefits to other users as well. For instance, adding buffers to narrow travel lanes may accomplish reductions in vehicle speeds, benefitting pedestrians as well as bicyclists.

Designers can refer to Chapter 14, *Bicycle Facilities*, for more information.

### 8.3.2 – Pedestrian Considerations

Road diets can include pedestrian facilities or wider shoulders for pedestrians. Additionally, road diets help reduce vehicle speeds and speed discrepancies midblock, making crossings easier and safer.

The primary considerations for pedestrians are similar to those for bicyclists:

- Is there already a sidewalk available?
- What is the level of pedestrian activity?
- Could the activity be expected to increase with the addition of facilities?

If there are no sidewalks lining the roadway, designers should consider adding them with the road diet. In some contexts, a sidewalk may not be necessary; however, adding a paved shoulder might benefit pedestrians.

The history of pedestrian crashes should factor into the decision as to whether to implement a road diet and what its components should be. Pedestrian crashes can be reduced by adding sidewalks or shoulders, adding pedestrian refuge islands and bulb-outs, and/or reducing the number of lanes pedestrians must cross. Land use and the intended pedestrian environment will also factor into decisions about implementing a road diet.

Designers can refer to Chapter 13, *Pedestrian Facilities*, for more information.

### 8.3.3 – Transit Considerations

It is important to consider the potential impact of existing or proposed transit features on all road users within a road diet segment. For example, transit vehicles may have more space available for bus stops, but they may present challenges by blocking a single through-lane when stopped.

Agencies should work with the corridor's transit providers to ensure that these stakeholders' needs are addressed. Although bus stops are typically located along the curb with on-street parking removed, the road diet design may incorporate pull-outs to prevent buses from blocking through traffic. Some stops might be eliminated or moved from either near-side or far-side locations at intersections to provide better pedestrian connections and to prevent buses from blocking the line of sight between pedestrians and motorists.

Designers can refer to Chapter 15, *Transit Facilities*, for more information.

## 8.3.4 – Freight Considerations

The unique needs of freight operators should be considered when developing a road diet. Freight operations can range from routine deliveries of goods to businesses along the corridor to freight generated within and outside a region. When evaluating a corridor for a road diet, designers must consider current and future freight operations, such as how stores and restaurants receive deliveries. Concepts addressing delivery receipt include rear-delivery access and strategically placed loading zones with time restrictions.

Road diets can appropriately accommodate freight movements while also serving other transportation users if some key factors are considered during the planning process:

- **Current Land Use**. Varied uses generate different volumes and types of truck movements. For example, restaurants in more densely populated areas or activity centers may generate relatively high volumes of truck movement when compared to lower-density residential areas. Keeping the land use along a corridor in mind will allow the design of a road diet to better meet local needs.
- **Truck Size**. Corridors that serve or connect to larger industrial properties may serve larger trucks that cannot easily maneuver on narrower roads. By contrast, commercial retail stores and offices are often served by smaller-unit delivery trucks.
- **Delivery Parking Areas**. Many urban areas lack dedicated truck-delivery parking areas, making it difficult for delivery trucks to find parking, thus increasing conflicts for all users. However, some urban areas can accommodate deliveries via alleys or side streets, avoiding some conflicts. Other options include dedicated curbside delivery parking areas or off-street parking lots.

Engaging freight stakeholders early in the project planning and development process provides an opportunity to align freight mobility with the goals of a planned road diet. Outreach to stakeholders, such as business owners, commercial and industrial property owners, and local carriers, can help identify potential issues with road diet implementation. Engagement with freight stakeholders increases the likelihood of agreement on a road-diet approach that balances freight mobility, safety, economic growth, and community needs.

Designers can refer to Chapter 16, *Freight*, for more information.

## 8.4 – Other Factors Influencing Implementation

Road diet design is typically tied to constructing the facility within the existing roadway cross section or right-of-way. However, in some cases, mitigating impacts to other corridor or non-corridor elements may be required. The acceptability of such impacts, with or without mitigation, should be considered when determining the practicality of a road diet. A more detailed analysis should be completed when all reasonable corridor cross-section alternatives are evaluated and compared.

Other factors influencing the implementation of a road diet include:

- Right-of-way availability and cost.
- Parallel roadways.
- Parallel parking.
- At-grade railroad crossings.
- Public outreach, public relations, and political considerations.

### 8.4.1 – Right-of-Way Availability

Many road diets can be completed within the existing curb-to-curb or roadway pavement envelope. In many cases, a road diet may include changes only in pavement markings. In these circumstances, a road diet may be a reasonable option if there are limitations on available right-of-way.

However, it may be necessary to incorporate changes in width at specific locations requiring additional right-of-way (e.g., at intersections for right-turn lanes).

### 8.4.2 – Parallel Roads

Road diets can cause some diversion of traffic to parallel routes. The designer must establish whether through vehicle drivers in the corridor of interest would desire parallel routes. This can be determined through discussions with those that travel the roadway or the application of appropriate simulation software.

The distance between parallel roadways should also be considered. It is less likely that motorists will divert to parallel routes that are farther away or congested. Another consideration relates to the community's concerns about motorists shifting to parallel local streets as "cut-through" traffic. If there is an increase in cut-through traffic, traffic calming or other mitigation measures on parallel streets may be warranted. It is important, then, that an increase in cut-through traffic is considered early in the road diet design process.

### 8.4.3 – Parking

Existing parking (full time or only during part of the day) and its impact on a road diet should be evaluated. This includes comparing the impact of parking maneuvers on a four-lane undivided roadway versus the three-lane cross section, as well as the interaction between bicyclists and parking vehicles (if a bicycle lane is added as part of the road diet).

### 8.4.4 – At-Grade Railroad Crossing

Railroad crossings must also be considered, since vehicles queued at an at-grade rail crossing need to be served by one through-lane after a four-lane to three-lane road diet. As vehicles wait for a train to pass, resulting queues may be approximately twice as long (which may not be acceptable).

It is also important to consider at-grade crossings for railroads that closely parallel the corridor. Where a parallel railroad is nearby, additional queuing due to a train passing would occur in the TWLTL in one direction and at the through lane in the other direction. If operation of the converted corridor is needed while a train passes, the addition of a right-turn lane with adequate storage may be necessary.

Signalization at these intersections also requires special attention both before and after the road diet conversion.

### 8.4.5 – Public Involvement

Although road diets have been applied for more than three decades, their implementation can still be challenging. Road diets remain relatively unusual and new to some transportation professionals, local jurisdictions, and the traveling public.

According to the Delaware Valley Regional Planning Commission’s Regional Road Diet Analysis Feasibility Assessment:

> “Education and outreach play a critical role in the success of a Road Diet. Many projects have demonstrated that public opposition can be strong in the early stages of a project. However, with committed stakeholders and an organized education and outreach program, the public can be better informed about the advantages and disadvantages of Road Diets”.

To address public concerns, communities have implemented trial road diet conversions. This approach requires restriping of the pavement within the proposed road diet area for a period of time before a determination is made to continue with a permanent installation. Temporary pavement marking materials, similar to those used in construction work zones, can be considered for this purpose.

The designer should also consider temporary signalization adjustments and potential issues related to turning vehicles. During the trial period, before-and-after operational studies can be completed, some preliminary crash analysis can be performed, and surveys can be conducted with adjacent landowners, first responders, and other community members. If the trial yields positive results, the municipality may agree to implementing a permanent road diet. If it is determined that a road diet is not the best option for the corridor, the roadway can be converted to its original lane configuration.

Trial road diets may not be necessary in areas where the benefits of the road diet might readily be recognized post-construction. However, due to road diets being relatively unusual and new to some transportation professionals, local jurisdictions and the traveling public adequate Public Involvement discussing road diets should be performed prior to final design of road diet projects.

## 8.5 – Design Considerations

Designers are guided by standards that serve to provide uniformity, but they are also flexible in achieving a project's context-specific needs and objectives. This is particularly true for road diets, where operational and geometric needs go hand in hand with a corridor's context.

This section provides insight into key design elements that need to be considered in developing road diets, including:

- Design vehicles
- Drivers
- Non-motorized users
- Speed

### 8.5.1 – Design Vehicles

Designers should consider the largest design vehicle that is likely to use a facility with considerable frequency, or a design vehicle with special characteristics appropriate to a location, in determining the design of critical features (such as the radii of intersections and turning roadways).

Design vehicle characteristics are important when considering new lane and shoulder widths (including possible traveled way widening on horizontal curves), storage lengths, and turning radii.

### 8.5.2 – Drivers

Considering driver expectations and performance remains as critical for road diet design as for any other facility type. Road diets can be particularly beneficial for older drivers who have slower reaction times and reflexes.

Designers should consider positive guidance, such as pavement markings, signing, and delineation) for all road users.

### 8.5.3 – Non-Motorized Users

When appropriately applied, road diets can generate benefits to all modes of transportation, including bicyclists and pedestrians. Pedestrian and bicycle dimensions, operating characteristics, and design guidance are presented in Chapters 13 and 14, respectively.

### 8.5.4 – Speed

Operational speeds of the road diet project should be evaluated against the existing corridor's operational speeds. As noted previously, studies have shown that a road diet can reduce the 85th percentile and average speed by 3 mph to 5 mph, particularly on roadways where speeding is present. Other studies have reported a 7% reduction in vehicles traveling over the posted speed limit, with a greater reduction in speed observed on corridors with higher traffic volumes.

Road diets have the potential to reduce operating speed differentials. The reduction in the number of through lanes can affect the speed differential by removing the ability to pass slower-moving vehicles. Changes in the road cross section may also influence drivers' perceptions of appropriate free-flow speeds.

## 8.6 – Design Elements

Basic principles of design apply to the corridor and the intersections bordering or within the road diet area. Given the cross-sectional changes, designers should perform new operational analyses at each intersection and explore the possibility of new lane arrangements and signal phasing.

Because road diets are usually within the existing roadway footprint, including shoulders, they typically do not change the basic roadway type. A road diet may be part of a reconstruction with no change to the roadway type, 3R, or pavement preservation project. The scope of work determines which design criteria to use.

Designers can refer to Chapters 3, *New Construction and Reconstruction Project CIRT*, and Chapter 4, *Reconstruction – NoCIRT, 3R, and Pavement Preservation Projects*, for more information on design criteria.

### 8.6.1 – Sight Distance

Significant changes in alignment are not expected during road diet conversions. Therefore, changes in sight distance due to the alignment design are likely to be insignificant.

However, changes in vehicle position due to cross section changes may have some impact on horizontal sight distance (i.e., available sight distance while traversing a horizontal curve, limited by sight obstructions on the inside of the curve) and/or intersection sight distance. Critical sight distance analysis for road diet conversions includes pedestrian crossings, transit stops, and locations where on-street parked vehicles serve as possible sight obstructions.

Road diets can provide sight distance improvements for mid-block, left-turning drivers at entrances due to the conversion of the undivided-roadway through lane to a TWLTL. Drivers in a four- or six-lane undivided situation experience negative offset with opposing traffic, which can block their view. In a TWLTL, this negative offset is removed, providing improved sight distance to drivers making left-turns.

Intersection sight distance at each intersection bordering or within the road diet area should be checked. It is possible that the required sight distance for minor streets intersecting a reduced-lane cross section will decrease, due to entering vehicles needing to cross fewer lanes. The available sight distance for vehicles turning left from the TWLTL is likely greater than that along a multi-lane, undivided cross section.

Designers can refer to Chapter 3 for more information on approach and departure sight triangles.

### 8.6.2 – Grade

Grades at locations with road diets will likely already be determined. Since a road diet may reduce the cross section to one through lane in each direction, the design vehicle performance will have a greater impact on overall vehicle operations. The grade and critical length of grade may have greater influence on performance than they do on a multi-lane cross section.

### 8.6.3 – Access Management

Due to operational changes that may occur through lane reductions, as well as the addition of a TWLTL, access management should be analyzed during the road diet design process.

The designer should consider the following at access points and intersections:

- Operations and efficiency of intersecting roadways.
- Access to property.
- Sight distance between vehicles and pedestrians.
- How driveways are used (e.g., backing out vs. forward out).

- Accessibility requirements.
- Accommodating bicycle lanes and sidewalks across intersections and driveways.
- Potential conflicts with bus stop locations.

## 8.6.4 – Cross-Sectional Design

Road diet conversions typically require the reallocation of the existing curb-to-curb or pavement-edge-to-pavement-edge distance. Deciding how to allocate these distances can be complex. In fact, a road diet is often selected because of its minimal impact on the general “footprint” of the roadway and because there is typically no need for right-of-way acquisition.

The reallocation of an existing cross section should consider the objectives for the existing corridor, as well as the needs of the road users it serves. In addition, designers must choose the type and width of each lane. Lane types along three-lane roadways may include, but are not limited to, through lanes, TWLTLs, bike lanes, transit lanes, and parking lanes. Each corridor undergoing conversion should be individually evaluated and designed.

The sections below discuss individual cross-sectional design criteria.

### 8.6.4.a – Lane Width

Lane width influences the operations, safety, quality of service, and security felt by road users. A road diet may reduce lane widths, and a design exception from the minimum lane widths as described in Chapters 3 and 4 might be appropriate. Transit routes may also influence the lane width. Transit design information is provided in Chapter 15.

### 8.6.4.b – Drainage

Road diets usually do not require significant changes in drainage design, as pavement widths and slopes remain relatively unchanged.

Designers can refer to Chapter 10, *Drainage*, and to PennDOT’s Publication 584 for more information on drainage.

### 8.6.4.c – Pedestrian Facilities

Road diets will typically not involve changes to the pedestrian sidewalk facilities outside the curb. For any changes to the pedestrian facilities, including the addition of pedestrian refuge islands, refer to Chapters 13 and 14.

### 8.6.4.d – Bicycle Facilities

Road diets can allow the addition or expansion of bicycle facilities. On roads where bicyclists previously shared lanes with motor vehicles, there are opportunities to provide bicycle lanes within the existing paved area. Where bicycle lanes already exist, the road diet can provide even more separation by adding a painted buffer or physical separation.

Bicycle lane widths should be based on context and anticipated use, including the speed, volume, and types of vehicles in adjacent lanes. The presence of a bicycle lane influences the recommended design of on-street parking accommodations, as well.

Where the road diet includes bicycle lanes, intersection designs should be modified accordingly. The bicycle facility should be carried up to and through the intersection. Where right-turn lanes are added, lane markings are needed to channelize and separate bicycles from right-turning vehicles. Additional considerations include provisions for left-turn bicycle movements, use of bicycle boxes, and bicycle-specific traffic signals.

Details related to these intersection design features are contained in Chapter 14.

**Exhibit 8.6.1 Right-Turn Transition Through Bike Lane**

### 8.6.4.e – On-Street Parking

Road diets provide the opportunity for on-street parking.

Designers can refer to Chapter 19, *Parking*, for more information.

### 8.6.4.f – Bus Turnouts

One potential concern with a road diet installation is that stopped buses block all downstream vehicles while loading and unloading. However, the available paved width provides space to potentially accommodate bus operations away from the traveled way via the use of turnouts as described in Chapter 15.  The designer should also confirm that in accommodating bus operations, other modes (bicycles, pedestrians, etc.) are not negatively compromised in terms of safety and operations.

### 8.6.4.g – Cross-Section Transitions

The starting and ending points of a road diet may require a transition from or to a different cross section. The design of these locations is typically a function of the width of the lane to be dropped and the posted or design speed at the lane drop locations. The *Manual on Uniform Traffic Control Devices* (MUTCD) provides additional detail.

Another important decision is the location of the cross-section transitions. Overall, continuity is important and transition points should occur at locations where the only decision a driver needs to make is related to the lane drop or addition. Therefore, when selecting a transition-point location, the objective is to minimize the complexity of the transition area and the number of decisions or potential conflicts that could occur while a driver is merging or diverging. For this reason, transitions should not occur at or near intersections or major driveways (within their influence area).

Some transitions are less complicated than others. For example, the transition from a three-lane roadway to a two-lane undivided roadway is relatively straightforward (as shown in **Exhibit 8.6.2**).

**Exhibit 8.6.2 Transition from Three-Lane to Two-Lane**

The transition from a four-lane undivided roadway to a three-lane roadway requires dropping the outside through lanes in advance of the complete cross-section conversion. This type of transition requires closer attention and involves the potential for through-vehicle conflicts. Overall, the lane drop and the introduction of the TWLTL should be installed in proximity to each other. The transition from a five-lane roadway to a three-lane roadway is a similar situation.

Overall, it is also important to look at the roadway cross sections near the end of the project limits for a road diet conversion. The overall objective is to minimize the number of transitions within a short distance. In other words, it may sometimes be more appropriate to extend the project limits to avoid this situation.

Also, through lanes should not be dropped as a turn lane at an intersection. This type of lane drop will often catch vehicles that want to continue through the intersection, resulting in inappropriate maneuvers.

## 8.6.5 – Intersection Design

Basic principles of intersection design apply to intersections bordering or within the road diet area. Given the cross-sectional change during road diet implementation, designers should perform a new operational analysis at each intersection. New lane arrangements and signal phasing are also possibilities.

The remainder of this section includes an overview of some design considerations for intersections bordering or within the road diet area.

### 8.6.5.a – Intersecting Roadways and Driveways

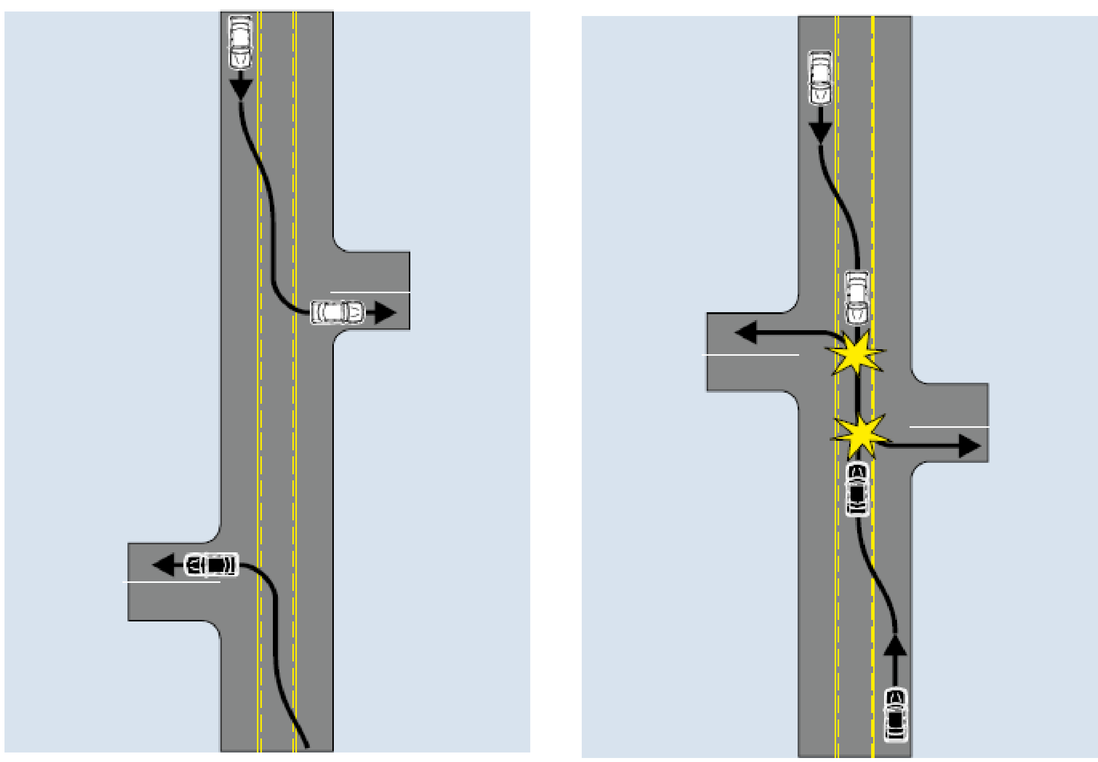
It is important to understand the impact of offset intersections and high-volume driveways on turning and through traffic. Operational and safety concerns may arise if there is a significant amount of through traffic crossing the major street from the offset minor streets or driveways.

If the offset is oriented such that vehicles crossing the main roadway must 'turn right' to continue through on the minor roadway or driveway, there is a greater possibility of conflict between the minor roadway vehicles and left-turning vehicles from the TWLTL for an intersection- or driveway-offset distance. This situation occurs when a vehicle traveling on a minor street enters the mainline and may stop in the TWLTL, negatively impacting other vehicles or making another unsafe maneuver.

**Exhibit 8.6.3** shows both favorable and unfavorable offsets configurations.

**Exhibit 8.6.3 Favorable and Unfavorable Offsets**

Favorable Offset | Unfavorable Offset



(Source: FHWA, *Access Management in the Vicinity of Intersections* FHWA-SA-10-002)



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### 8.6.5.b – Right-Turn Lanes

With a road diet, it may be possible and desirable to provide right-turn lanes, depending on the delay analysis. Some cases may require additional right-of-way and/or pavement width. The designer should always consider pedestrian safety when deciding whether to add a right-turn lane at intersections. If the right-turn lane is free-flow and yield-controlled, or if a right-turn-on-red is allowed at the intersection, pedestrians will be affected.

Where pedestrians and bicyclists are present, but trucks are only occasionally present, it may be desirable to use smaller turning radii to decrease the intersection area and reduce turning speeds.

However, the designer should analyze likely turning paths and encroachments of larger vehicles using the intersection and their effect on traffic operations and safety. Depending on truck volumes, the typical size of trucks using the intersection, and nearby truck-traffic generators, designers may need to consider larger radii to accommodate these road users.

The inside- and outside-turning radii of design vehicles should also be considered when the corridor being converted is not straight (e.g., the main designated route that is converted comprises two legs of an intersection that are at right angles to each other). Pavement markings and corner radii should be designed in combination to serve the left- and right-turning movement of the design vehicle at these locations.

### 8.6.5.c – Intersection Control Changes

The designer should evaluate traffic-signal phasing and timing when reducing the number of lanes. Performing an operational analysis will allow evaluation of the potential impacts of the proposed cross section, signalization on major and minor streets, vehicle and pedestrian delay, and queue lengths. This evaluation should also consider the potential impact of heavy vehicles.

In general, signal timing and phasing, along with the type and number of lanes on all intersection approaches, may need to be altered to minimize the operational impact of the road diet conversion. Specifically, mainline traffic may need additional "green time" due to the lane capacity reduction, especially during peak hours, to maintain mainline level of service. This could increase side-street delay during those time periods.

It is also important to adjust the positioning of the signal heads in a road diet to align them with the new lane configuration and to ensure that there is a minimum of one signal head installed over each traffic lane.

The designer should refer to the signalization information in the MUTCD, particularly Part 4, which focuses on highway traffic signals and includes a discussion of pedestrian controls. The signing needed for signalized locations is also contained in the MUTCD. The designer may also wish to review the FHWA's *Signalized Intersections Informational Guide*, as well as the FHWA's intersection safety website.

Experience has demonstrated that it may not be appropriate to complete a road diet when new signalization locations are needed along the same corridor. This is especially true if a road diet is a new concept within a jurisdiction.

In general, it is important for road users to understand what type of delays, if any, may be due to the conversion. The source of additional delays is not clear when a road diet is implemented along with new signalization locations. Each corridor is unique, and the success of a road diet is based on the objectives for each roadway. The two improvements might also be implemented separately (i.e., the signalization could be done before or after the road diet conversion).

A single-lane roundabout can be a good fit geometrically as part of a road diet installation. A roundabout provides additional opportunities for improved safety by eliminating most angle and head-on crash types, and by reducing intersection operating speeds. Roundabouts can provide operational improvements to the intersection by reducing queues and providing more consistent flow.

# Chapter 9 – Maintenance and Protection of Traffic (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 10 – Drainage (To be Added Later)

This chapter will be published in the future.  Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 11 – Erosion and Sediment Pollution Control (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 12 – Roadside Design (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 13 – Pedestrian Facilities (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 14 – Bicycle Facilities

In this chapter there are references to future chapter that are currently not included in this Publication 13.

Until they are included in this Publication, please refer to relevant topics in Publication 13M.

# Chapter 14 – Bicycle Facilities

## 14.0 – Introduction

Bikeways and bicycle facilities are an integral part of an interconnected multimodal transportation network, providing safe and convenient access to community goods and services for users of all ages and level of skill and abilities.

A bikeway is a facility intended for bicycle travel which designates space for bicyclists distinct from motor vehicle traffic. A bikeway does not include shared lanes, sidewalks, signed routes, or shared lanes with shared lane markings, but does include bicycle boulevards.

Bikeways differ from the more general term "bicycle facilities." Bicycle facilities include parking and storage facilities, or shared roadways not specifically designed for bicycle use, but which support and encourage bicycle use. Adding to or enhancing bicycle facilities increases equitable access to jobs, schools, parks, and health care, especially for individuals that rely on transit or do not own motor vehicles.

Bicycles operating on Pennsylvania roadways are considered vehicles and should be expected on all of the Commonwealth's roadways, with the exception of most limited access facilities or freeways. Therefore, the design criteria and treatment guidance provided in this chapter is intended to support the operation of bicycles as vehicles. In that light, the design of all PennDOT facilities, except those roadways where bicyclists are currently prohibited, shall include appropriate and reasonable accommodations for bicyclists.

The standards recommended in and presented as exhibits throughout this chapter have been successfully implemented in Pennsylvania or elsewhere in the United States. Within each section, treatments are covered with a brief description, specific design guidance, schematics/images, and references. By understanding the unique characteristics and needs of the interested but concerned cyclist, a designer can provide quality facilities that improve the non-motorized network, support access to community resources, and improve the level of comfort for users of all ages and abilities—all while minimizing user risk.

**Americans with Disabilities Act Standards for Transportation Facilities**

In addition to the design criteria provided in this chapter, the 2006 Americans with Disabilities Act Standards for Transportation Facilities (as required by 49 CFR 37.41 or 37.43) impose additional requirements for the design and construction of facilities, such as shared-use paths and structures that include provisions for pedestrians.

Providing the correct bicycle facility type for a corridor also requires an understanding of the intended users, transportation facility's context and key design components.

The designer should ask these important context questions:

- Is this bicycle facility in an urban or rural setting?
- Is this bicycle facility identified in a local, state, or regional transportation plan (indicating its importance to local bicyclists)?
- What types of bicyclists are desired for the facility (e.g., commuters, young or inexperienced bicyclists, touring bicyclists, recreational bicyclists, disabled bicyclists)?
- Will the facility accommodate and be intuitive for the most vulnerable users, including children, inexperienced bicyclists, and physically or intellectually disabled bicyclists?
- Will this facility be used by others (e.g., pedestrians, equestrians, skaters, dog walkers)?

Key design components include:

- **Working to Minimize Conflict Points**. Dangerous conflicts can arise between bicyclists and motorists at intersections when they share space on the roadway. The designer should consider designs that include physical infrastructure improvements that reduce motorized vehicle speeds (such as appropriate traffic calming measures) or eliminate identified conflict points. At a minimum, the design should include sign placement and pavement markings for bicycle lanes, especially those that enable the person riding a bike to safely and conveniently access and navigate the intersection. For example, Single-Point Urban Interchanges (SPUIs) are difficult for bicyclists to negotiate; separate facilities may be the best option for non-motorized users. If SPUIs must be used, signal timing should be adjusted to accommodate bicyclists. The designer must take care to properly mark, sign, and signalize those areas where the trail and roadway intersect, as well as avoid using one facility to accommodate both motor vehicles and bicycles (where possible and appropriate).
- **Being Cognizant of Barriers.** Numerous obstacles can present significant barriers to bicycles, especially when compared to those encountered by motorists. Furthermore, obstacles that may appear minor for able-bodied bicyclists can be insurmountable for disabled bicyclists (who may account for up to 15% of an urban bicycling community). For example, many disabled bicyclists live with chronic pain conditions, and cycling can be a less painful experience for these bicyclists than walking, except where they must cross humps, rumble strips, or other engineered uneven surfaces.

  Other barriers include: shoulders (which should be of adequate width with a smooth surface), on-street parking (which can limit sight distance, making it difficult to maneuver through traffic - especially when lane widths are narrow), railroad tracks, rough pavement, drainage grates, and bridge expansion joints (which can trap bicycle tires).

- **Working Toward Continuity and Connectivity**. Continuity of facilities is key to convenient utilitarian bicycle use. The designer should evaluate the way in which a bicycle facility ties into other bicycle paths and routes in the region and to transit service. As much as practical, the designer should consider consistency in width and user expectations.

  Providing continuity that supports bicycle trips to community resources, such as schools, employment centers, and parks, may take additional project development time and require the acquisition of additional right-of-way, but these efforts ultimately support Department goals and should be considered. Project managers should also consult local, regional, and statewide plans to determine if there are existing or planned bicycle routes that the project could enhance with additional work.

## 14.0.1 – Resources and References

Bicycle facility design is rapidly evolving as communities across the United States innovate and develop creative solutions to common transportation challenges. Many design resources at the federal and state levels incorporate the latest proven practices and encourage further implementation.

The development and design of bikeways within the Department's right-of-way should utilize a wide range of street design guidance to identify the treatment that best fits the project's context. The following is a list of available resources currently recognized by PennDOT as acceptable design guides.

- *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* (2015), FHWA.
- *Bikeway Selection Guide* (2019), FHWA.
- *Guide for Incorporating On-Road Bicycle Networks in Resurfacing Projects* (2015), FHWA.
- *Guide for the Development of Bicycle Facilities* (2012), AASHTO.
- *Roadside Design Guide* (2011), AASHTO.
- *Separated Bike Lane Planning & Design Guide* (2015), FHWA.
- *Small Town and Rural Multimodal Networks* (2016), FHWA.
- *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* (2018) FHWA.

The following resources provide the designer additional direction in the design and development of bicycle facilities. The use of some treatments in these resources, including any treatment outside of this chapter, will require special approval by the Director of the Bureau of Project Delivery, in coordination with the Bureau of Maintenance and Operations and the Multimodal Deputate.

- *Bicycle Boulevard Design Tools and Guidelines* (2000), City of Berkeley, California.
- *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (2010), Institute of Transportation Engineers.
- *Iowa Bicycle and Pedestrian Long-Range Plan* (2018), Iowa Department of Transportation.
- *On-Street Motor Vehicle Parking and the Bikeway Selection Process* (2021), FHWA.
- *Technical Analysis and Intersection Considerations to Inform Bikeway Selection* (2021), FHWA.
- *Transit Street Design Guide* (2016), National Association of City Traffic Officials (NACTO).
- *Urban Bikeway Design Guide* (2014), NACTO.
- *Urban Street Design Guide* (2013), NACTO.

Various text and graphics have been provided by the Tri-County Regional Planning Commission in Harrisburg, Pennsylvania, from their *Regional Bicycle Connections Study* (with permission from Alta Planning and Design).

## 14.1 – The Bicycle as a Design Vehicle

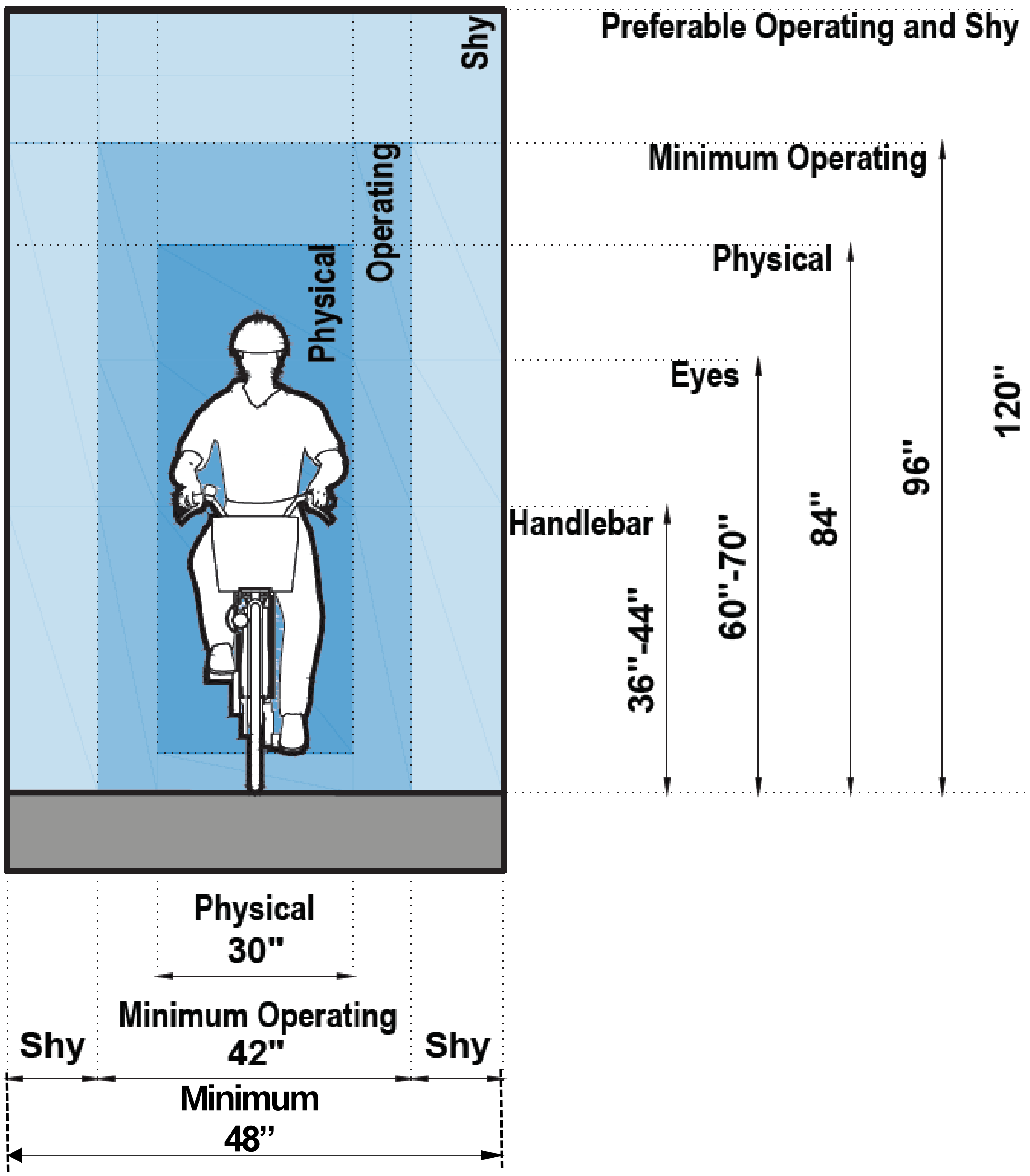
Most design criteria for roadways will not be affected by the bicycle as a design vehicle, except for the addition of space for a bike lane or paved shoulder. However, the bicycle as a design vehicle is an important consideration in the design of bicycle facilities themselves.

On a shared-use path, the bicycle and other non-motorized modes are applied as design vehicles. As with motor vehicles, bicyclists and their bicycles exist in a variety of sizes and configurations. These variations include vehicle type (such as a conventional bicycle, a recumbent bicycle, or a tricycle) and behavioral characteristics (such as the comfort level of the bicyclist). The design of a bikeway should consider expected bicycle types and utilize the appropriate dimensions.

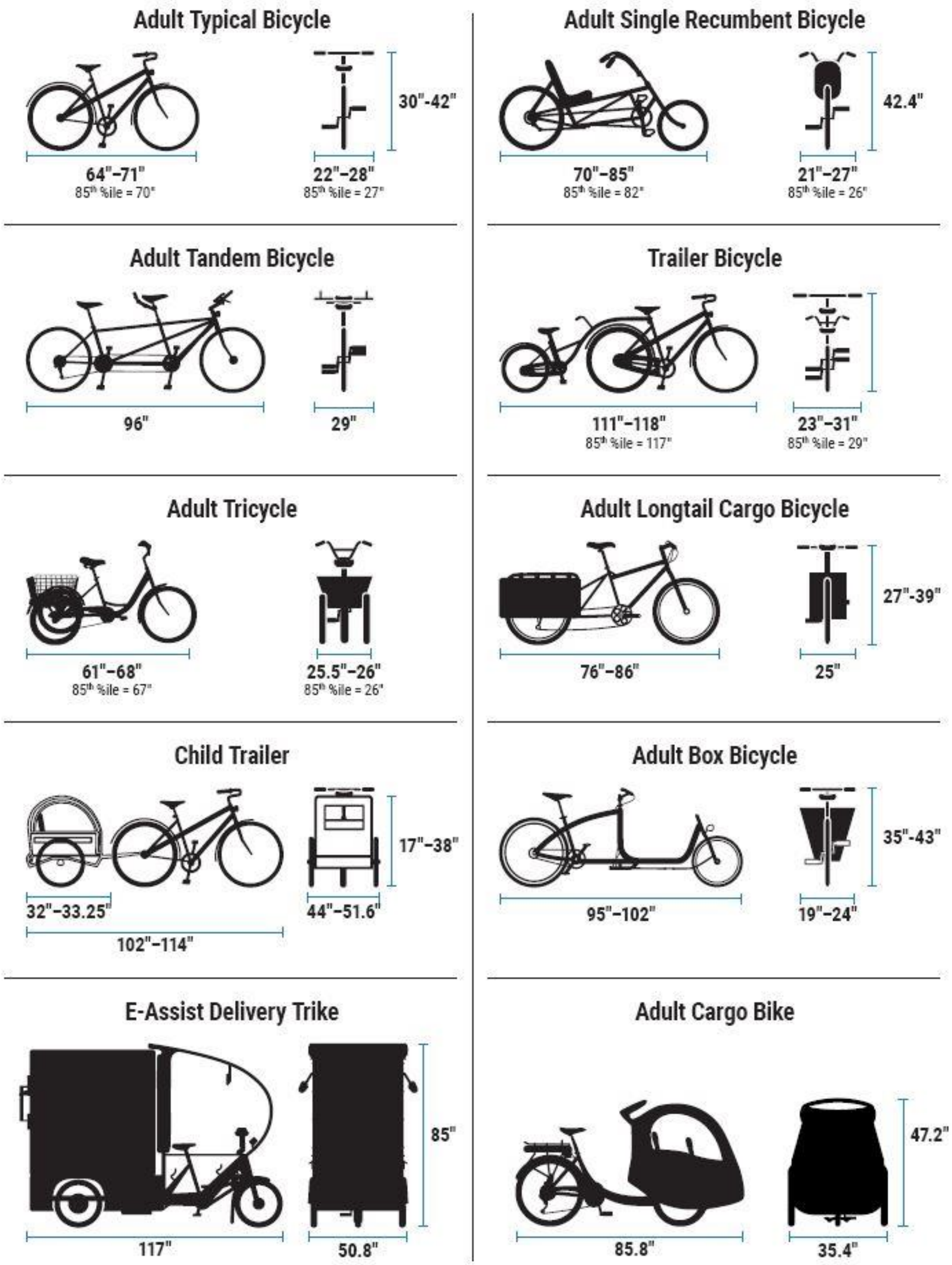
**Exhibit 14.1.1** illustrates the operating space and physical dimensions of a typical adult bicyclist, which is the basis for typical facility design. Bicyclists require clear space to operate within a facility and additional shy distance. Therefore, the minimum operating width is always greater than the physical dimensions of the bicyclist. Bicyclists prefer 5 feet or more operating width, although 4 feet is minimally acceptable.

In addition to the design dimensions of a typical bicycle, there are other commonly used pedal-driven cycles and accessories to consider when planning and designing bicycle facilities. The most common types include tandem bicycles, recumbent bicycles, and trailer accessories. Disabled cyclists may use wheelchair tandem pedalcycles, or side-by-side tandem bicycles, all of which require additional width. **Exhibit 14.1.2** summarizes typical dimensions for most bicycle types.

**Exhibit 14.1.1 – Standard Bicycle Rider Dimensions**



## Exhibit 14.1.2 – Typical Bicycle Dimensions



The expected speed that different types of bicyclists can maintain under various conditions also influences the design of facilities. **Exhibit 14.1.3** provides bicyclist design speeds for a variety of types and conditions. For signal timing purposes, lower design speeds (as low as 8 mph) should be used to account for lower-speed users. Design speeds that exceed 30 mph should rarely be used.

**Exhibit 14.1.3 – Bicycle Design Speed Expectations**

| Bicycle Type | Feature | Typical Speed |
|---|---|---|
| **Upright Adult Bicyclist** | Paved level surfacing | 15 mph |
| | Crossing Intersections | 10 mph |
| | Downhill | 30 mph |
| | Uphill | 5 -12 mph |
| **Recumbent Bicyclist** | Paved level surfacing | 18 mph |

*Tandem bicycles and bicyclists with trailers have typical speeds equal to or less than upright adult bicyclists.

## 14.2 – Selecting the Appropriate Bicycle Facility

Throughout Pennsylvania, the appearances of bicycle networks vary considerably, depending on the context, user groups, date of construction, and facility types. Different facility types serve different purposes, and designs and dimensions can vary significantly due to the surrounding context. Thus, the bicycle facility type within a project depends on the surrounding environment (e.g., automotive speed and volume, topography, adjacent land use) and expected bicyclist needs (e.g., bicyclists commuting on a highway versus students riding to school on residential streets).

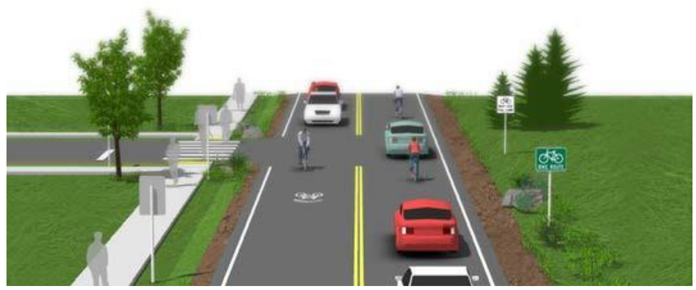
PennDOT supports the inclusion of a variety of facility types based on individual project needs. Studies have found that the most significant factors influencing a corridor's use by bicycles are traffic volumes and speeds. Other factors beyond speed and volume that affect facility selection include the traffic mix of automobiles and heavy vehicles, the presence of on-street parking, intersection density, surrounding land use, topography, and roadway sight distance. Additionally, the consistent use of treatments and applications along a bikeway facility allow users to anticipate whether they would feel comfortable riding on a particular facility and plan their trips accordingly.

### 14.2.1 – Facility Classification

The following classifications, which are consistent with bicycle facility classifications throughout the nation, identify facility types by their degree of separation from motor vehicle traffic.

- **Shared Roadways** – Shared roadways are roadways where bicyclists and cars operate within the same travel lane, either side by side or in single file, depending on roadway configuration. This category includes utilizing the shoulder and bicycle boulevards. These types of roadways do not accommodate the majority of people riding bicycles or other personal mobility devices and are far less desirable in urban and suburban contexts without the treatments discussed below.

  Except where prohibited, all roadways are shared roadways. Certain circumstances/constraints may warrant the consideration of shared lane signing/markings. The most basic type of bikeway is a shared roadway. This facility provides continuity with other bicycle facilities (usually bike lanes) or designates preferred routes through high-demand corridors.

  Shared roadways can incorporate various roadway treatments to enhance the shared-lane environment for both bicycles and motor vehicles. Treatments may include pavement markings, signage, and other treatments (including directional signage, traffic diverters, chicanes, chokers, and/or other traffic calming devices) to reduce vehicle speeds or volumes.

- **Visually Separated Bikeways** – Visually separated bikeways, such as bike lanes or buffered bike lanes, use signage and pavement markings to delineate the right-of-way assigned to bicyclists and motorists. These bikeways encourage predictable movements by both bicyclists and motorists. However, they do not provide the physical protection from motor vehicles desired by the majority of people who ride bicycles.



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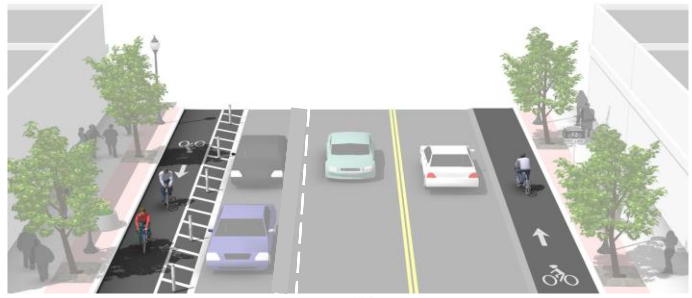
- **Physically Separated Bicycle Lanes** – Physically separated bicycle lanes are exclusive facilities that combine the user experience of a separated path with the on-street infrastructure of a conventional bike lane.



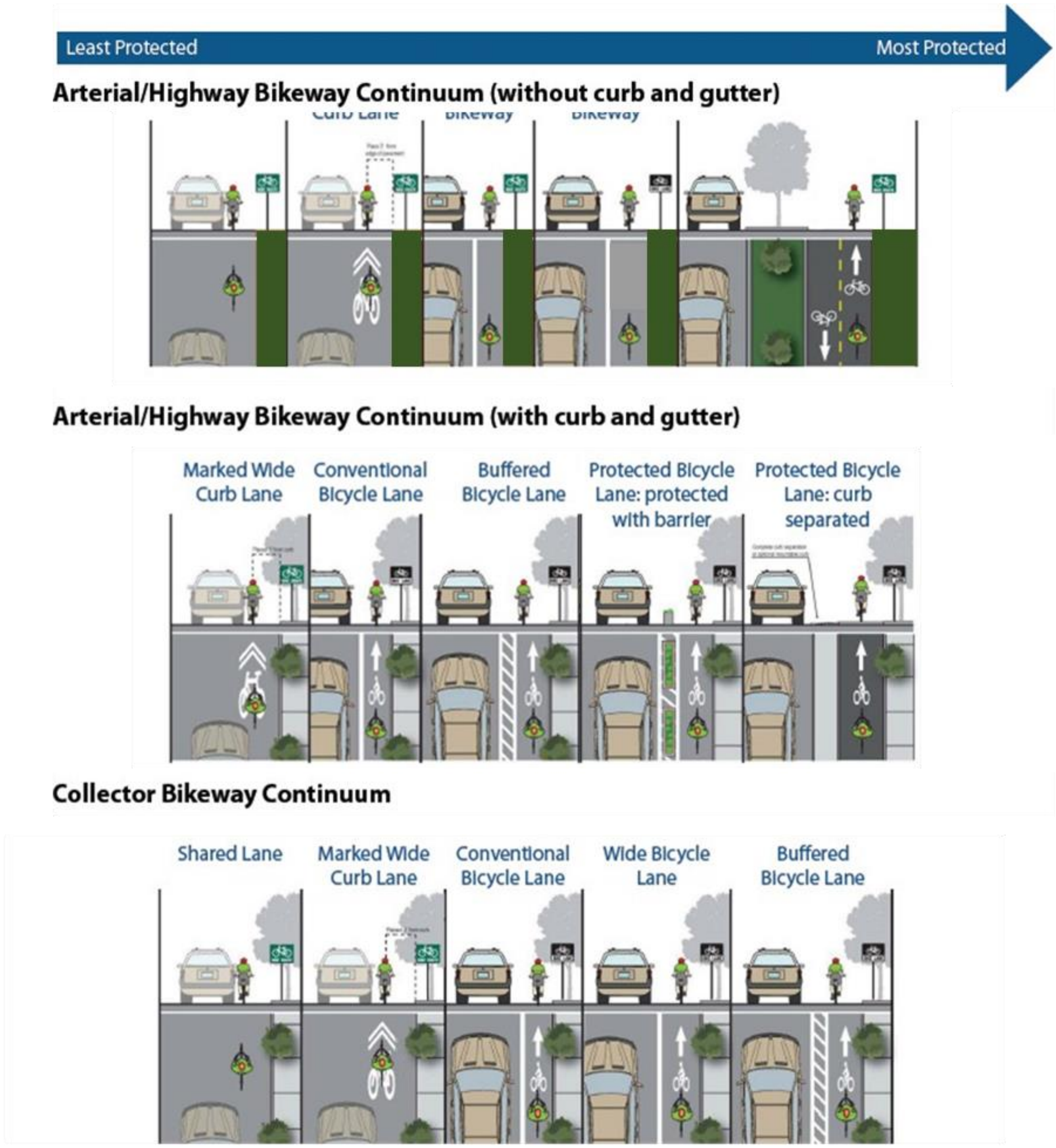
- **Shared-Use Paths –** Shared-use paths are facilities separated from roadways for use by bicyclists and pedestrians.

### 14.2.2 – Bikeway Treatments for Various Roadway Environments

**Exhibit 14.2.1** illustrates the range of bicycle facilities applicable to various roadway environments, based on the roadway type and desired degree of separation. The designer should use engineering judgment, traffic studies, previous municipal planning efforts, community input, and local context to refine criteria when developing bicycle-facility recommendations.

While the exhibit provides examples on how a bicycle facility might interact with various roadway classifications, some bicycle facilities may be a better fit with a particular roadway classification, depending on vehicle speeds, volumes, and surrounding land-use context. For example, in some corridors it may be desirable to construct facilities to provide a higher degree of separation from motor vehicle traffic to enhance user safety and comfort. In other cases, existing and/or future motor vehicle speeds and volumes may not justify the recommended level of separation, and a less intensive treatment may be acceptable.

**Exhibit 14.2.1 – Range of Bicycle Facilities Applicable to Various Roadway Environments**




## 14.2.3 – Urbanized Area Contextual Guidance

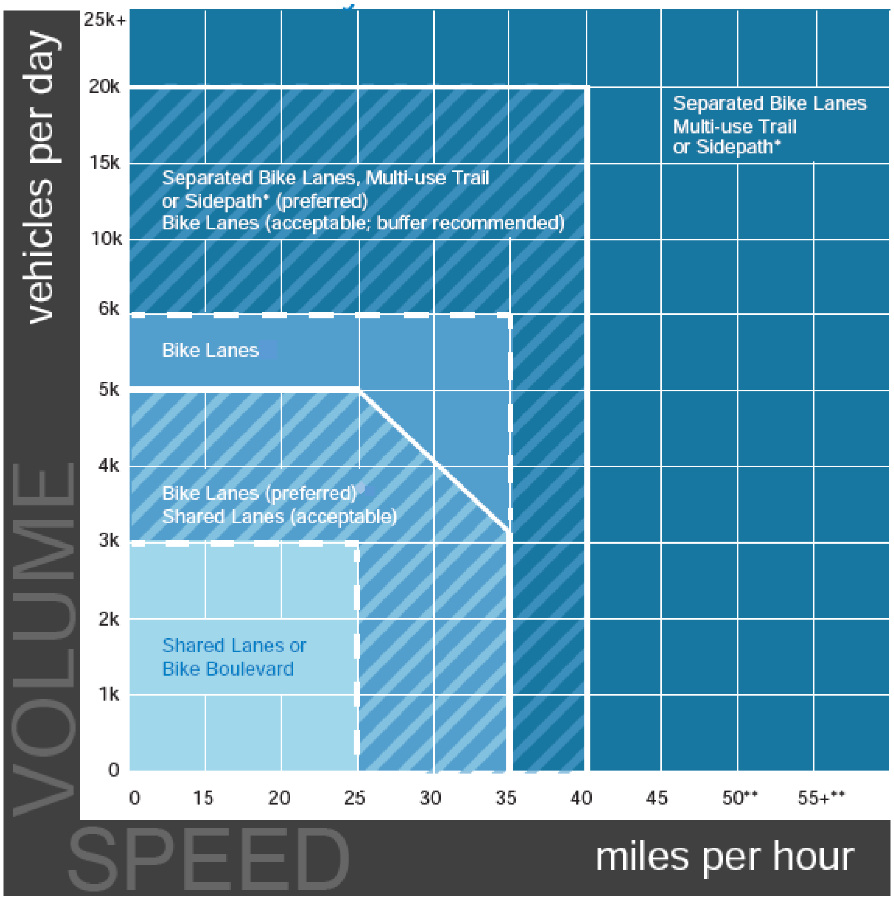
Selecting the best bikeway facility type for a given roadway can be challenging. This is due in part to factors that influence bicycle users' comfort and safety, such as when the speed differential between bicyclists and motor vehicle traffic is high and/or separation is low.

As a starting point, the designer should identify the anticipated or desired end user, then work to identify a preferred facility. Keeping in mind other considerations discussed in this chapter,

**Exhibit 14.2.2** can be helpful in determining the recommended type of bikeway for the end user based upon roadway speed and volume. In using the chart, the designer identifies the daily traffic volume and travel speed on an existing or proposed roadway, then locates the facility type indicated by those key variables.

Although **Exhibit 14.2.2** provides bicycle facility guidance, the other factors discussed in section 14.2. of this chapter should be considered in the facility selection and design process.

**Exhibit 14.2.2 – Urban and Suburban Facility Selection Matrix (Shoulder use is discussed in section 14.3.1)**




♦ To determine whether to provide a multi-use trail/sidepath or separated bike lane, consider pedestrian and bicycle volumes or, in the absence of volume, consider land use.

♦♦ Speeds 50 mph or greater in urban areas are typically found in urban/rural transition areas.

Source: Iowa Bicycle and Pedestrian Long-Range Plan

## 14.2.4 – Performance Measurement

The *Highway Capacity Manual* (HCM) establishes an objective method for determining the level of bicycle accommodation (i.e., Level Of Service or LOS) based upon the geometric and operational characteristics of the roadway analyzed. This method is based upon numerous research projects that quantified which factors influence how bicyclists perceive a roadway's safety and comfort. The model for links (i.e., roadway segments between intersections) includes the following factors:

- Width of the outside through lane
- Presence and width of a paved shoulder or bike lane
- Geometric encroachments into the bike lane
- Presence and width of a parking lane
- Percentage of parking occupied by parked vehicles
- Pavement condition
- Operating speeds on the roadway
- Traffic volume on the roadway
- Percentage of heavy vehicles on the roadway

Other options for measuring the level of accommodation include level of traffic stress and quantitative indices, as the HCM system does not fully address user experience beyond LOS. The HCM addresses the typical bicyclist, rather than advanced/proficient cyclist, and therefore may suggest that a LOS C provides adequate accommodations for the desired end user.

The primary geometric conditions that influence the level of accommodations are the width of the outside lane, presence and width of a paved shoulder, presence of guiderail or curb and gutter, existing bike lanes and their possible widths, and geometric encroachments into the bike lane or shoulder (such as a turn lane). It is likely that shoulders and/or bike lanes will be the facility of choice for accommodating bicycles in more-rural areas. However, a shared lane or wide outside through lane may be adequate.

On some projects, the pavement cannot be widened or restriped to provide shoulder or bike lane width. On these roads, the designer should analyze the available roadway space and traffic conditions to determine if bicycle accommodation can be achieved by adjusting lane widths or by removing travel lanes to provide widened shoulders or other engineering treatments. It is important to note that wider curb lanes (i.e., lanes adjacent to a curb) are not a preferred design because they support increased motor vehicle speeds, reducing safety and comfort for bicyclists.

Application of performance measurement for bicycle facility projects, whether qualitative or quantitative, is based on the context of the project and community desires.

### 14.2.5 – Bike Routes

A bike route is not an actual facility type. Rather, a bike route designates a facility (or collection of facilities) that links origins and destinations that have been improved or are considered preferable for bicycle travel. Bike routes include a system of wayfinding and route signs that provide at least the following basic information:

- Destination of the route
- Distance to the route's destination
- Direction of the route

Bike routes can be designated as general routes or number routes. General routes are links with a single origin and a single destination. Number routes form a network of bike routes that connect several origins to several destinations.

### 14.2.5.a – General Bike Routes

General routes connect users to destinations within a community. Typical destinations include attractions (such as stadiums and parks), neighborhoods (such as downtown and historic districts), and trail networks or trailheads.

Bicycle guide signs may be provided along designated bicycle routes to inform bicyclists of route direction changes and to confirm route direction, distance, and destination. The MUTCD provides several different types of signs that can be used to provide guidance along bike routes. Messages and installation of bicycle guide signs should follow the Tourist Oriented Directional Signs Policy described in Publication 46, *Traffic Engineering Manual*.

D1-1b

D1-3c


### 14.2.5.b – Numeric, Alpha, or Alphanumeric-Labeled Bike Routes

Some communities may implement a numeric-, alpha-, or alphanumeric-labeled system of bike routes. These routes should be designated using bicycle route signs per the MUTCD and Publication 236*, Handbook of Approved Signs*.


M1-8 M1-8a M1-8a


M1-8a

Bicycle route signs can be customized by adding a specific community logo in the upper portion of the ellipse. However, the Chief of the Highway Safety and Traffic Operations Division must approve customized signs.

There are several designated and labeled state bicycle routes throughout the Commonwealth and in the United States bicycle route system. Publication 236 provides sign design and location guidance for projects that include these routes.

Where a designated bicycle route extends through two or more states, the affected states send a coordinated submittal to the American Association of State Highway and Transportation Officials (AASHTO). AASHTO will then assign it a US bicycle route number. A system of proposed US Bicycle Routes is being developed. The US BIKE ROUTE sign (MI-9) is used to designate these routes; the MUTCD provides design details for this sign.


M1-9

## 14.3 – On-Road Bicycle Facility Design Considerations

On-road bicycle facilities are bicycle routes that use part of the roadway, either in a shared or dedicated space. Cyclists using on-road facilities are considered vehicles and shall obey all traffic rules.

The design of on-road facilities shall consider how motorists and cyclists may interact and reduce conflicts to the extent practicable. The designer should bear in mind available space and the potential for additional space when considering the inclusion of an on-road bicycle facility.

Strategies for finding extra space for on-road bicycle facilities include:

- Installing pavement markings and signage on existing paved shoulders.
- Physically widening the roadway as necessary to include bicycle facilities.
- Restriping the roadway to provide additional room (i.e., road diets).
- Removing a travel lane to provide additional room (i.e., road diets).

PennDOT recognizes four types of on-road bicycle facilities, which organized from least-protected to most-protected include:

- Shared Roads
- Bicycle Boulevards
- Visually Separated Bike Lanes
- Physically Separated Bike Lanes

### 14.3.1 – Shared Roads

On shared roadways, bicyclists and motor vehicles use the same roadway space. These facilities are typically used on roads with low speeds and low traffic volumes; however, they can be used on higher-volume roads with wide outside lanes or shoulders.

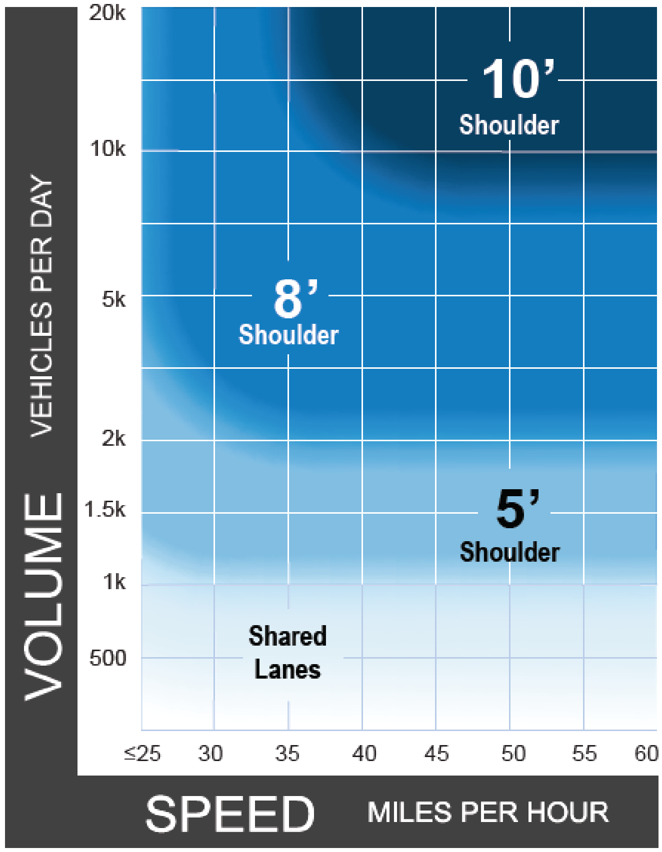
Shared roadways employ a variety of treatments from simple (e.g., no signage or markings or simple signage and shared-lane markings) to complex (e.g., use of directional signage, traffic diverters, chicanes, chokers, and/or other traffic calming devices to reduce vehicle speeds or volumes).

#### 14.3.1.a – Rural Conditions

In rural areas, bicycles will most often be accommodated through a shared roadway with no signing or markings. However, the suitability of a shared roadway decreases as traffic speeds and volumes increase, particularly on roads with sight-distance challenges. Where bicycle use or demand is potentially high and motor vehicle volumes and speeds are high, roads should be either physically widened or via striping to include paved shoulders or shoulder bikeways (shoulder bikeways are part of an intentional bikeway network and have intersection treatments).

**Exhibit 14.3.1** illustrates recommended shoulder widths for accommodating bicycles based on corridor speed and volume. Chapter 12 of this manual provides details on the design of rumble strips.

**Exhibit 14.3.1 Shoulder Width Considerations for Rural, Rural Town, and Suburban Bicycle Accommodations**




**Notes**

1 *This 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 operating 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 10%, consider providing a wider shoulder or a separated pathway.*

Source: FHWA Bikeway Selection Guide

### 14.3.1.b – Signing

The BICYCLE MAY USE FULL LANE sign (R4-11) may be used on roadways where the lanes are too narrow for bicyclists and motorists to operate side by side within a single lane or on roadways with significant volumes (where motorists would likely be delayed while waiting for a gap to pass the bicyclist). The sign informs users that bicyclists have the legal right to claim the lane if the right-hand lane is not wide enough to be safely shared with motor vehicles. Both the MUTCD and Publication 236 provide guidance on sign R4-11.

R4-11

The designer may consider using the SHARE THE ROAD sign (W16-101) where there is a need to warn drivers to watch for bicycles traveling along the roadway, or where the limited available lateral clearance makes it likely that bicyclists will either travel on the roadway or on the shoulder near the roadway. However, this sign is often minimally effective and should not be used alone or to avoid implementing higher-level roadway improvements. The sign is not to be used for long stretches of roadway. It is more useful at key locations or pinch points.

W16-101

For maximum effect, these signs should be used with discretion. The designer should consider their placement where:

- A relatively high number of cyclists can be expected on the roadway.
- The road narrows for a short distance (such as at the end of a bike lane or bridge approach), and a motorist and bicyclist may unexpectedly find themselves very near each other on the roadway.
- There is a history of bicycle crashes.
- Designated bicycle trails are located on short stretches of a major roadway that has not been improved for bicycling.
- A known conflict exists on the roadway.
- There are sections of roadway adjacent to shared-use paths where some bicyclists choose to ride on the roadway.

Both the MUTCD and Publication 236 provide guidance on sign W16-101. Additionally, Chapter 9 of the MUTCD and AASHTO's *Guide for the Development of Bicycle Facilities* provide information pertaining to signing and pavement markings for bicycle facilities.

### 14.3.1.c – Suburban and Urbanized Conditions

Many suburban and urban streets can function as shared roadways when traffic speeds and volumes are commensurate to the bicycle facility type. Further, there are many traffic calming techniques that can make these streets more comfortable for both bicyclists and motorists.





Road markings, known as sharrows, are typically used in urban settings to indicate a shared-lane environment for bicycles and motor vehicles.

Sharrows are often used when there is inadequate roadway width or right-of-way to accommodate a separate bicycle facility. These markings assist a bicyclist with lateral positioning in a shared lane that is too narrow for a motor vehicle and a bicycle to travel side-by-side within the same traffic lane. Sharrows alert road users of the lateral location bicyclists are likely to occupy within the traveled way.

Sharrows typically work best on low-speed and low-volume roadways, or to connect short distances between other bicycle facilities. These facilities typically are not major biking routes, but serve as short connections between major routes, into communities, or to other cycling networks.

Publication 111, Chapter 9 of the MUTCD, and AASHTO's *Guide for the Development of Bicycle Facilities* provide guidance on sharrow design and placement.

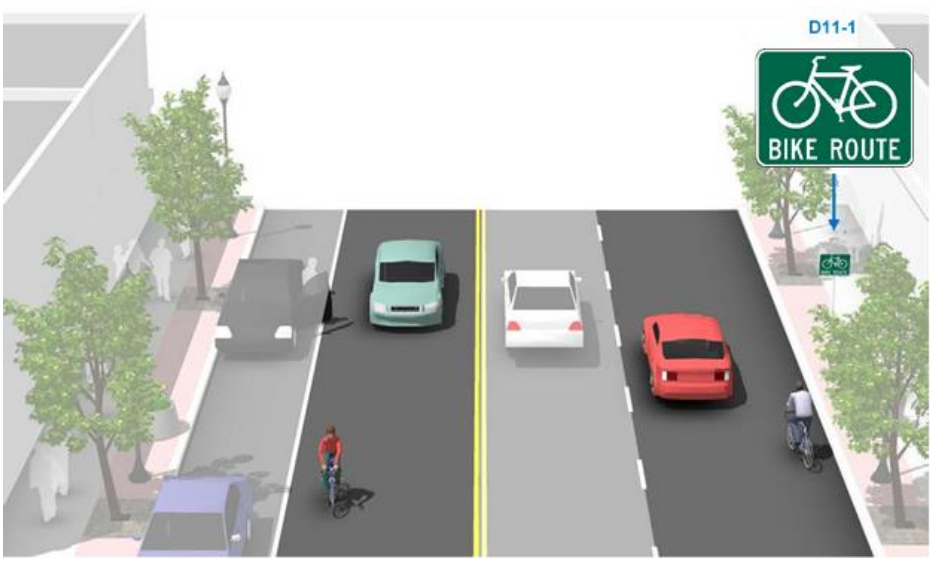
### 14.3.1.d – Signed Shared Roadways

Signed shared roadways are facilities shared with motor vehicles and are signed to make drivers aware of possible bicycle presence. They are typically used on roads with low speeds and traffic volumes; however, if appropriate, these facilities can be used on roads with higher volumes or speeds.

> **Guidance**
>
> Bike route signage (i.e., D11-1 sign) should be applied at intervals frequent enough to remind motorists of the presence of bicyclists. Commonly, this includes placement at:
>
> - The beginning or end of a bicycle route.
> - At major changes in direction or at intersections with other bicycle routes.
> - At intervals along a bicycle route, not to exceed 0.5 miles.

Usually, a motorist will have to cross into the adjacent travel lane to pass a bicyclist, unless a wide outside lane or shoulder is provided.

Signed shared roadways provide continuity with other bicycle facilities (usually bike lanes) or designate preferred routes through high-demand corridors. These facilities provide directional guidance and a wayfinding element for bicyclists, as well as alert motorists to the presence of bicyclists. However, the bicyclist is not provided with lane positioning guidance otherwise afforded through lane markings or sharrows.



### 14.3.1.e – Marked Shared Roadways

A marked shared roadway is a general-purpose travel lane delineated with shared-lane markings and possibly signed as a bike route to encourage proper positioning within the lane.

In constrained conditions, shared-lane markings are placed in the middle of the lane. On a wide outside lane, shared-lane markings can be used to promote bicycle travel to the right of motor vehicles. Shared-lane markings should always be placed outside of the door zone of parked cars.

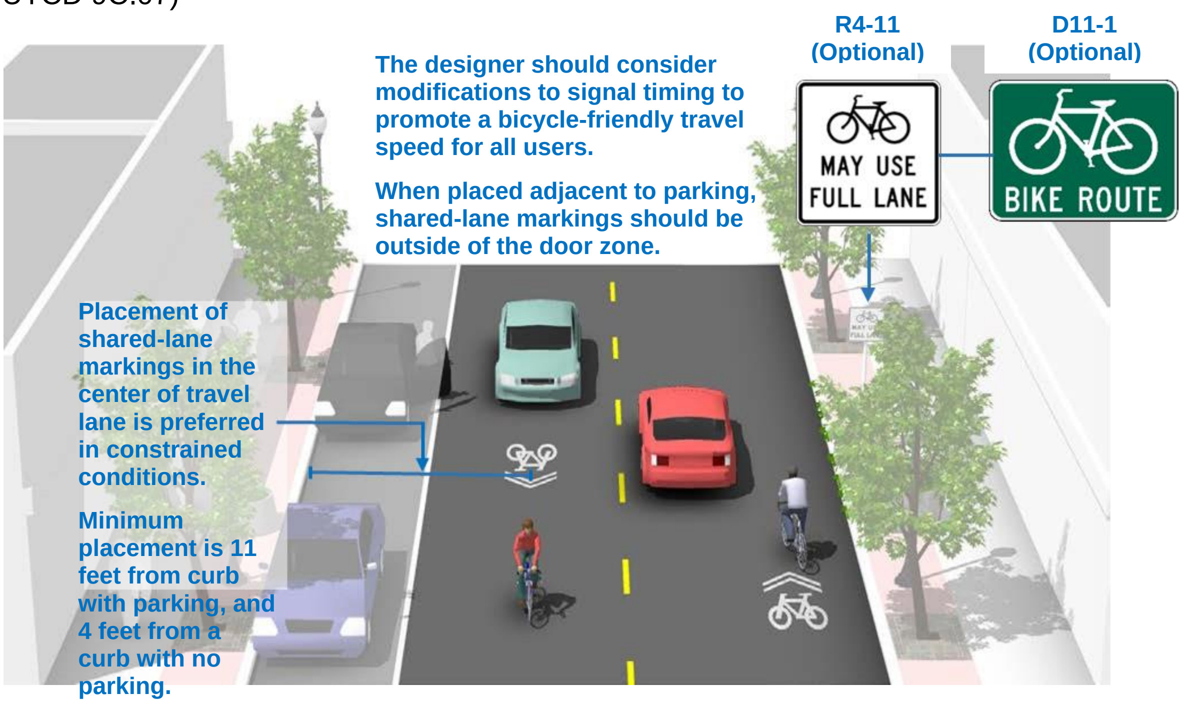
On a collector or arterial roadway, shared-lane markings should not be a substitute for dedicated bicycle facilities if space is available.

The designer should consider bike lanes on roadways with outside travel lanes wider than 14 feet, or where other lane narrowing, or removal strategies may provide adequate road space.

**Guidance**

- Shared-lane markings may be used on streets with a speed limit of 35 mph or lower (with a speed limit lower than 30 mph preferable).
- In constrained conditions, the preferred placement of shared-lane markings is in the center of the travel lane. This minimizes wear and promotes single-file travel.
- The minimal placement of the shared-lane marking centerline is 11 feet from the edge of a curb with on-street parking and 4 feet from the edge of a curb with no parking. If the parking lane is wider than 7.5 feet, the shared-lane marking should be moved out accordingly.

Shared-lane markings shall not be used on shoulders, in designated bike lanes, or to designate bicycle detection at signalized intersections. (MUTCD 9C.07)





pennsylvania
DEPARTMENT OF TRANSPORTATION

### 14.3.1.f – Shared Roadway Adjacent to Diagonal Parking

In areas with high parking demand, such as urban commercial centers, diagonal parking (also called angle parking) can be used to increase parking supply.

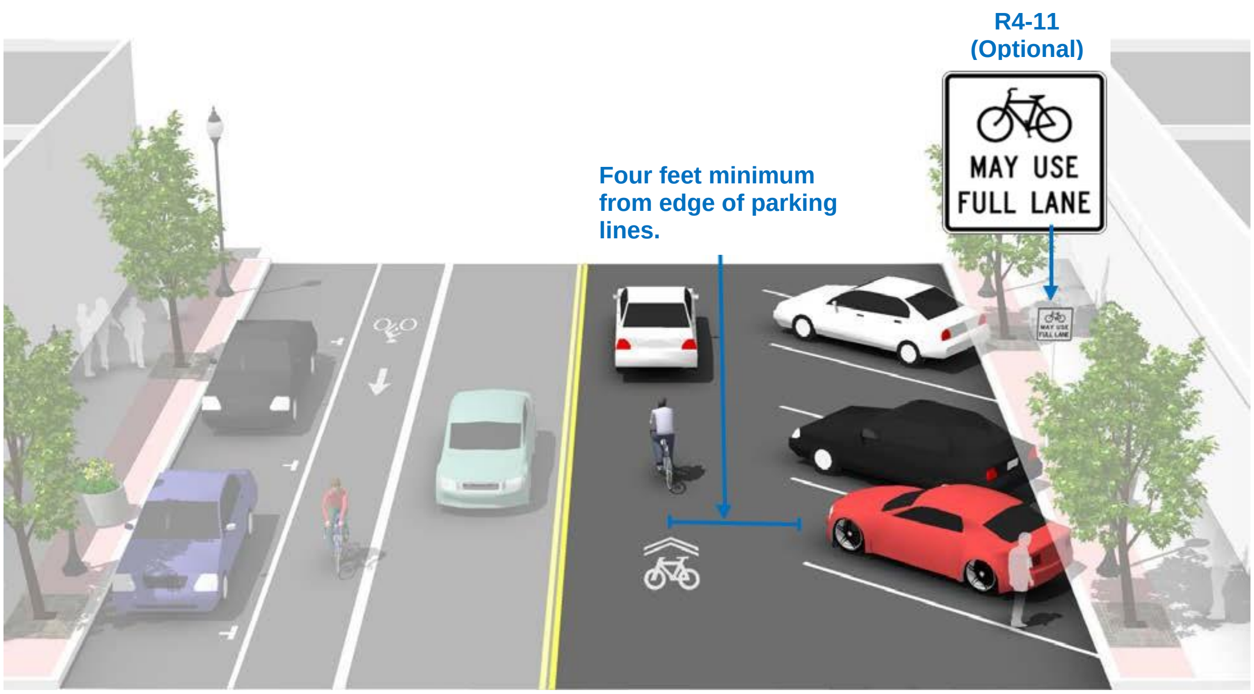
When compared to conventional front-in diagonal parking, front-out diagonal parking improves sight distances between drivers and bicyclists. Front-out diagonal parking also provides additional benefits, including loading and unloading of the trunk at the curb rather than in the street.

Front-out diagonal parking is typically an easier maneuver for drivers than conventional parallel parking. However, there may be encroachment into the sidewalk or pedestrian zone if an insufficient buffer is provided.

Conversely, front-in diagonal parking is not compatible or recommended in conjunction with high levels of bicycle traffic, as drivers backing out may have poor visibility in regard to approaching bicyclists.

**Guidance**

- In constrained conditions, the preferred placement is in the center of the travel lane to minimize wear and promote single file travel.
- Minimum placement of the shared-lane marking centerline is 4 feet from the edge of parking lines.



## 14.3.2 – Bicycle Boulevards

Bicycle Boulevards, also known as Neighborhood Greenways, take the shared roadway bike facility to another level by creating a convenient and comfortable bicycling environment for cyclists of all ages and skill levels.






Bicycle boulevards are low-volume and low-speed streets optimized for bicycle travel with treatments such as traffic calming and traffic reduction, signage and pavement markings, and improved intersection crossings. These treatments allow through movements for bicyclists while discouraging similar trips by non-local motorized traffic. They also maintain reasonable motor-vehicle access to properties along the route and to adjacent collector and arterial roads.

Although bicycle boulevards vary greatly in their individual design elements, each shares the common theme of reducing the volume and speed of motor vehicle traffic (particularly non-local, cut-through traffic), and creating a comfortable space where bicyclists, and often pedestrians, have priority along the street.

The primary characteristics of a bicycle boulevard include:

- Low motor vehicle volumes.
- Low motor vehicle speeds.
- Logical, direct, and continuous routes that are well marked and signed.
- Convenient access to desired destinations.
- Minimal bicyclist delay.
- Comfortable and safe crossings for cyclists at intersections.

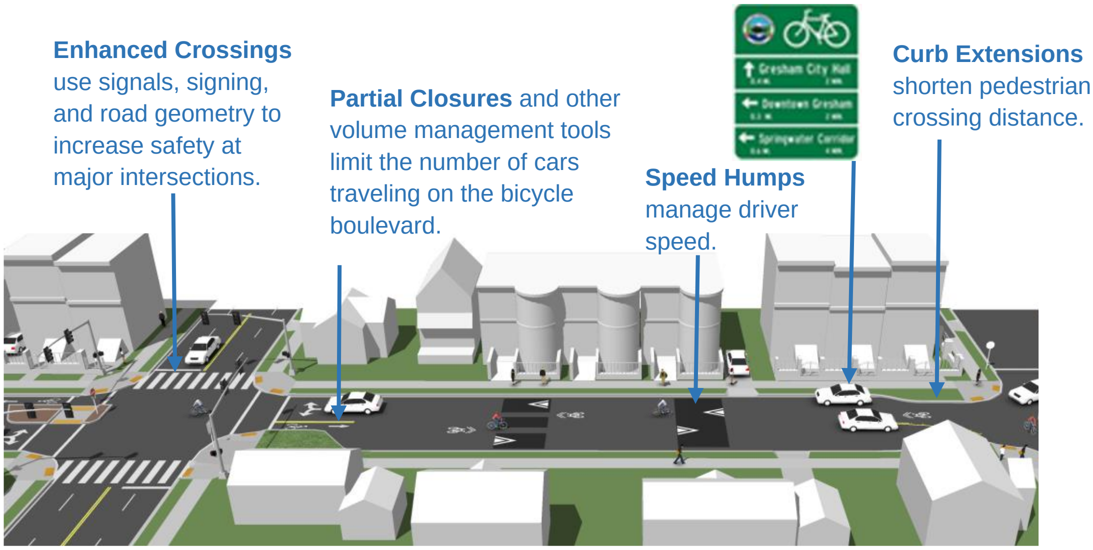
Some local streets may already provide optimal traffic conditions for a bicycle boulevard, requiring little more than signage and pavement markings to create the bikeway. Other streets, particularly roadways used frequently by motorists for through-trips, require features that reduce motor vehicle speeds and volumes and assist bicyclists in crossing busy intersections.

The specific design elements for creating a bicycle boulevard must be tailored to the unique conditions of each corridor. A variety of design options are available, including traffic calming, signage and pavement markings, traffic reduction strategies, intersection treatments, and prioritization of bicyclist travel. All or some of these elements may be employed on a single corridor depending on how favorable existing conditions are for bicycle travel.

Transportation professionals must employ good engineering judgment in selecting the combination of treatments to create the ideal conditions for a bicycle boulevard. The National Association of City Transportation Official's *Urban Bikeway Design Guide* provides additional guidance in creating bicycle boulevards.

**Guidance**

- Signs and pavement markings are the minimum treatments necessary to designate a street as a bicycle boulevard.
- Bicycle boulevards ideally should have a maximum posted speed of 25 mph.
- A speed differential between motor vehicles and cyclists of no more than 15 mph is desirable.
- Volume control treatments should be based on the context of the bicycle boulevard, using engineering judgement. Target motor vehicle volumes is less than 3,000 vehicles per day.
- Intersection crossings should be designed to enhance safety and minimize delay for bicyclists.
- Messages and installation of bicycle guide signs should follow the Tourist Oriented Directional Signs Policy described in Publication 46.




Bicycle Boulevards (Neighborhood Greenways) are not recommended for streets with traffic volumes higher than 3,000 vehicles/day. However, a segment of a neighborhood greenway may accommodate more traffic for a short distance, if necessary, to complete the corridor. Providing additional separation with a bike lane, protected bike lane, or other treatment is recommended where traffic calming or diversion cannot reduce volumes below this threshold.

### 14.3.2.a – Basic Treatments

At a minimum, signs and pavement markings are a necessity in designating a street as a bicycle boulevard or neighborhood greenway for both bicyclists and motorists. Signs and pavement markings also help bicyclists remain on the designated route.


Wayfinding signs displaying destinations, distances, and riding time can help to dispel common misperceptions, while increasing users' comfort and accessibility to the neighborhood greenway network.

In addition, signs can direct bicyclists to key destinations, including commercial districts, transit hubs, schools and universities, and other bikeways.

**Guidance**

**Pavement Markings**

- Symbols should be placed every 250 to 800 feet along a linear corridor, as well as after every intersection.
- Pavement markings should be placed in the center of the travel lane every 50 to 100 feet on narrow streets where a motor vehicle cannot pass a bicyclist within one lane of traffic.
- The Shared Roadway section of this chapter provides additional information on the use of shared-lane markings.

**Signs**

- Some cities have developed unique logos or colors for wayfinding signs that help brand their neighborhood greenways. Guidance on Bikeway Signing is contained within the Tourist Oriented Directional Signs Policy described in Publication 46.
- Sign content, design, and intent must be consistent. Colors reserved by the MUTCD for regulatory and warning road signs are not permitted.
- Signs can include information about intersecting bikeways, as well as distance and time information for key destinations.
- A bicycle sign, along with distinctive coloration, can be added to a standard road sign.

## 14.3.2.b – Vertical Traffic Calming

Speed affects the frequency at which motor vehicles pass bicyclists and the severity of potential crashes. Maintaining motor vehicle speeds closer to that of bicyclists greatly improves bicyclist's comfort on a street. Slower vehicular speeds also improve motorists' ability to see and react to bicyclists and to minimize conflicts at driveways and other turning locations.

Vertical speed control measures include slight rises in the pavement. To cross these rises, motorists and bicyclists must reduce their speed.




**Guidance**

- Bicycle Boulevards (Neighborhood Greenways) should have a maximum posted speed of 25 mph.
- Speed humps are raised areas usually placed in a series across both travel lanes. Speed humps can be challenging for bicyclists. They can force an unavoidable camber that tips over a three-wheeled pedal cycle or acts as a barrier to bicyclists with a chronic pain condition. Gaps can be provided in the center or by the curb to aid bicyclists and to improve drainage.
- Speed humps or cushions can be offset or contain gaps to accommodate the wheel tracks of emergency vehicles. A 14-foot long hump reduces impacts to emergency vehicles.
- Flat-topped speed tables are longer than speed humps. Raised crosswalks are speed tables that are marked and signed for a pedestrian crossing.
- The designer can refer to Chapter 18 of this manual for guidance on vertical traffic calming and specific design dimensions.

### 14.3.2.c – Horizontal Traffic Calming

Horizontal traffic calming devices cause drivers to slow down by constricting the roadway space or requiring careful maneuvering. Such measures may reduce the design speed of a street and can be used in conjunction with reduced speed limits to reinforce the expectation of lowered speeds.


Temporary Curb Extension

Horizontal speed control measures should not infringe on bicycle space. Where possible, the design should provide a bicycle route outside of the measure, so bicyclists can avoid having to merge into traffic at a narrow pinch point.

Choker or Neckdown

These measures can be implemented on a trial basis. Vehicle volumes on adjacent streets should be monitored to determine whether traffic calming results in undesirable traffic diversion. Please see Chapter 18, Traffic Calming, for further information.


Pinch Point with Bicycle Access

**Guidance**

- The design should maintain a minimum clear width of 20 feet (or 28 feet with parking on both sides), with a constricted length of at least 20 feet in the direction of travel.
- Chicanes are a series of raised or delineated curb extensions, edge islands, or parking bays on alternating sides of a street forming a S-shaped curb. They reduce vehicle speeds by requiring motorists to shift laterally through narrowed travel lanes.
- Pinch points are curb extensions placed on both sides of the street, narrowing the travel lane and encouraging all road users to slow down. When placed at intersections, pinch points are known as chokers or neckdowns. They reduce curb radii and further lower motor vehicle speeds.
- Mini-roundabouts can be used at minor street intersections in low speed environments. Mini-Roundabouts are small roundabouts with a fully traversable central island and splitter islands that are raised or delineated.

### 14.3.2.d – Traffic Diversion

Motor-vehicle traffic volumes affect the operation of a Bicycle Boulevard (Neighborhood Greenway). Higher vehicle volumes reduce bicyclists' comfort and can result in more conflicts. Using engineering judgment, the designer should implement volume control treatments based on the context of the neighborhood. Target motor vehicle volumes should be less than 3,000 vehicles per day. Above these volumes, the route should be striped as a bike lane or considered for a signed shared roadway.





**Guidance**

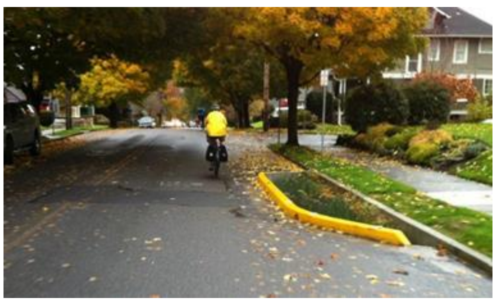
- Traffic diversion treatments reduce motor vehicle volumes by completely or partially restricting through-traffic on a neighborhood greenway.
- Partial closures allow full bicycle passage while restricting vehicle access to one-way traffic.
- Diagonal diverters require all motor vehicle traffic to turn.
- Median diverters provide a refuge for bicyclists to cross in two stages by restricting through motor vehicle movements.
- Street closures create a "T" that blocks motor vehicles from continuing on a neighborhood greenway, while allowing bicycle travel to continue unimpeded. Full closures can accommodate emergency vehicles by using mountable curbs that are a maximum of 6 inches high.

### 14.3.2.e – Minor Intersection Treatments

Treatments at minor roadway intersections (typically stop, yield or uncontrolled traffic control intersections) are designed to improve the visibility of a Bicycle Boulevard (Neighborhood Greenway), raise motorists' awareness that they are likely to encounter bicyclists, and enhance safety for all road users.


Stop signs increase bicycling time and energy expenditure, frequently leading to bicyclists' and motorists' non-compliance and/or use of other less-desirable routes. Bicycle boulevards should have fewer stops and delays than other local streets. According to Berkeley, California's *Bicycle Boulevard Design Tools and Guidelines*, a typical bicycle trip of 30 minutes can increase to 40 minutes if there is a stop sign at every block.


However, stop sign removal should be carefully evaluated beforehand. The warrants for stops signs should be re-evaluated to determine possible removal.

## Guidance

- On a Bicycle Boulevard (Neighborhood Greenway), most intersections with minor roadways should stop-control cross traffic to minimize bicyclist delay. This will maximize bicycling efficiency.
- Mini-roundabouts can be used at minor street intersections in low speed environments. Roundabouts reduce conflict potential and severity while providing traffic calming in the corridor.
- Roundabouts are yield controlled, typically have pedestrian access, give priority to circulating vehicles, and allow only counter-clockwise circulation.
- If a STOP sign is present on the bicycle boulevard, a second stop bar for bicyclists can be placed closer to the centerline of the cross street than the motorist stop bar. This treatment increases the visibility of bicyclists waiting to cross the street.
- Curb extensions can be used to move bicyclists closer to the centerline. This treatment improves visibility and encourages motorists to let bicyclists cross.

### 14.3.2.f – Major Intersection Treatments



The quality of treatments at major intersections (one or more major roadway, typically signal-controlled) along a bicycle boulevard that do not include adequate treatments to accommodate all ages and abilities of people on bicycles will become impassible barriers to non-motorized travel and directly conflict with the goals and vision of the Department's Active Transportation Plan. Without treatments for bicyclists, these intersections can become major barriers along the bicycle boulevard and compromise the effectiveness of the route.

Bicycle Boulevard retrofits are typically located on local streets without existing signalized accommodation at collector and arterial roadways crossings. The designer should consider signal warrants (i.e., traffic-control signal needs studies) for crossings of major streets.

**Guidance**

- A bike box is a designated area at the head of a traffic lane at a signalized intersection that provides bicyclists with a safe and visible way to get ahead of queuing traffic during the red signal phase. Where no separate bicycle signal or regulation exists that allows riders to proceed with the pedestrian signal, the designer should use the upper end of the recommended depth (12-16 feet) for the bike box (*NACTO Urban Bikeway Design Guide*).
- Median islands, provided at uncontrolled intersections of Bicycle Boulevards and major streets, allow bicyclists to cross one direction of traffic at a time as gaps in traffic occur. Again, care must be taken to ensure that the design allows pedal cyclists to use the facility.
- The National Cooperative Highway Research Program's (NCHRP) Report #562*, Improving Pedestrian Safety at Unsignalized Crossings,* offers guidance on the appropriate use of crossing treatments. Treatments are designed to improve visibility and encourage motorists to stop for pedestrians. With engineering judgement, many of the same treatments are appropriate for use along Neighborhood Greenways.

### 14.3.3 – Visually Separated Bike Lanes

Visually separated bikeways are designated exclusively for bicycle travel. They are generally segregated from vehicle travel lanes by striping and can include pavement markings and other treatments. Visually separated bikeways are most appropriate on arterial and collector streets where higher traffic volumes and speeds warrant greater separation.

See Appendix 14A for bike lane request procedures for new bike lanes.

Visually separated bikeways can increase safety and promote proper riding by:

- Defining road space for bicyclists and motorists, reducing the possibility that motorists will stray into the bicyclists' path.
- Discouraging bicyclists from riding on the sidewalk.
- Reducing the incidence of wrong way riding.
- Reminding motorists that bicyclists have a right to the road.





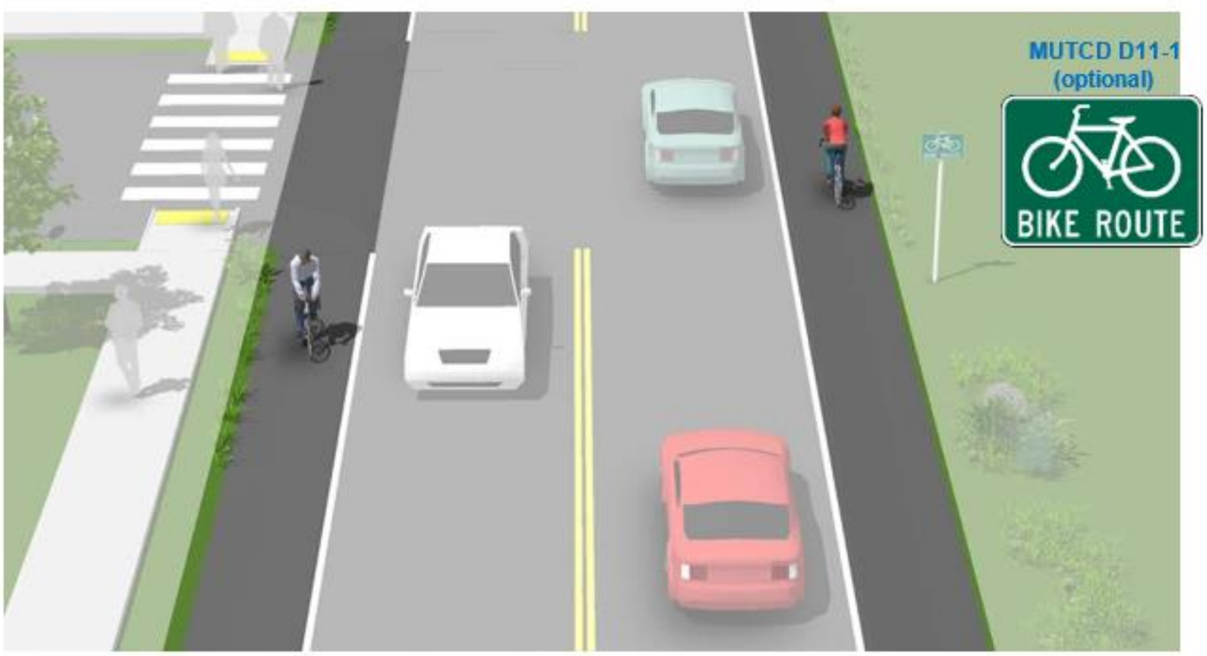
### 14.3.3.a – Shoulder Bikeways/Bike Lanes

Besides providing an area for bicyclists to ride on, paved shoulders are provided on rural highways for a variety of safety, operational, and maintenance reasons (including emergency stopping for motorists, escapes from potential crashes, and stormwater discharge).

Typically found in less-dense areas, shoulder bikeways are paved roadways with striped shoulders wide enough for bicycle travel (i.e., 4 feet or more). Shoulder bikeways may (but not always) include signage alerting motorists to expect bicycle travel along the roadway.

**Guidance**

- If 4 feet or more is available for bicycle travel, the full bike lane treatment including signs, pavement markings, and a 6-inch lane line would be provided.
- Rumble strips are not recommended on shoulders used by bicyclists unless there is a minimum 4-foot clear path.
- The minimum functional width for a paved shoulder used by bicyclists is 4 feet (especially if placed between rumble strips and the edge of pavement).



### 14.3.3.b – Conventional Bike Lanes

Bike lanes designate an exclusive space for bicyclists through the use of pavement markings and signage. The bike lane is located adjacent to motor vehicle travel lanes and is used in the same direction as motor vehicle traffic. Bike lanes are typically on the right side of the street, between the adjacent travel lane and curb, road edge, or parking lane.

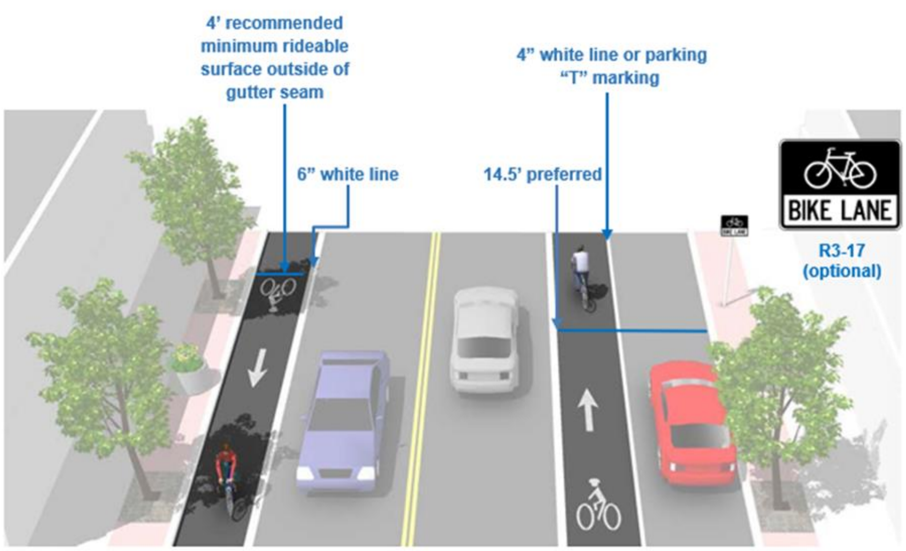
Many bicyclists, particularly less experienced riders, are more comfortable riding on a busy street if it has a striped, signed, and physically separated bikeway.

Wider bicycle lanes are desirable in certain situations, such as on arterials with speeds exceeding 45 mph. In these situations, the use of a wider bicycle lane increases separation between passing vehicles and bicyclists.

Appropriately signing and pavement marking of wide bicycle lanes is important to ensure motorists do not mistake the bicycle lane for a vehicle lane or parking lane. The designer should consider buffered and separated bike lanes when further separation is desired.

**Guidance**

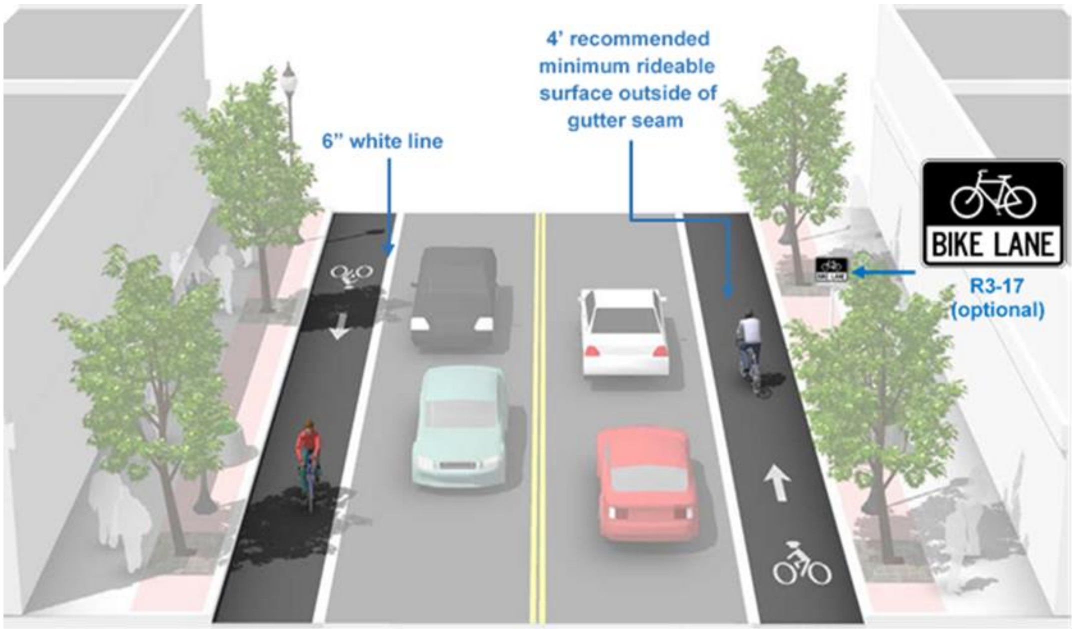
- The minimum bike lane width should be 4 feet when no curb is present or 5 feet if there is curb without gutter.
- When adjacent to a vertical curb and gutter, the width of bike lane shall be a minimum of four feet and will not include the gutter seam.
- The minimum width from the curb face to the edge of the bike lane should be 12 feet (with a preferred width of 14.5 feet if a 4-foot bike lane width is used) when on-street parking is present.
- The maximum width of the bike lane should be 7 feet when adjacent to arterials with high travel speeds. Greater widths may encourage motor vehicle use of bike lane.
- Bike lanes can be configured as buffered bicycle lanes when a wider facility is desired.



### 14.3.3.c – Bike Lane Without On-Street Parking

Wider bicycle lanes are desirable in certain situations, such as on arterials with speeds exceeding 45 mph. In these situations, the use of a wider bicycle lane would increase separation between passing vehicles and bicyclists.

Appropriately signing and pavement marking of wide bicycle lanes is important to ensure motorists do not mistake the bicycle lane for a vehicle lane or parking lane. The designer should consider buffered and separated bike lanes when further separation is desired.

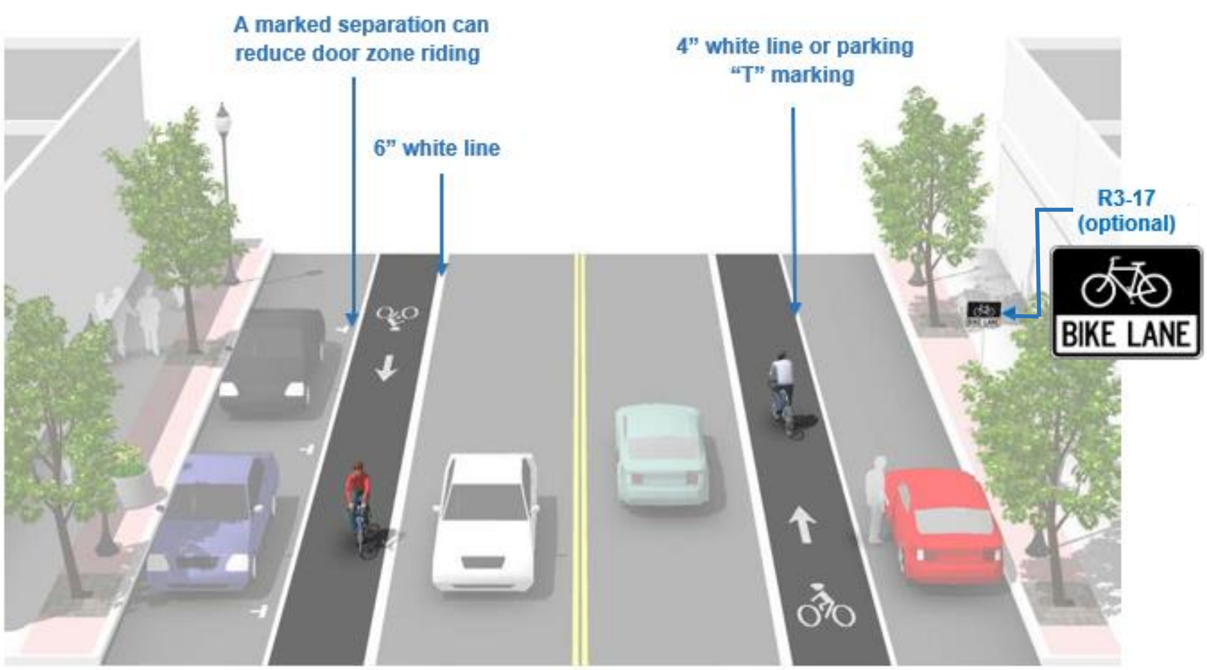


### 14.3.3.d – Bike Lane Adjacent to On-Street Parallel Parking

Bike lanes designate an exclusive space for bicyclists using pavement markings and signage. The bike lane is located adjacent to motor vehicle travel lanes and is used in the same direction as motor vehicle traffic. Bike lanes are typically on the right side of the street between the adjacent travel lane and curb, road edge, or parking lane.

Bike lanes adjacent to on-street parallel parking require special treatment to avoid crashes caused by an open vehicle door. The bike lane should have sufficient width to allow bicyclists to maneuver out of the door zone. Note the door zone is typically 4 feet wide and may consist of the parking width markings area, a buffer area between parking area and the bike lane, and/or a portion of the bike lane. The minimum width from the curb face to the edge of the vehicle travel lane / bike lane should be 12 feet. The preferred width is 14.5 feet if a 4-foot bike lane width is used.

Parking stall markings (i.e., parking "T" markings) create a parking-side buffer that encourages bicyclists to ride farther away from the door zone and motorists to park closer to the curb. However, there is often limited room available and the full width of the bike lane cannot be provided. This should not discourage placement of a narrower bike lane, as drivers and vehicle occupants have a responsibility to confirm bicyclists are not at risk of being "doored" when exiting their vehicle. The minimum distance between the "T" markings and the line lane marking is 6 inches.



## 14.3.3.e – Bike Lanes and Diagonal Parking

Front-out diagonal parking is strongly preferred (as compared to front-in diagonal parking), as it improves sight distances between drivers and bicyclists. Front-out parking is best paired with a dedicated bicycle lane.

Conventional front-in diagonal parking is not compatible or recommended with the provision of bike lanes, as drivers backing out have limited visibility of approaching bicyclists. Under these conditions, shared-lane markings should be used to guide bicyclists away from reversing automobiles.

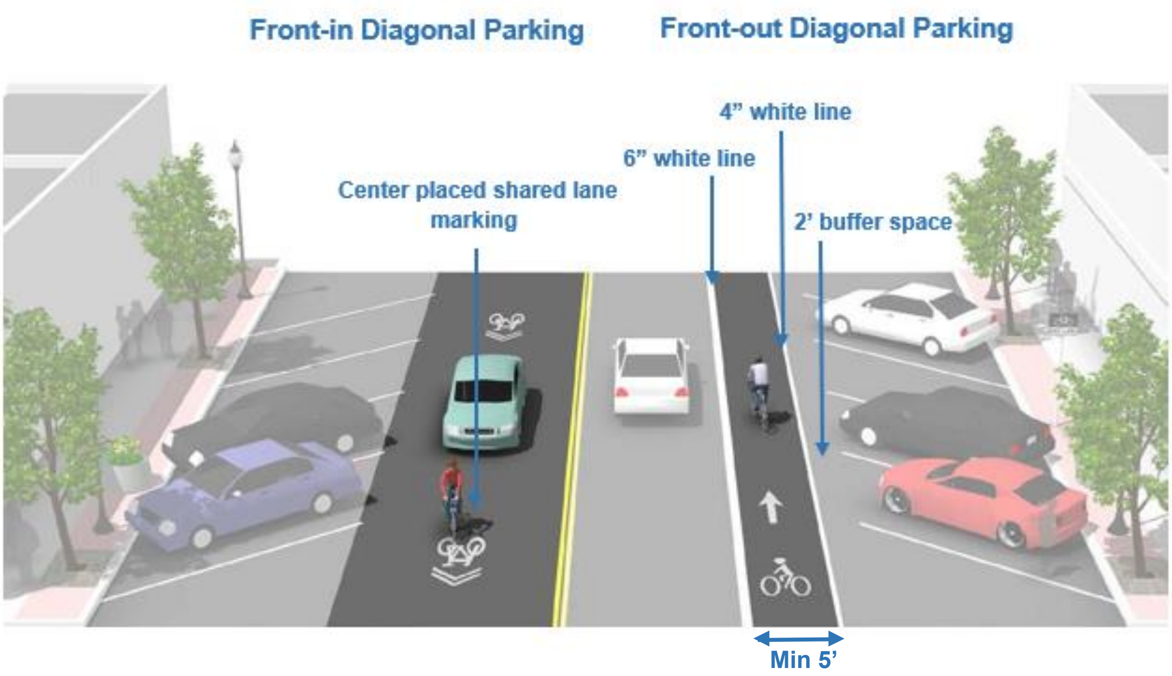
**Guidance**

**Front-in Diagonal Parking**

- Shared-lane markings are the preferred facility type.

**Front-out Diagonal Parking**

- The bike lane has a minimum 5-foot marked width.
- Parking bays are sufficiently long to accommodate most vehicles (so vehicles do not block the bike lane).



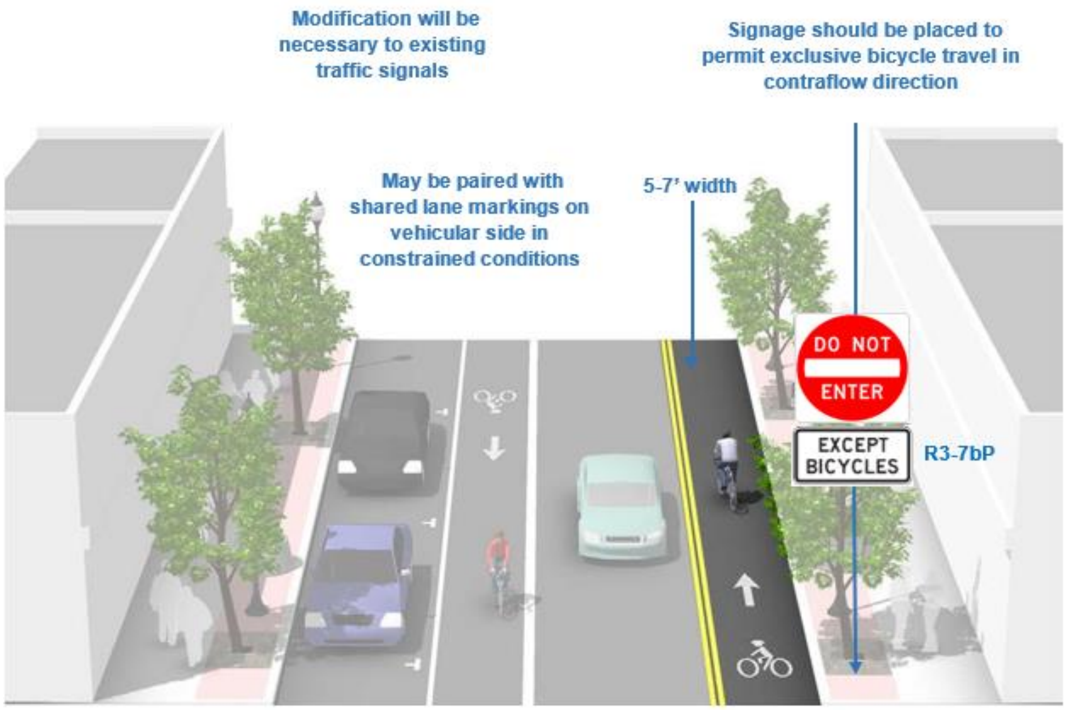
### 14.3.3.f – Contraflow Bike Lanes

Contraflow bike lanes provide bidirectional bicycle access on a roadway that is one-way for motor vehicle traffic. This treatment can provide direct access and substantially increase network connectivity for people on bicycles. Creating a one-way road from a two-lane roadway by replacing a motor vehicle travel lane with a contraflow bike lane can reduce traffic volumes and speeds in residential neighborhoods. Contraflow lanes should be on the left side from the direction of motor vehicle travel for the road.

**Guidance**

- The contraflow bike lane should be 5 to 7 feet wide and marked with a solid double yellow line and appropriate signage. Bike-lane markings should be clearly visible to ensure that the contraflow lane is exclusively for bicycles. The designer should consider coloration in the bike lane.
- Signage specifically allowing bicycles at the entrance of the contraflow lane is necessary.

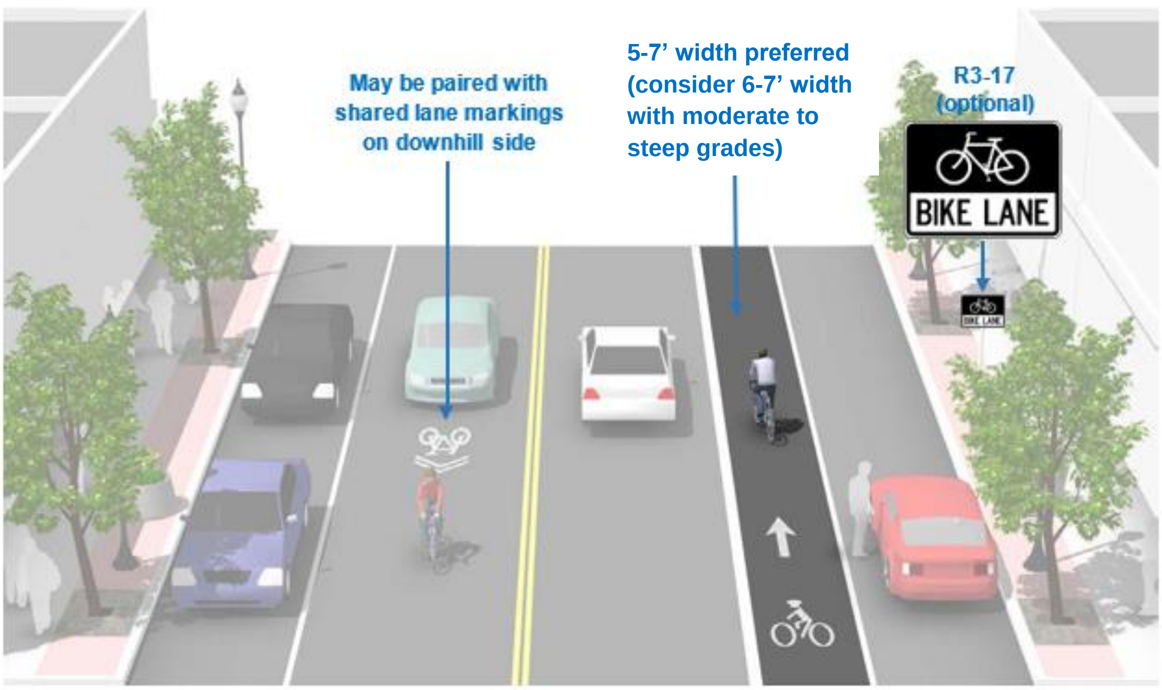
Because of the opposing direction of travel, contraflow bike lanes increase the speed differential between bicyclists and motor vehicles in the adjacent travel lane. If space permits, the designer should consider a buffered bike lane or protected bike lane configuration to provide additional separation.



### 14.3.3.g – Uphill Bicycle Climbing Lanes

Uphill bike lanes (also known as climbing lanes) enable motorists to safely pass slower-speed bicyclists, improving conditions for both travel modes.

Accommodating an uphill bicycle lane often includes delineating on-street parking (if provided), narrowing travel lanes, and/or shifting the centerline if necessary.



### 14.3.3.h – Buffered Bike Lanes

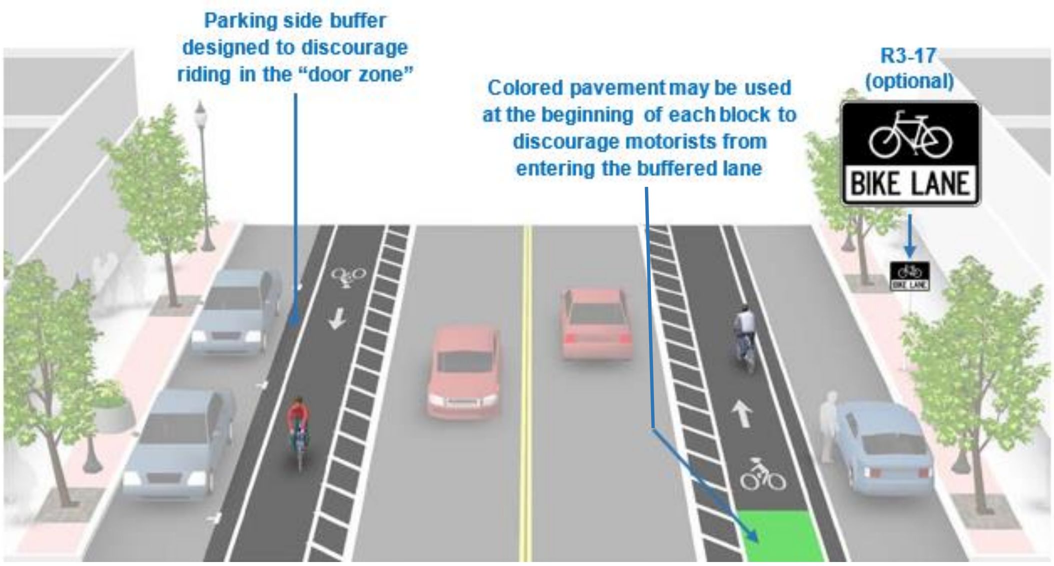
Buffered bike lanes are conventional bicycle lanes paired with a designated buffer space, separating the bicycle lane from the adjacent motor vehicle travel lane and/or parking lane. Buffered bike lanes follow general guidance for buffered preferential vehicle lanes as per MUTCD guidelines.

Buffered bike lanes are designed to increase the space between the bike lane and the travel lane and/or parked cars. This treatment is appropriate for bike lanes on roadways with high motor vehicle traffic volumes and speed, adjacent to parking lanes, or a high volume of truck or oversized vehicle traffic.

The frequency of right turns by motor vehicles at major intersections should determine whether continuous or truncated buffer striping should be used approaching the intersection. The MUTCD recommends 50 to 200 feet of dotted line in advance of the intersection, depending on the presence of bus stops and the volume of right turns. Commonly configured as a buffer between the bicycle lane and motor vehicle travel lane, a parking side buffer may also be provided to help bicyclists avoid the door zone of parked cars.

**Guidance**

- The minimum bicycle travel area (not including buffer) is 4-feet wide, 5 to 7 feet preferred to allow passing.
- Buffers should be at least 2-feet wide. Buffers 3 feet or wider should contain gore markings. For clarity at driveways or minor street crossings, the designer should consider a dotted line for the inside buffer boundary where cars are expected to cross.
- Buffered bike lanes can buffer just the travel lane, or just the parking lane depending on available space and the objectives of the design.
- The MUTCD recommends 50 to 200 feet of dotted line in advance of the intersection if needed to accommodate bus stops and/or vehicular right turns at the intersection.



## 14.3.4 – Physically Separated Bike Lanes

Physically separated/protected bike lanes are considered among the most desirable and safest of all on-road bicycle facilities. These facilities are considered protected because they separate bicycle travel from both motor vehicle lanes and pedestrian facilities through a physical form of vertical separation (e.g., delineators) and horizontal separation as necessary and appropriate. This type of facility is most suitable for urban roadways where high traffic volumes or speed warrant increased separation between bicycles and motor vehicles. However, the designer may consider this facility in suburban or even rural contexts, if warranted.

Depending on the roadway context, separated bike lanes may be designed for two-way or one-way bicycle travel along either side of a roadway. These facilities can be constructed at the street level, at the intermediate level between the sidewalk and the street, or at the same elevation as the sidewalk.

Depending on the roadway context and the comfort level required by facility users, the form of separation may contain one or a combination of the following applications:


- Painted Buffer Zone with Flexible Delineators
- Raised Curb or Median

The designer may consider other similar separation applications, but these features will require the Director of Bureau of Project Delivery approval. These facilities are also required to go through the formal request process for installation of a bicycle lane. When introducing any barrier/fixed object, the designer must consider safety as it relates to all modes.

Additionally, the designer needs to address changes in drainage patterns and ADA considerations, as well as assess maintenance impacts, prior to the implementation of any of the separation applications. AASHTO's *Roadside Design Guide* does allow flexibility in the use of barriers on low-speed roadways.

Although separated bike lanes help to protect cyclists from potential conflicts with motor vehicles, they may also restrict the cyclists' ability to make left turns or access mid-block destinations. To accommodate turning movements for all modes, the design should consider traffic signalization at intersections or expected crossing points, if warranted.

Contraflow bike lanes may also be designed as separated bike lanes. As previously discussed, a contraflow bike lane is a dedicated lane that travels in the opposite direction of traffic. These are most often used on one-way streets. Contraflow lanes should be on the left side from the direction of motor vehicle travel for the road.

When installing either a contraflow or a two-way separated bike lane, signage and pavement markings are vital for informing roadway users to expect opposing bicycle traffic and to ensure that only bicyclists use the bicycle facility.

The designer should address sight distances at intersections and driveways. Furthermore, on-street parking, vegetation, and other street appurtenances should be evaluated and potentially removed at conflict points to maintain sight distances.

Two-way separated bikeways intended for contraflow require a higher level of control at intersections to allow for a variety of turning movements. These movements should be guided by separated signals for bicycles and motor vehicles.

Transitions into and out of two-way protected bike lanes should be simple and easy, deterring bicyclists from continuing to ride against the flow of traffic.

At driveways and minor intersections, bicyclists riding against roadway traffic in two-way protected bike lanes may surprise pedestrians and drivers not expecting bidirectional travel. To minimize risks, the design requires appropriate signage.

### 14.3.4.a – Bikeway Separation and Placement

Separation is provided through physical barriers. Separated bike lanes using these protection elements typically share the same elevation as adjacent travel lanes.

Raised and separated bike lanes may be level with the adjacent sidewalk or set at an intermediate level between the roadway and sidewalk to separate the bikeway from the pedestrian area.

Sidewalks or other pedestrian facilities should rarely be narrowed to accommodate the protected bike lane, as pedestrians will likely walk on the bike lane if sidewalk capacity is reduced. Visual and physical cues (e.g., pavement markings and signage) should be used to clearly indicate where bicyclists and pedestrians should travel. If possible, the design should separate the protected bike lane and pedestrian zone with a furnishing zone. The designer can also refer to Chapter 13 for more information on ADA guidance for more information.

**Guidance**

- Protected bike lanes should ideally be placed along streets with long blocks and few driveways or mid-block motor vehicle access points.
- Protected bike lanes located on one-way streets have fewer potential conflict areas than those on two-way streets.
- In situations where on-street parking is allowed, protected bike lanes shall be located between the parking lane and the sidewalk.

### 14.3.4.b – One-Way Separated Bike Lanes

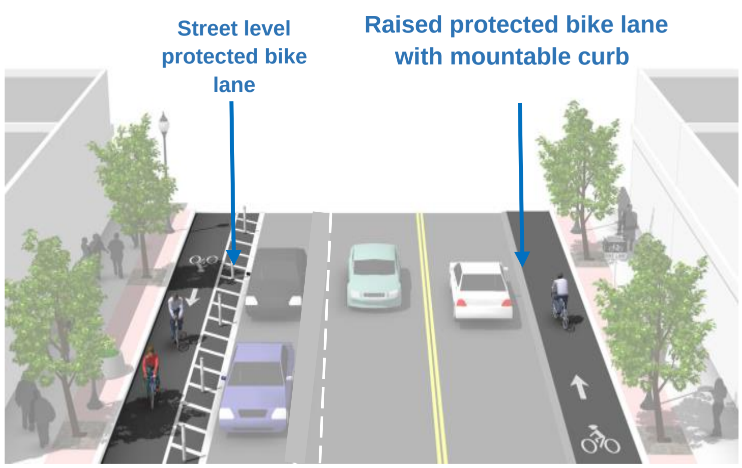
One-way separated bike lanes are physically separated/protected from motor vehicle traffic and distinct from the sidewalk. Protected bike lanes are either raised or at street level and use a variety of elements for physical protection from passing traffic.

Special consideration should be given in managing bicycle and pedestrian interactions at transit stops. Guidance for these locations is provided in the Federal Highway Administration's (FHWA*) Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* and the National Association of City Traffic Official's (NACTO) *Transit Street Design Guide*.

**Guidance**

- The minimum width of a one-way separated bike lane is 4 feet (preferred 5 to 7 feet to allow passing).
- When placed adjacent to parking, the parking buffer should be at least 2-feet wide. Buffers 3 feet or wider should contain gore markings.
- When placed adjacent to a travel lane, one-way raised protected bike lanes may be configured with a mountable curb. This allows entry and exit from the bicycle lane for passing other bicyclists or to access vehicular turn lanes.

Driveways and minor street crossings present unique challenges to protected bike-lane design. To improve visibility, parking should be prohibited within a range of 30 to 60 feet of the intersection, depending upon the speed of turning vehicles and the driveway or intersection geometry. Color, yield markings, and yield to bikes signage should be used to identify the conflict area and make it clear that the protected bike lane has priority over entering and exiting traffic. If configured as part of a raised protected bike lane, the crossing should be raised so that the sidewalk and protected bike lane maintain their elevation through the crossing.



### 14.3.4.c – Two-Way Separated Bike Lanes

Two-way separated bike lanes are physically partitioned bike lanes that allow bicycle movement in both directions on one side of the road. Two-way protected bike lanes share some of the same design characteristics as one-way protected bike lanes but may require additional considerations at driveways and side-street crossings.

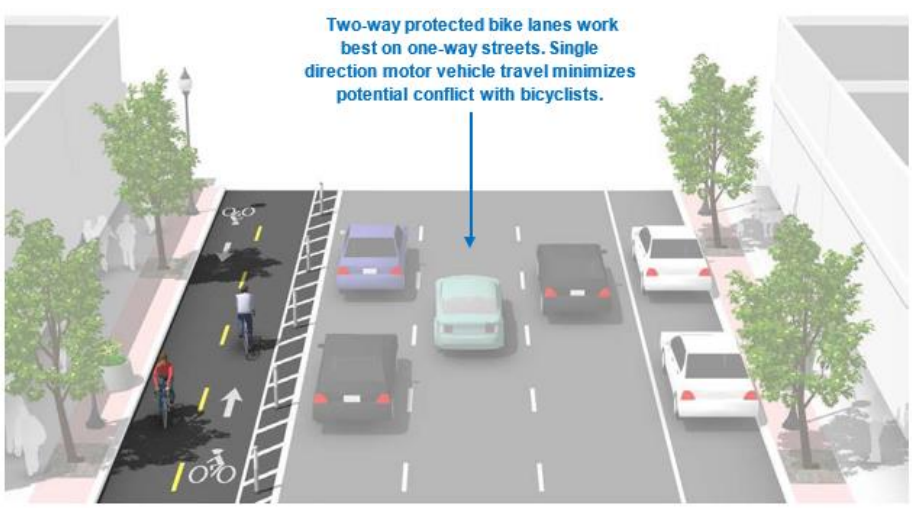
**Guidance**

- The minimum width for a two-way facility is 10 feet, with a preferred width of 11 feet.
- In constrained locations for short distances, the minimum width can be reduced to 8 feet.
- When placed adjacent to parking, the parking buffer should be at least 2-feet wide. Buffers 3 feet or wider should contain gore markings.
- The designer should consider bicycle design speeds of 15 mph (unless geometry indicates higher speeds) for sight distance purposes at intersections.

A two-way protected bike lane may be configured as a separated bike lane at street level with a barrier between the bikeway and the motor vehicle travel lane, or as a raised and physically separated bike lane to provide vertical separation from the adjacent motor vehicle lane.

Two-way protected bike lanes require a higher level of control at intersections to allow for a variety of turning movements. These movements should be guided by separated signals for bicycles and motor vehicles. Transitions into and out of two-way protected bike lanes should be simple and easy to use and should clearly deter bicyclists from continuing to ride against the flow of traffic.

At driveways and minor intersections, bicyclists riding against roadway traffic in two-way protected bike lanes may surprise pedestrians and drivers not expecting bidirectional travel. Therefore, appropriate signage is required. In some cases, the designer may need to consider signalization with separate phasing for bicycles and vehicular left turns, depending on volumes and potential safety concerns.



### 14.3.4.d – Driveways and Minor Street Crossings

The separation provided by protected bike lanes constitutes that additional intersection considerations be addressed.

At driveways and minor street crossings, bicyclists should not be expected to stop at these minor intersections if motorized traffic on the major street does not stop.

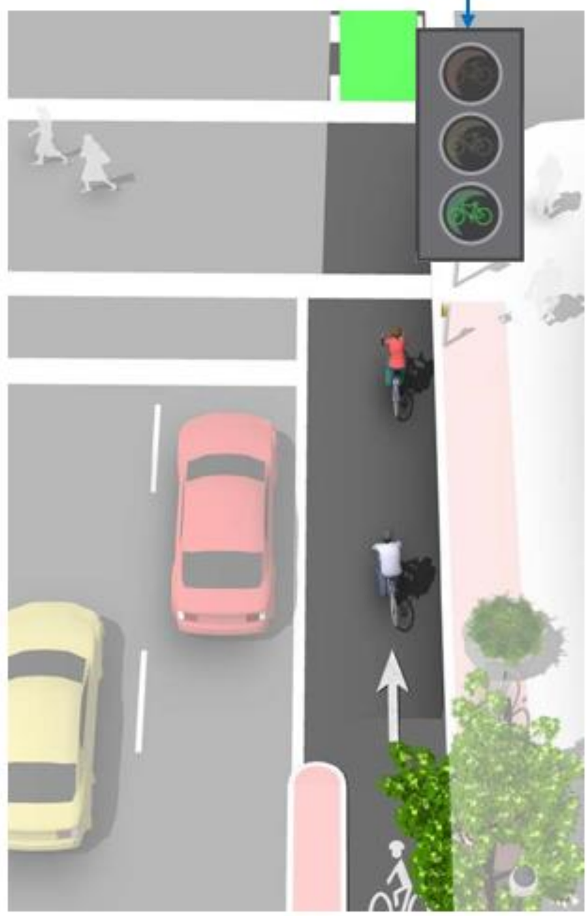
However, bicyclist visibility is important at these locations, as a buffer of parked cars or vegetation can reduce the visibility of a bicyclist traveling in the protected bike lane. Markings and signage should be present, alerting all travelers to where bicyclists and pedestrians should be travelling.

Access management should be used to reduce the number of driveway crossings on a protected bike lane because driveway consolidations and restrictions on motorized traffic movements reduce the potential for conflict.

**Guidance**

- If raised, the height of the protected bike lane should be maintained through the crossing, requiring automobiles to cross over it.
- Parking should be removed 30 feet prior to the intersection.
- Colored pavement markings and/or shared-lane markings should be used through the conflict area.
- Warning signage should be placed to identify the crossing.

### 14.3.4.e – Major Street Crossings




Separated bike lanes approaching major intersections must minimize or mitigate potential conflicts and provide connections to intersecting facility types.

Maintaining separation between bicyclists and motor vehicle traffic leading up to and through the intersection via a protected intersection design is the best way to improve safety for all roadway users. This prevents several of the most common crash types, including the right hook, left hook, and overtaking, and is supported by research indicating that motorists regularly fail to appropriately scan for pedestrians or cyclists before making turning movements in urban environments.

This treatment includes the use of a bicycle signal phase, which reduces conflicts with motor vehicles by separating bicycle movements from conflicting motor vehicle movements.

A bicycle signal head can also be set to provide protected bike lane users a green phase in advance of vehicle phases. The length of the signal phase will depend on the width of the intersection. The FHWA Interim Approval MUTCD IA-16, provides guidance regarding the use of a bicycle signal face, including information about bicycle signal indications, application parameters, design and location of bicycle signal faces, operation, and regulatory signing requirements. Additionally, the guidance provides prohibitions on the use of a bicycle signal face.

Additional bicycle signalization details are provided in Section 14.7.4.d.

Similar conflicts exist at non-signalized intersections. Warning signs, special markings, and the removal of on-street parking in advance of the intersection can raise visibility and awareness of bicyclists.

**Guidance**

- The protected bike lane buffer should be dropped and transitioned to a bike lane 16 feet in advance of the intersection.
- Parking should be removed 16 to 50 feet in advance of the buffer termination.
- A bike box or advanced stop line treatment should be used to place bicyclists in front of traffic.
- Colored pavement markings should be used through the conflict area.
- Two-stage turn boxes should be provided for left-turning movements.
- A protected phase bicycle signal might be considered to isolate conflicts between bicyclists and motor vehicle traffic.
- In constrained conditions with right-turn-only lanes, transitioning to a shared bike lane/turn lane might also be considered.

## 14.4 – Intersection Treatment Considerations





Intersections are junctions where different modes of transportation meet, and facilities overlap. An intersection facilitates the interchange between bicyclists, motorists, pedestrians, and other modes to advance traffic flow in a safe and efficient manner.

Designs for intersections with bicycle facilities should reduce conflict between bicyclists (and other vulnerable road users) and vehicles by heightening the level of visibility, denoting clear right-of-way, and facilitating eye contact and awareness. Intersection treatments can improve both queuing and merging maneuvers for bicyclists and are often coordinated with timed or specialized signals.

The configuration of a safe intersection for bicyclists may include elements such as color, signage, medians, signal detection, and pavement markings. Intersection design should take into consideration existing and anticipated bicyclist, pedestrian, and motorist movements.

In all cases, the degree of mixing or separation between bicyclists and other modes is intended to reduce the risk of crashes and increase bicyclist comfort. The level of treatment required for bicyclists at an intersection will depend on the bicycle facility type used, whether bicycle facilities are intersecting, and the adjacent street function and land use.

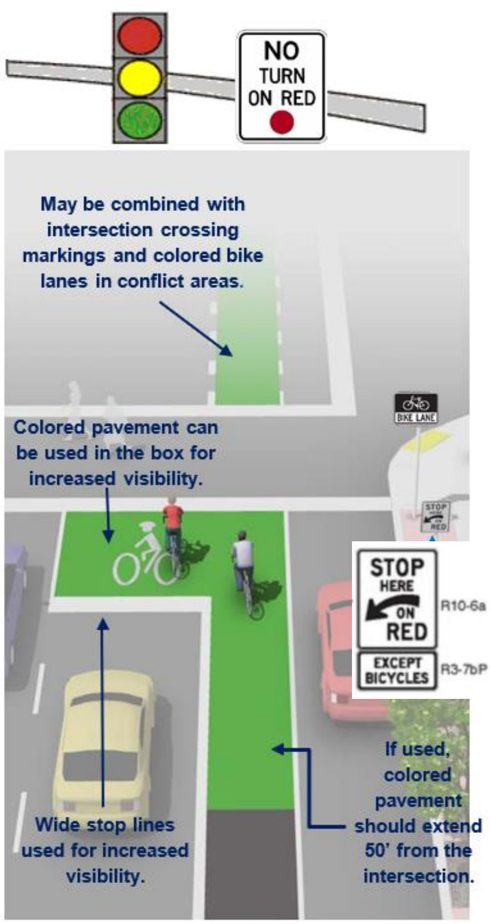
Details pertaining to these treatments are provided in AASHTO’s *Guide for the Development of Bicycle Facilities*, the MUTCD, and NACTO’s *Urban Bikeway Design Guide*.

### 14.4.1 – Bicycle Box

A bicycle box is a designated area located at the head of a traffic lane at a signalized intersection. It provides bicyclists with a safe and visible space to get in front of queuing motorized traffic during the red signal phase. Motor vehicles must queue behind the white stop line at the rear of the bicycle box.

Bicycle boxes should be used in locations with a large volume of bicyclists and are best utilized in central areas where traffic is usually moving more slowly. A bicycle box is not needed if a separated or protected facility is extended to the intersection.

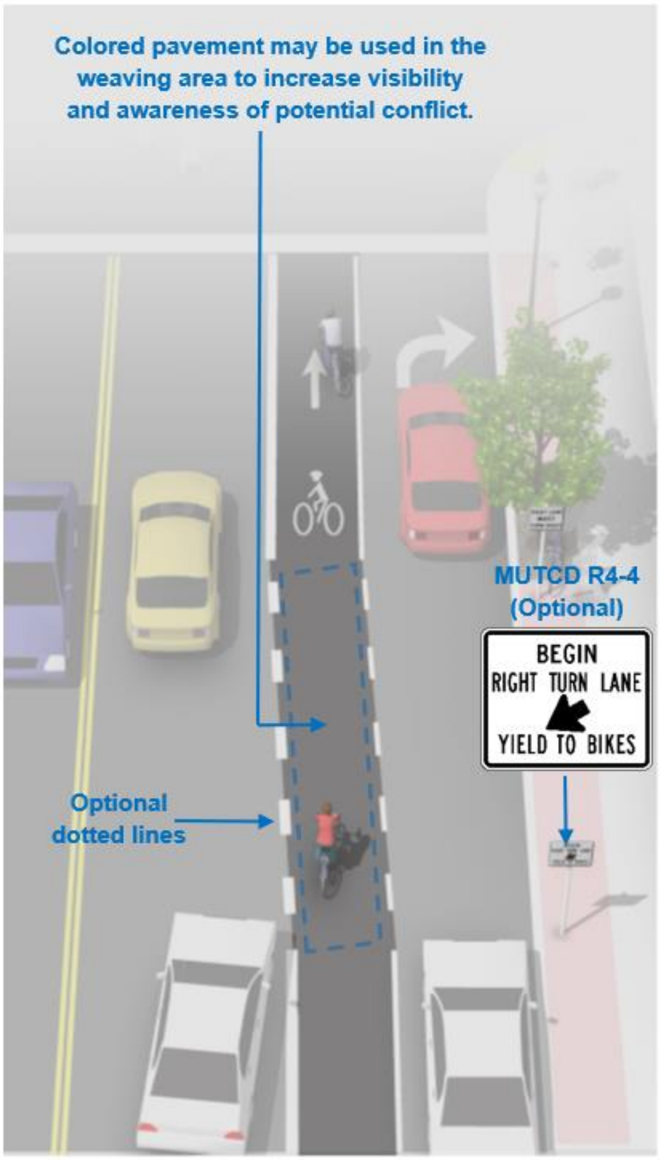
Bicycle boxes should be placed only at signalized intersections, and right turns on red shall be prohibited for motor vehicles. Prohibiting right turns on red improves safety for bicyclists yet does not significantly impede motor vehicle travel. Details about bicycle boxes are provided in the FHWA Interim Approval MUTCD IA-18.




**Guidance**

- A bicycle box shall be formed by an advance stop line placed at least 10 feet in advance of the intersection stop line.
- At least one bicycle symbol shall be placed within a bicycle box (MUTCD IA-18 provides placement details).
- Where a bicycle box is provided across multiple lanes of an approach, countdown pedestrian signals (per MUTCD Section 4E.07) shall be provided for the crosswalk across the approach on which the bicycle box is located. This informs bicyclists whether there is adequate time remaining to cross to an adjacent lane before the onset of the green signal phase for that approach.
- Turns on red shall be prohibited from the approach where a bicycle box is placed using a NO TURN ON RED (R10-11 series) sign.
- At least 50 feet of bicycle lane should be provided on the approach to a bicycle box.
- A STOP HERE ON RED (R10-6 or R10-6a) sign should be provided at the advance stop line, with an EXCEPT BICYCLES (R3-7bP) plaque below (per MUTCD IA-18).
- Green-colored pavement (per MUTCD IA-14) may be used within a bicycle box and the bicycle-approach lane.

## 14.4.2 – Bike Lanes at Right-Turn Only Lanes




See the MUTCD for signing and pavement marking details.

The designer should consider eliminating the right-turn-only lane where right-of-way is insufficient to extend the bikeway to the intersection. Or, use a shared bike/turn lane.

Another treatment at right-turn lanes is to place the bike lane between the right-turn lane and the rightmost through lane or, where right-of-way is insufficient, to use a shared bike lane/turn lane.

The graphic on the left illustrates a bike lane pocket, with signage indicating that motorists should yield to bicyclists through the conflict area.

Sections 14.3 and 14.4 of this chapter offer more discussion on potential approaches to providing accommodations for bicyclists at intersections with turn lanes.

The MUTCD, NACTO *Urban Bikeway Design Guide*, Publication 111, and Publication 236 provide more information on signing and pavement marking details.

Along many of Pennsylvania's rural corridors, separate bicycle lanes are not warranted which typically results in bicyclists riding on the shoulder. At intersections along these roadways, the shoulder area is sometimes narrowed to provide room for turn lanes or is completely replaced by them. At these locations, appropriate intersection designs should be used to encourage safe interactions.

**Configuration as an On-Street Bike Lane** – In this scenario, the shoulder is used as a bike lane and a right-turn lane is introduced to the right of the bike lane. Dotted line extensions should be used to define the tapered entrance into the right-turn lane from the shoulder, and signs should direct motorists to yield to bicyclists. For more information, refer to the guidance on bike lanes and the FHWA's MUTCD.

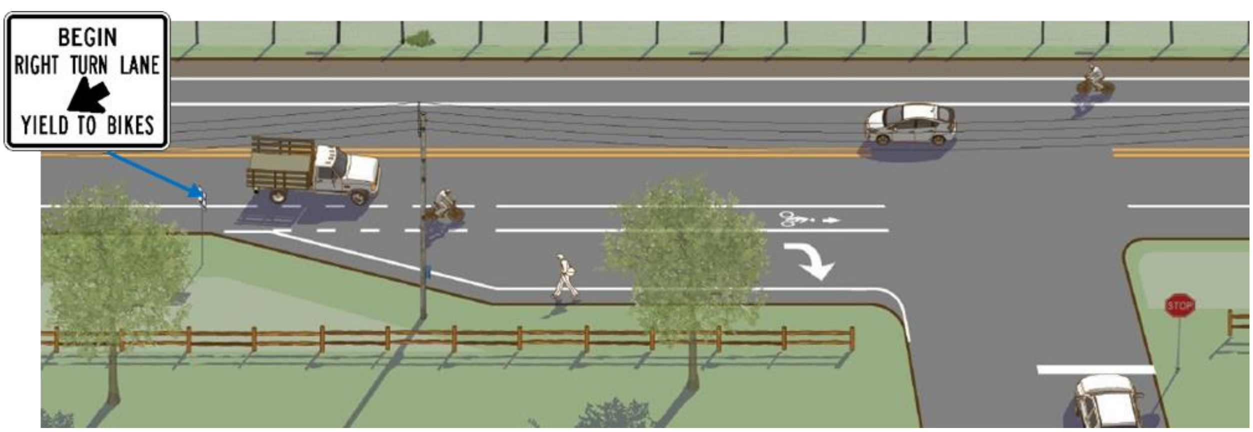
**Guidance**

**At auxiliary right-turn only lanes**

- The existing bike lane width should be continued, with a standard width of 5 to 6 feet (or 4 feet in confined locations).
- Signage should be used to indicate that motorists must yield to bicyclists through the conflict area.
- Colored conflict areas may be used to promote visibility of the mixing zone.

**Where a through lane becomes a right-turn only lane**

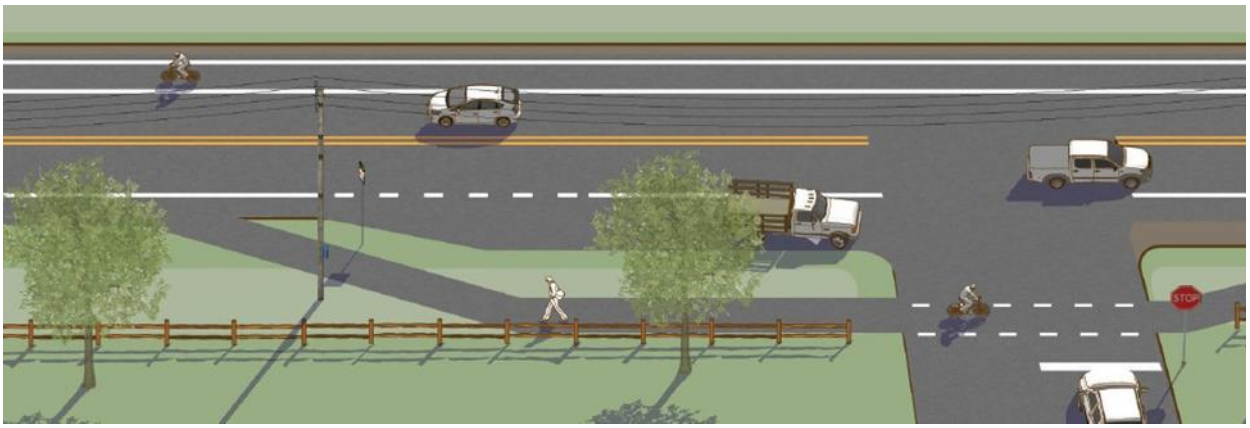
- A dotted-line merging path for bicyclists should not be defined.
- The bicycle lane should be dropped in advance of the merge area.
- Shared-lane markings should be used to indicate shared use of the lane in the merging zone.




Source: FHWA Small Town and Rural Design Guide

**Configuration as a Separated Bike Lane or Shared-Use Path** – Where a high degree of user comfort is desired, the shoulder may transition into a one-way separated bike lane or shared-use path in advance of intersections. Once established, the separated facility may maintain separation up to the crossing. This increased separation provides an opportunity for motorists to slow in advance of the turn and yield to bicyclists.

More information on separated bike lanes is provided in Section 14.3.1 of this chapter.




Source: FHWA Small Town and Rural Design Guide

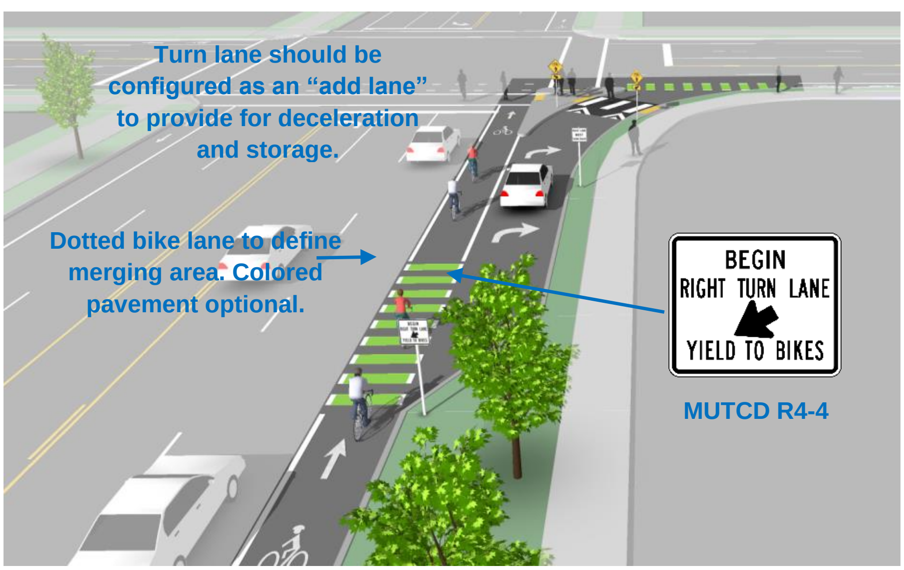
## 14.4.3 – Channelized Right-Turn Lanes

Traditional solutions, such as configuring the intersection with a channelized turn lane, support more vehicle through-put and reduce queueing. However, they do not improve safety and comfort for cyclists traveling through the intersection. The cyclist needs to pass through a mixing zone from a bicycle facility on the right side of the roadway to vehicular through lane.

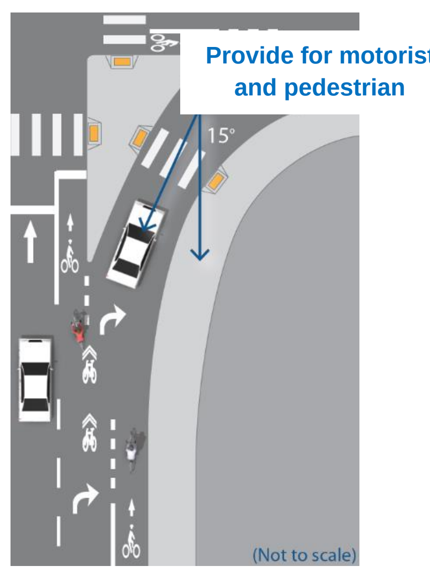
As an alternative, the designer should avoid using the channelized free right turn and instead require queuing in stop or signal-controlled intersection before making a turn into the receiving lanes. The designs can include features that support traffic calming features that direct merging of all vehicles into a mixing zone where cyclists can utilize the right-turn lane to continue straight through or potentially the existing through lane. This also has the additional benefit of producing a safer environment for pedestrians.

**Guidance**

- The preferred angle of intersection between the channelized turn lane and the joined roadway is no more than 15 degrees. This allows for simultaneous visibility of pedestrians and potential roadway gaps.
- The design should incorporate a maximum 30- to 35-foot turning radius.
- Signing should include the PEDESTRIAN CROSSING sign assembly (i.e., W11-2) or YIELD sign (i.e., R1-2) to encourage yielding. The YIELD TO BIKES (i.e., R4-4) or similar signage should be used if bike lanes are present.
- Incorporating raised crossings in the channelized turn lane may slow driver speed through the turning area.

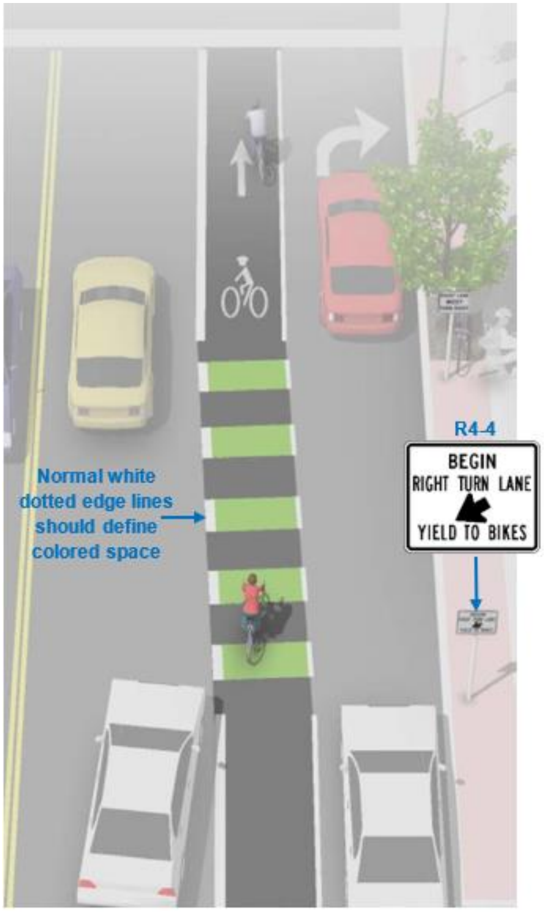



Add Lane Configuration Option




Slip Lane Configuration Option
(Not a preferred condition)

### 14.4.4 – Colored Bike Lanes in Conflict Areas




The MUTCD, Publication 111, and Publication 236 provide details for signing and pavement marking details on colored bike lanes.

Colored pavement within a bicycle lane increases the visibility of the facility and reinforces bicyclist priority in conflict areas.

Like a zebra-style cross walk, these conflict zones are stand-alone pavement marking blocks that span the length of the bicycle/vehicle interaction area. Their green interior is bounded by white on the inside and outside, with an overall pavement marking at a width of around 2 feet and a length matching the connecting bike lanes. The white markings should be retroreflective to enhance visibility, while the green markings should meet current glass bead standards for pavement markings.

Although they can occur in other scenarios, bicycle-lane conflict-zone markings are predominantly used at intersections where a left- or right-turning vehicle crosses a bicycle through-movement.

**Guidance**

- The colored surface should be skid resistant and retro-reflective.
- A YIELD TO BIKES (i.e., R4-4) sign should be used at intersections or driveway crossings to reinforce that bicyclists have the right-of-way in colored bike lane areas.

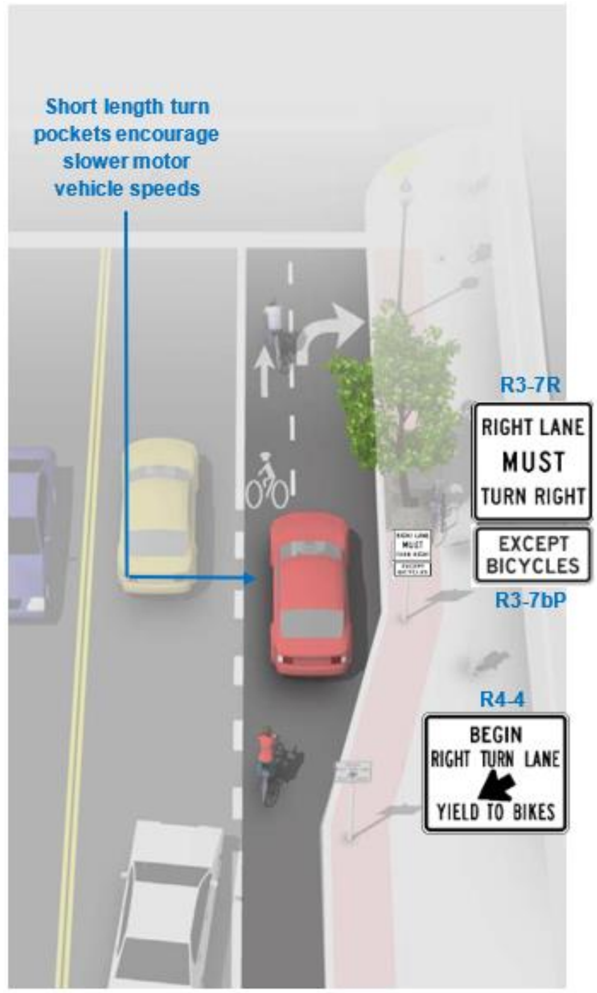
## 14.4.5 – Combined Bike Lanes/Turn Lanes

The combined bike lane/turn lane places a standard-width bike lane on the left side of a dedicated right-turn lane. A dotted line delineates the space for bicyclists and motorists within the shared lane. This treatment also includes signage, advising motorists and bicyclists of proper positioning within the lane.

This treatment is recommended at intersections lacking sufficient space to accommodate both a standard through-bike lane and right-turn lane.

Researchers with the Pedestrian and Bicycle Information Center at the University of North Carolina cite case studies demonstrating that this treatment works best on streets with lower posted speeds (i.e., 30 mph or less) and with lower traffic volumes (i.e., Average Daily Traffic [ADT] of 10,000 vehicles or fewer). Consequently, a combined bike lane/turn lane may not be appropriate for high-speed arterials, intersections with long right-turn lanes, or intersections with large percentages of right-turning heavy vehicles.

The MUTCD, Publication 111, and Publication 236 provide details for signing and pavement marking in these lanes.




### Guidance

- The minimum shared turn lane width is 13 feet.
- The bike lane pocket should have a minimum width of 4 feet, with a preferred width of 5 feet.
- A dotted 4-inch line and bicycle lane marking should be used to clarify bicyclist positioning within the combined lane, without excluding cars from the suggested bicycle area.
- A RIGHT TURN ONLY (i.e., R3-7R) sign with an EXCEPT BICYCLES (i.e., R3-7bP) plaque is needed to legally permit through bicyclists to use a right-turn lane if the bike lane or shoulder becomes a right-turn lane and no other accommodation is made for cyclists to continue forward.

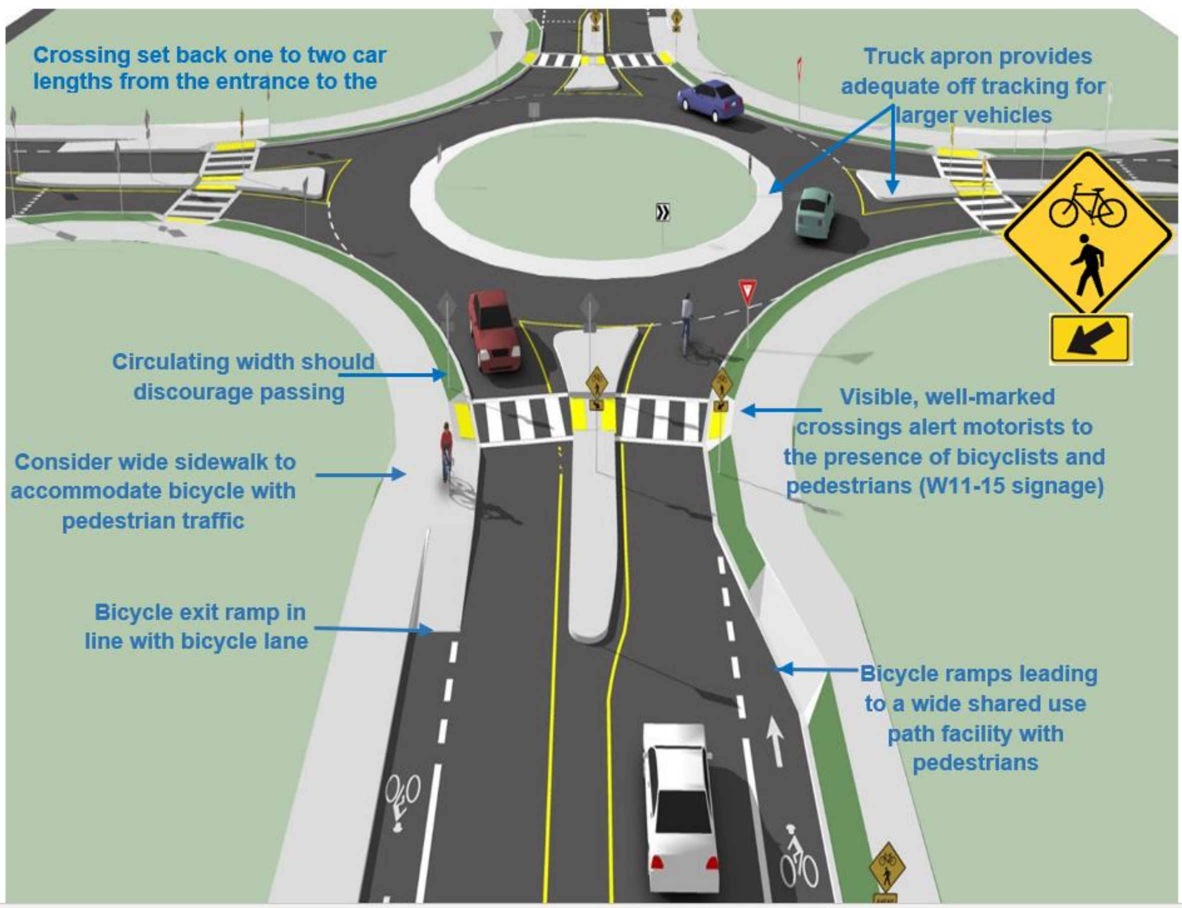
### 14.4.6 – Bicyclists at Roundabouts

In single-lane roundabouts, it is important to indicate to motorists, bicyclists, and pedestrians the right-of-way rules and the correct way to circulate using appropriately designed signage, pavement markings, and geometric design elements.

Research indicates that while single-lane roundabouts may benefit bicyclists and pedestrians by slowing traffic, multi-lane roundabouts may present greater challenges and increase safety concerns for these users. Providing bicycle ramps to allow users to self-select a route on a separate path can improve safety and accessibility for bicycle riders.

**Guidance**

- The circulating operating speed in a roundabout is typically less than 25 mph. Bicyclists should be encouraged to navigate the roundabout like motor vehicles and "take the lane." The BICYCLE MAY USE FULL LANE (R4-11) sign may be considered on the approach to the roundabout.
- Separated facilities may be considered for bicyclists who prefer not to navigate the roundabout on the roadway.



## 14.4.7 – Bike Lanes at Ramp Lanes

Some arterials may contain high-speed freeway-style designs, such as merge (entrance) lanes and diverge (exit) ramps, which can create difficulties for bicyclists. The entrance and exit lanes typically have intrinsic visibility problems because of low approach angles and high-speed differentials between bicyclists and motor vehicles.

Strategies to improve safety emphasize removing these designs where possible, increasing sight distances, creating formal crossings, and minimizing crossing distances. The **layouts shown below** avoid the bike lanes using the gore areas and provide perpendicular crossings of the ramps.

### Guidance

**Entrance Ramps**

- The bike lane should be configured to increase the approach angle with entering traffic.
- The crossing should be positioned before drivers' attention is focused on the upcoming merge.

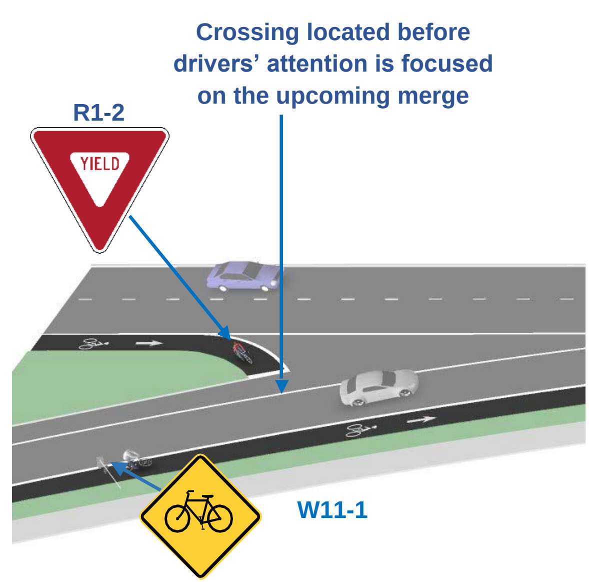
**Exit Ramps**

- A jug-handle turn should be used to increase the approach angle with exiting traffic and should include yield striping and signage on the bicycle

While the jug-handle approach is the preferred configuration at exit ramps, an option should be provided that allows through-bicyclists to perform a vehicular merge and proceed straight through under safe conditions. Additionally, stopping sight distances needs to be evaluated.

### Example Entrance Ramp Layout

**Note: Appropriate yield or stop bar should be used.**





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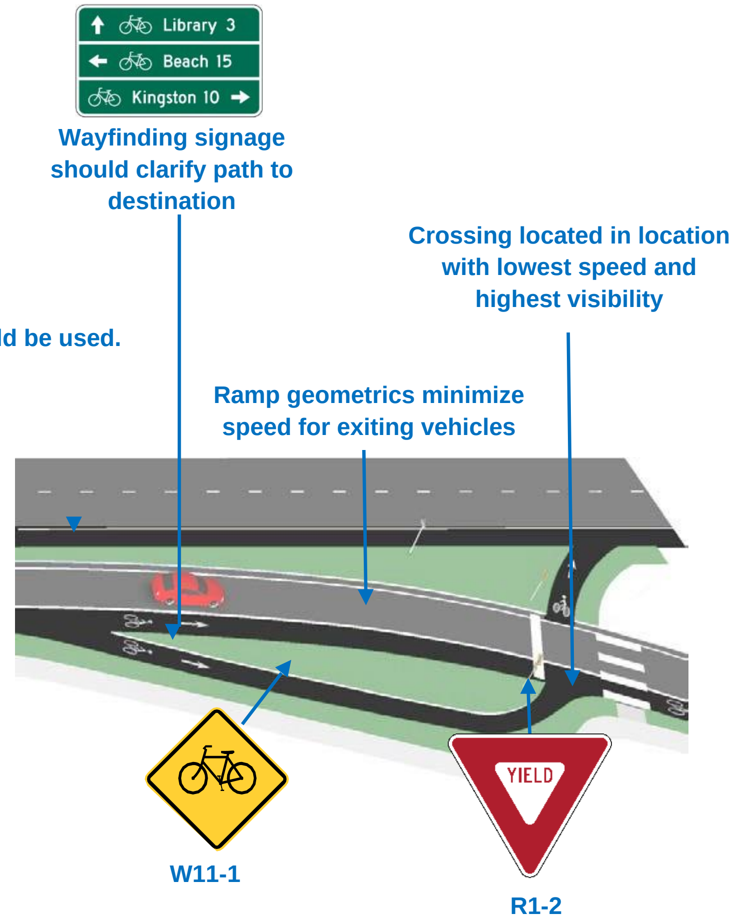
### Example Exit Ramp Layout

**Note: Appropriate yield or stop bar should be used.**




**Messages and installation of bicycle guide signs should follow the Tourist Oriented Directional Signs Policy described in Publication 46, *Traffic Engineering Manual***

## 14.5 – Shared-Use Path/Bikeway Crossings

At-grade roadway crossings can create potential conflicts between path users and motorists. However, well-designed crossings can mitigate many operational issues and provide a higher degree of safety and comfort for path users. This is evidenced by the thousands of successful facilities around the US with at-grade crossings.

In most cases, at-grade path crossings can be properly designed to provide a reasonable degree of safety and meet existing traffic and safety standards. Path facilities that cater to bicyclists require additional considerations due to the higher travel speed of bicyclists versus pedestrians.

Consideration must be given to adequate warning distance based on vehicle speeds and line of sight, with the visibility of any signs being critical. Directing the active attention of motorists to roadway signs may require additional alerting devices, such as a flashing beacon, roadway striping, or changes in pavement texture. Signing for path users may include a standard STOP or YIELD sign and pavement markings, possibly combined with other features, such as bollards or a bend in the pathway to prohibit motor vehicle access (but not to slow bicyclists, as these areas can be crash conflict areas). Care must be taken not to place too many signs at crossings lest they begin to lose their visual impact. The FHWA's *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* contains significant and useful guidance on this topic.

A number of striping patterns to delineate path crossings have emerged over the years. Crosswalk striping is typically a matter of local and state preference and may be accompanied by pavement treatments to help warn and slow or stop motorists. In areas where motorists do not typically yield to crosswalk users, additional measures may be required to increase compliance.

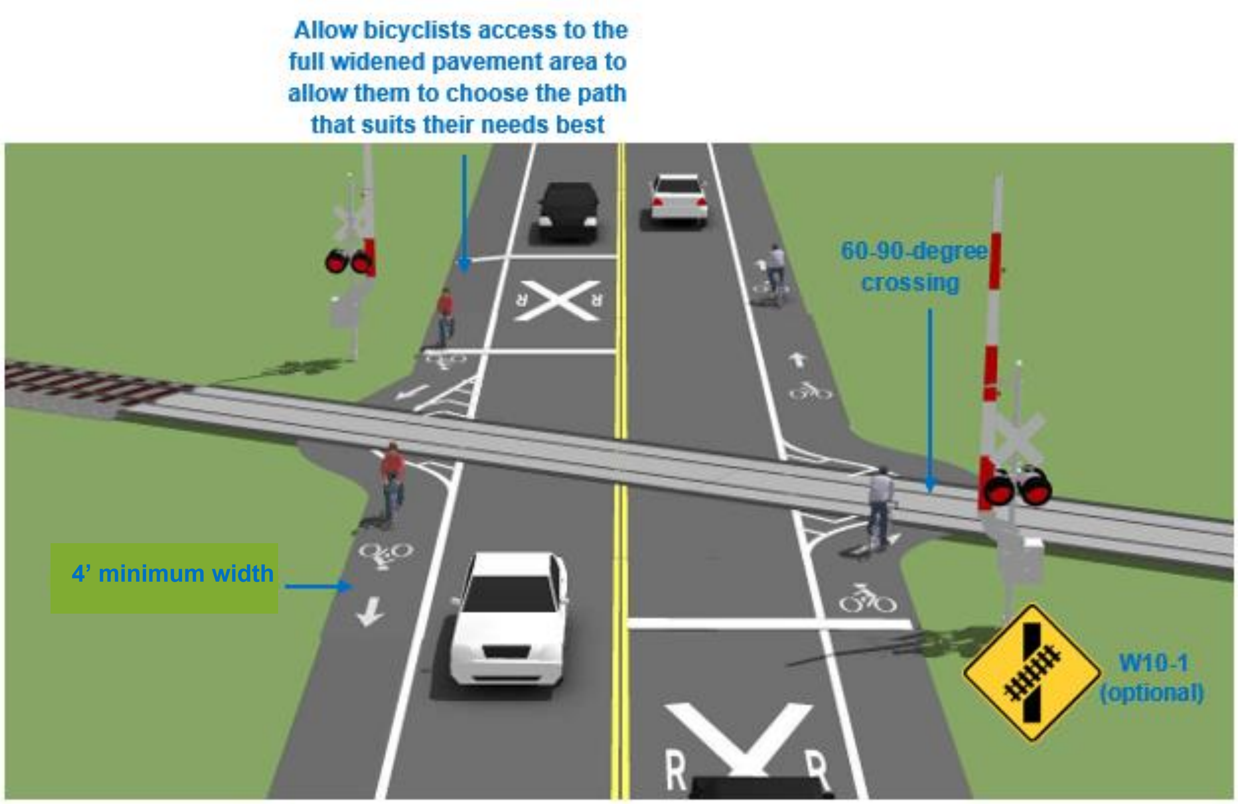
### 14.5.1 – Bicycle Lanes at Railroad Grade Crossings

Bikeways that cross railroad tracks at a diagonal may cause steering difficulties or loss of control for bicyclists due to slippery surfaces, degraded rough materials, and the size of the flangeway gaps. Angled track crossings also limit sight triangles, impacting the ability to see oncoming trains.

Improvements to track placement, surface quality, flangeway opening width, and crossing angle can minimize risks to riders. Also, address any potential pedestrian conflicts if directing bicyclists to sidewalks.

**Guidance**

- The minimum shoulder/bike lane width is 4 feet ( 5 to 7 feet preferred).
- If the skew angle is less than 45 degrees, special attention should be given to the sidewalk and bicycle alignment to improve the approach angle to at least 60 degrees (or to a preferred angle of 90 degrees, where possible).
- W10-1 or W10-12 signs might be posted to alert bicyclists.





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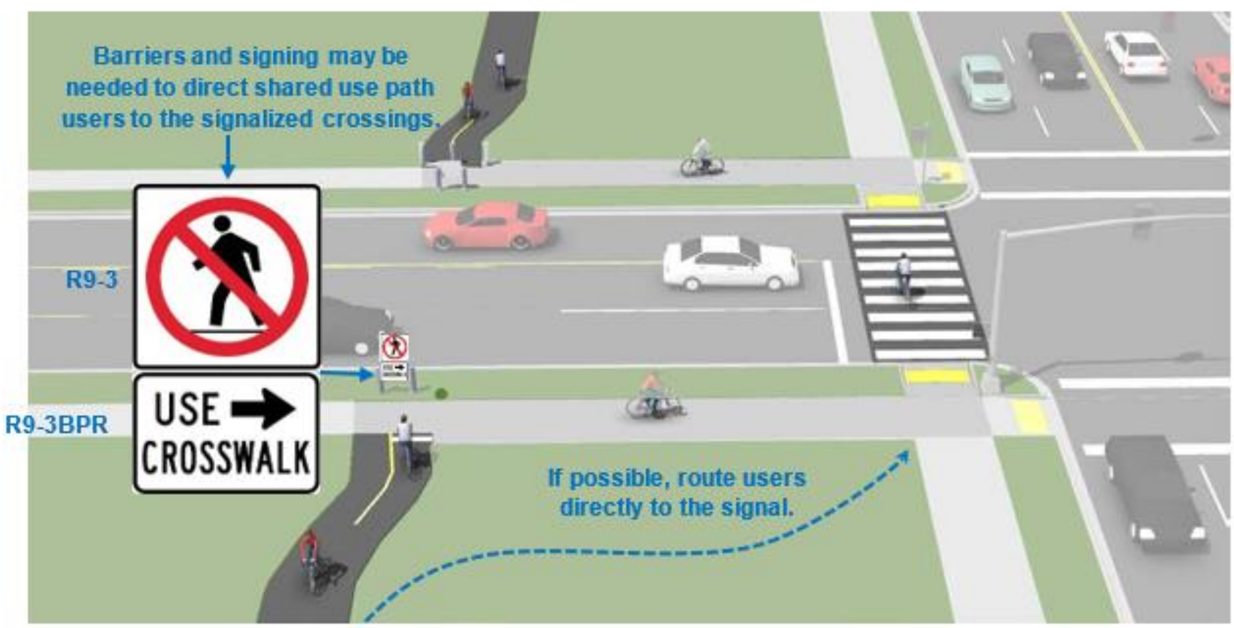
## 14.5.2 – Routing Users to Signalized Crossings

> **Guidance**
>
> Path crossings should not be provided within the functional area of an existing signalized intersection. If possible, the path should be routed directly to the signal.

Path/trail crossings within the functional area of an existing signalized intersection are typically diverted to the signalized intersection to avoid traffic operation problems. For this restriction to be effective, barriers and signing may be needed to direct path users to the signalized crossing. If no pedestrian crossing exists at the signal, modifications should be made.

The use of bicycles on trails and sidewalks is covered in **PA Title 75 Consolidated Statutes §3508**, which states,“ A person riding a pedalcycle upon a sidewalk or pedalcycle path used by pedestrians shall yield the right-of-way to any pedestrian and shall give an audible signal before overtaking and passing a pedestrian.” The statute also states, “A person shall not ride a pedalcycle upon a sidewalk in a business district unless permitted by official traffic-control devices, nor when a usable pedalcycle-only lane has been provided adjacent to the sidewalk.”

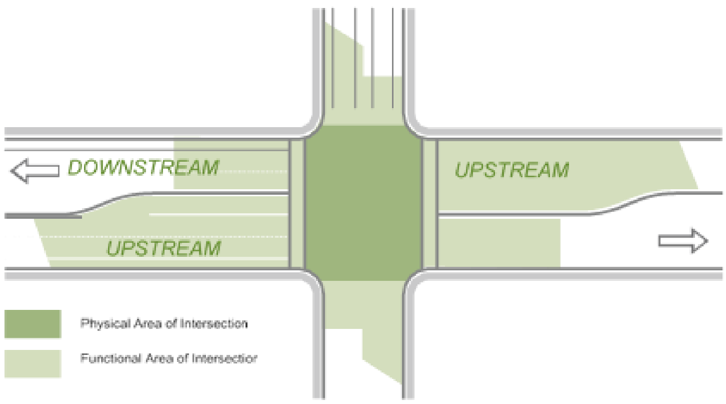



The functional area of an intersection, as illustrated in **Exhibit 14.5.1**, is the area beyond the physical intersection of two roadways (or roadway and path) that includes decision and maneuvering distance, plus any required vehicle storage length.

The functional area includes the length of road upstream from an oncoming intersection needed by motorists to perceive the intersection and begin maneuvers to negotiate it. The upstream area includes distance for travel during perception-reaction time, travel for maneuvering and deceleration, and queue storage. The functional area also accounts for the length of road downstream from the intersection needed to reduce conflicts between through-traffic and vehicles entering and exiting a property.

Because of individual intersection characteristics, the functional area of an intersection varies from one location to another. Due to heightened safety concerns within the functional area of an intersection, bike/pedestrian crossings should be limited to the physical area of the intersection. Driveways and other mid-block crossings should be outside of the intersection's functional area.

**Exhibit 14.5.1 – Functional and Physical Areas of an Intersection**




To calculate the functional area of an intersection, it is important to understand the traffic dynamics as a driver approaches the intersection. As shown in **Exhibit 14.5.2**, an intersection's functional area accounts for perception-reaction time, deceleration, and queue storage, which all relate to design speed.

**Exhibit 14.5.2 – Diagram of the upstream functional area of an intersection**

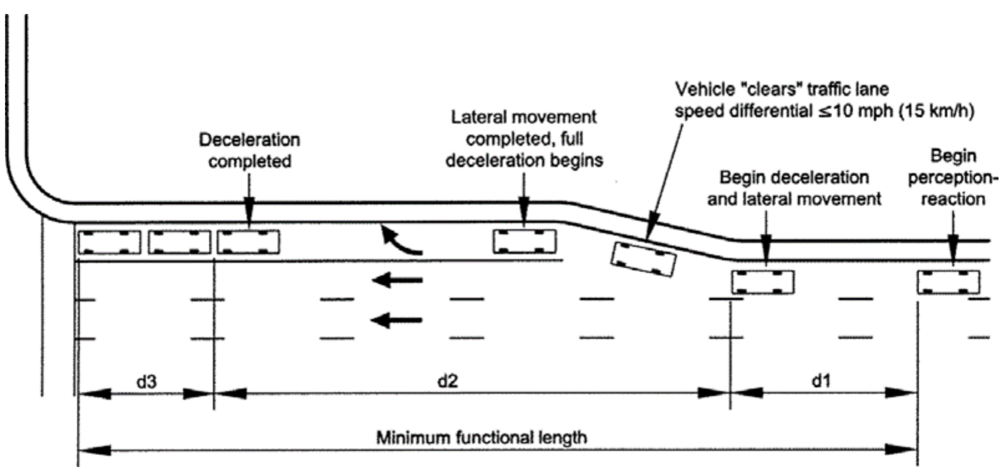


**Exhibit 14.5.2** illustrates:

- **Distance d1** – Distance traveled during braking reaction time as a driver approaches the intersection, assuming a break reaction time of 1.5 seconds for urban and suburban conditions and 2.5 seconds for rural conditions.
- **Distance d2** – Deceleration distance while the driver maneuvers to a stop upstream of the intersection.
- **Distance d3** – Queue storage at the intersection.

Calculations of d1 (brake reaction time) and d2 (braking distance) are located in the Green Book, Chapter 3 under Stopping Sight Distance. Methodology for estimating d3 (queue storage) is provided in Publication 46, *Traffic Engineering Manual*.

The downstream functional area is the distance immediately downstream of the intersection so that a driver can completely clear the intersection before needing to react to something downstream, stopping sight distance is the typical distance.

## Example: Upstream Functional Area of an Intersection

There is an intersection on an urban roadway with a 35-mph speed limit. The intersection approach has -2% vertical grade. Assume a standard braking deceleration of 11.2 ft/s$^2$. What is the minimum functional length on the upstream approach to this intersection?

**Distance d1:**

$$\mathrm{d1} = 1.47\mathrm{Vt}$$ [Stopping Sight Distance Chapter of AASHTO Green Book]

$$\mathrm{V} = \text{design speed, mph}$$

$$\mathrm{t} = \text{brake reaction time, s}$$

$$\text{Given: } \mathrm{V} = 35 \text{ mph; } \mathrm{t} = 1.5 \text{ s (use 1.5 seconds for urban and suburban conditions)}$$

$$\mathrm{d1} = 1.47\mathrm{Vt} = (1.47) * (35) * (1.5)$$

$$\mathrm{d1} = 77.175 \approx 77 \text{ ft}$$

**Distance d2:**

$$d2 = \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) \mp G\right]}$$

[Stopping Sight Distance Chapter of AASHTO Green Book]

V = design speed, mph

a = deceleration rate, ft/s$^2$

G = roadway grade ft/ft

Given: V = 35 mph; a = 11.2 ft/s$^2$ (from AASHTO Green Book); G = -0.02

$$d2 = \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) \mp G\right]} = \frac{(35)^2}{30\left[\left(\frac{11.2}{32.2}\right) - 0.02\right]}$$

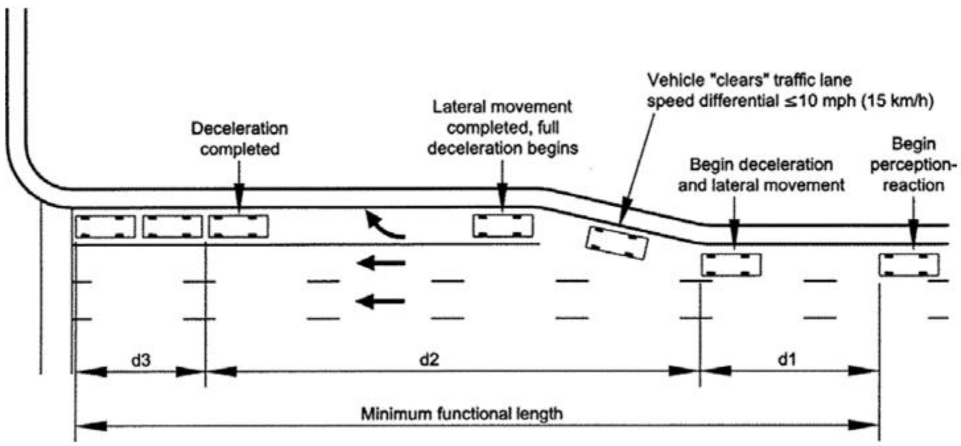
$$d2 = 124.559 \approx 125 \text{ ft}$$

**Distance d3:**

$$d3 = Q$$

Queue Storage at an intersection is generally accepted as the 95th percentile queue for a lane, as described in the Turn Lane Guidelines section of Publication 46, Traffic Engineering Manual. This is usually determined by using traffic engineering software packages. For use in this example problems it is assumed that software was used to find a 95th percentile queue of 150 ft.

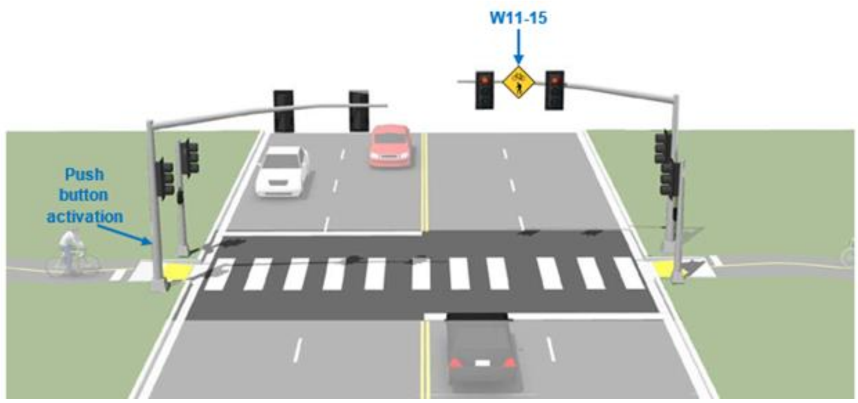
$$d3 = Q = 150 \text{ ft}$$




$$\text{Minimum Functional Length} = d1 + d2 + d3 = 77\text{ft.} + 125\text{ft.} + 150\text{ft.}$$

$$\textbf{Minimum Functional Length} = \textbf{352 ft}$$

### 14.5.3 –Traffic-Control Signalized Crossings




Traffic-control signalized crossings are traffic signal installations for bicycle and pedestrian crossings (typically shared-use paths intersecting with a roadway). This should not be confused with Pedestrian Hybrid Beacons (PHB) or "Hawk" beacons, which are currently not allowed in the Commonwealth. Traffic-control signalized crossings utilize "typical" signal timing patterns, where PHB systems are dark (i.e., no light indication) until activated.

Signalized crossings provide the greatest protection for crossing-path users through the use of signal indication to stop conflicting motor vehicle traffic. However, the use of traffic control signals should be limited to only locations where less-restrictive traffic control devices provide inadequate crossing opportunities. Even at locations where traffic-control signals are warranted, other treatments (such as traffic calming) should be considered first because signals can increase delays, as well as certain crash types.

A full traffic signal installation treats the path crossing as a conventional four-way intersection and provides standard red, yellow, and green traffic signal heads for all legs of the intersection.

Shared-use path signals are normally activated by push buttons but may also be triggered by embedded loop, infrared, microwave, or video detectors. The **maximum** delay for activation of the signal should be 2 minutes, with minimum crossing times determined by the width of the street. (Note: Delays longer than 30 seconds can result in bicyclist or pedestrian impatience, potentially leading to unsafe crossings. Activation times of less than 2 minutes are preferred.)

Each crossing, regardless of traffic speed or volume, requires the designer to evaluate sight lines, potential impacts on traffic progression, timing with adjacent signals, capacity, and safety.

#### 14.5.3.a - Determining Need

Designers have the flexibility to estimate future demand if, in the absence of a signal, existing conditions limit crossing opportunities. In some cases, the number of pedestrians and bicyclists crossing a street may be insufficient to satisfy a traffic-signal warrant. This may indicate people's reluctance to use the crossing because of inadequate gaps in traffic and concern for their safety. For these locations, it is more appropriate to use an estimated crossing demand that assumes better crossing conditions, as research shows that once a street crossing is safer, individuals will cross in greater numbers.

A gap study can evaluate the availability and frequency of critical gaps for safe crossing. As defined in the HCM, a critical gap provides enough time for a person to cross a street at a normal walking or bicycling speed without conflict after the person perceives a gap in traffic. The HCM also provides a methodology to calculate the average pedestrian and bicyclist delays for an uncontrolled crossing. The critical gap is determined by calculating the pedestrian or bicyclist departure sight distance that allows a person enough time to judge a gap and complete a full crossing of the roadway.

### 14.5.3.b – Applicable Traffic Signal Warrants

The MUTCD offers information on traffic-control signal warrants to help in determining if a traffic-control signal should be installed. The designer has some flexibility in applying warrants to determine if a signal is needed at a bicycle crossing. For example, since bicyclists may operate as a vehicle or as a pedestrian at crossings, they may be counted as either for a traffic-signal warrant analysis.

The most applicable warrants for evaluating the need for traffic-control signals in assisting bicyclists crossing a street include:

- **Warrant 4 (Pedestrian Volume) –** This warrant may be considered for locations where pedestrians and bicyclists experience excessive delays in attempting to cross a high-volume street. Both pedestrians and bicyclists should be considered in this analysis. The criterion for Warrant 4 may be reduced as much as 50% if the 15th percentile crossing speed of pedestrians is less than 3.5 feet per second.
- **Warrant 5 (School Crossing)** – This warrant may be considered for locations where there is a desire for schoolchildren to cross and there are not adequate gaps for them to do so.
- **Warrant 7 (Crash Experience)** – This warrant may be considered for locations where a threshold of crashes that could be corrected by a traffic-control signal have occurred over a 12- or 36-month period. Thresholds vary depending upon the number of approach lanes, type of crash, and context*.* The MUTCD Interim Approval for Optional Use of an Alternative Signal Warrant – Crash Experience (IA-19) allows designers to consider alternative crash experience data.

## 14.5.4 – Undercrossings

Bicycle/pedestrian undercrossings provide critical non-motorized system links by joining areas separated by barriers, such as railroads and highway corridors. In most cases, these structures are built in response to user demand for safe crossings.

There are no minimum roadway characteristics for considering grade separation. Depending on the type of facility or the user group, grade separation may be considered in many types of projects.

Safety is a major concern with undercrossings. Shared-use path users may be temporarily out of sight from public view and may experience poor visibility themselves. To mitigate safety concerns, an undercrossing should be spacious, well-lit, and completely visible for its entire length.

**Guidance**

- The minimum width of an undercrossing is 14 feet, with greater widths preferred for lengths over 60 feet.
- The minimum height of an undercrossing is 12 feet.
- The undercrossing should have a centerline stripe, even if the rest of the path does not.
- Lighting should be considered for undercrossings in culverts and tunnels or locations with high anticipated use.

### 14.5.5 – Overcrossings

Bicycle/pedestrian overcrossings provide critical non-motorized system links by joining areas separated by barriers such as deep canyons, waterways, or major transportation corridors. In most cases, these structures are built in response to user demand for safe crossings.

There are no minimum roadway characteristics for considering grade separation. Depending on the type of facility or the desired user group, grade separation may be considered in many types of projects. Refer to Publication 15M, *Design Manual Part 4 -Structures* for fencing requirements.

For new construction and reconstruction projects, the vertical clearance is 1 foot greater than the vertical clearance required for the highway over which the structure is located.

For 3R and pavement preservation projects, see chapters in this design manual on these topics to determine minimum vertical clearances.

**Guidance**

- Overcrossings shall provide a minimum 8 feet (10 feet desirable) horizontal clearance between railings (on low-volume bicycle use with occasional pedestrian use only paths), with 14 feet or greater preferred for other-volume or other-use paths).
- If the overcrossing borders scenic vistas, additional width should be provided to allow for stopping. A separate 5-foot localized pedestrian area may be provided for facilities with high bicycle and pedestrian use.
- Overcrossings should maintain 10 feet of headroom for the users.
- An overcrossing should have a centerline stripe even if the rest of the path does not.

Requirements for overcrossings for bicycles and pedestrians typically fall under the ADA, which strictly limits ramp slopes to 5% (1:20) with landings at 400-foot intervals or 8.33% (1:12) with landings every 30 feet. Overcrossings also pose potential design challenges related to visual impact and functional appeal.



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## 14.6 – Shared-Use Paths and Off-Street Bicycle Facilities

A shared-use path allows for two-way, off-street bicycle use and may be used by pedestrians, skaters, wheelchair users, runners, and other non-motorized users.

These facilities are frequently found in parks, along rivers and beaches, and in greenbelts or utility corridors where there are few conflicts with motorized vehicles. Path facilities can also include amenities such as lighting, signage, and fencing.

Key features of shared-use paths include:

- Frequent access points from the local road network.
- Directional signs that direct users to and from the path.
- A limited number of at-grade crossings with streets or driveways.
- Termination points easily accessible to and from the street system.
- Separation of pedestrians and bicyclists when heavy use is expected.

At-grade roadway crossings create potential conflicts between path users and motorists. Consideration must be given to adequate warning distance based on vehicle speeds and sight distance.

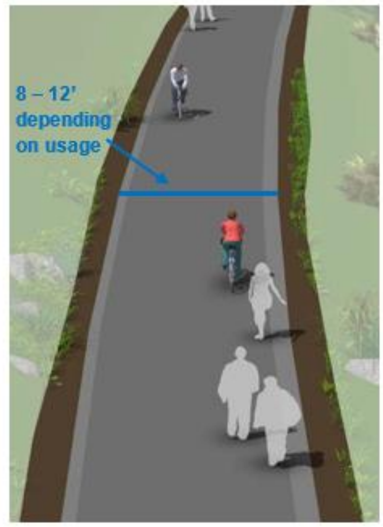
Directing the active attention of motorists to roadway signs may require additional alerting devices, such as roadway striping or changes in pavement texture. Signing for path users may include a standard STOP or YIELD sign and pavement markings, possibly combined with other features, such as bollards or a bend in the pathway to slow bicyclists. Care must be taken not to place too many signs at crossings, lest they begin to lose their visual impact.

Trail design guidance is provided in the Pennsylvania Department of Conservation and Natural Resources' (DCNR) *Pennsylvania Trail Design & Development Principles: Guidelines for Sustainable, Non-motorized Trails* and *Pennsylvania Trail Design Manual for Off-Highway Recreational Vehicles* as well as the AASHTO's *Guide for the Development of Bicycle Facilities*. Guidance for roadway considerations is provided in the MUTCD.

### 14.6.1 – General Design Practices

Shared-use paths can provide a desirable facility, particularly for recreation and users of all skill levels preferring separation from traffic. Bicycle paths can provide directional travel opportunities not provided by existing roadways.

The design should terminate the path where it is easily accessible to and from the street system, preferably at a controlled intersection or at the beginning of a dead-end street.




## Guidance

**Access Points**

- Any access point to the path should be well-defined with appropriate signage designating the pathway as a bicycle facility and prohibiting motor vehicles.
- Access points should provide sight distance based on the speed of the roadway.

**Width**

- 8-feet is the minimum allowed for a two-way shared-use path, and only allowed if low-volume bicycle use with occasional pedestrian use, or for short lengths due to other significant constraints.
- 10-feet is recommended in most situations and will be adequate for moderate to heavy use.
- 12-feet is recommended for heavy use situations with high concentrations of multiple users. A separate track (5-feet minimum) can be provided for pedestrian use.

**Lateral Clearance**

- A 2-foot or greater shoulder on both sides of the path should be provided. An additional foot of lateral clearance (total of 3-feet) is required by the MUTCD for the installation of signage or other furnishings.
- If bollards are used at intersections and access points, they should be colored brightly and/or supplemented with reflective materials to be visible at night.

**Overhead Clearance**

- Clearance to overhead obstructions should be 8-feet minimum with 10-feet recommended.

**Pavement Marking**

- When pavement markings are required, use a 4-inch dashed yellow centerline stripe with 4-inch solid white edge lines.
- Solid centerlines can be provided on tight or blind corners, and on the approaches to roadway crossings.

### 14.6.2 – Shared-Use Paths Along Roadways

Shared-use paths along roadways, also called side paths, run adjacent to a street.

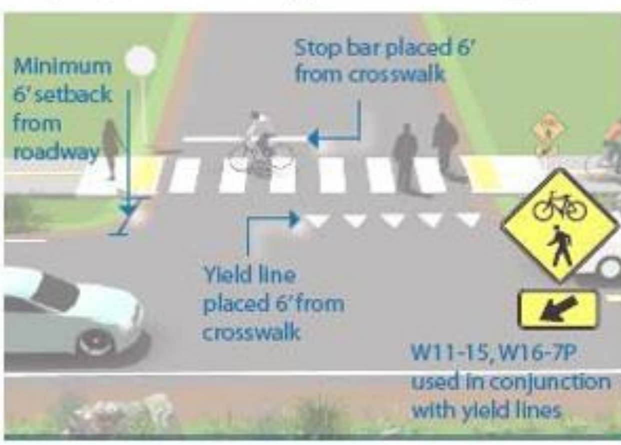
AASHTO's *Guide for the Development of Bicycle Facilities* also cautions practitioners about the use of two-way side paths on urban or suburban streets with many driveways and street crossings.

In general, the two approaches to side-path crossings are adjacent and setback, as illustrated below.

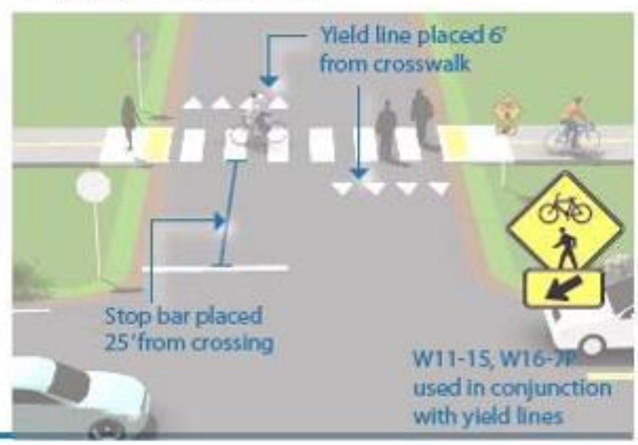
**Guidance**

- Guidance for side paths should follow that for general design practices of shared-use paths.
- To minimize potential conflicts, alternatives to side paths should be considered on streets with a high frequency of intersections or heavily used driveways.
- Where a side path terminates, special consideration should be given to transitions that discourage bicyclists from unsafely riding the wrong way.
- Crossing design should emphasize visibility of users and clarify expected yielding behavior. Crossings may be stop or yield-controlled, depending on sight lines and bicycle and motor vehicle volumes and speeds.

**Adjacent Crossing** - A separation of 6 feet emphasizes the conspicuity of riders at the approach to the crossing.




**Setback Crossing** - A set back of 25 feet separates the path crossing from merging/turning movements that may be competing for a driver's attention.



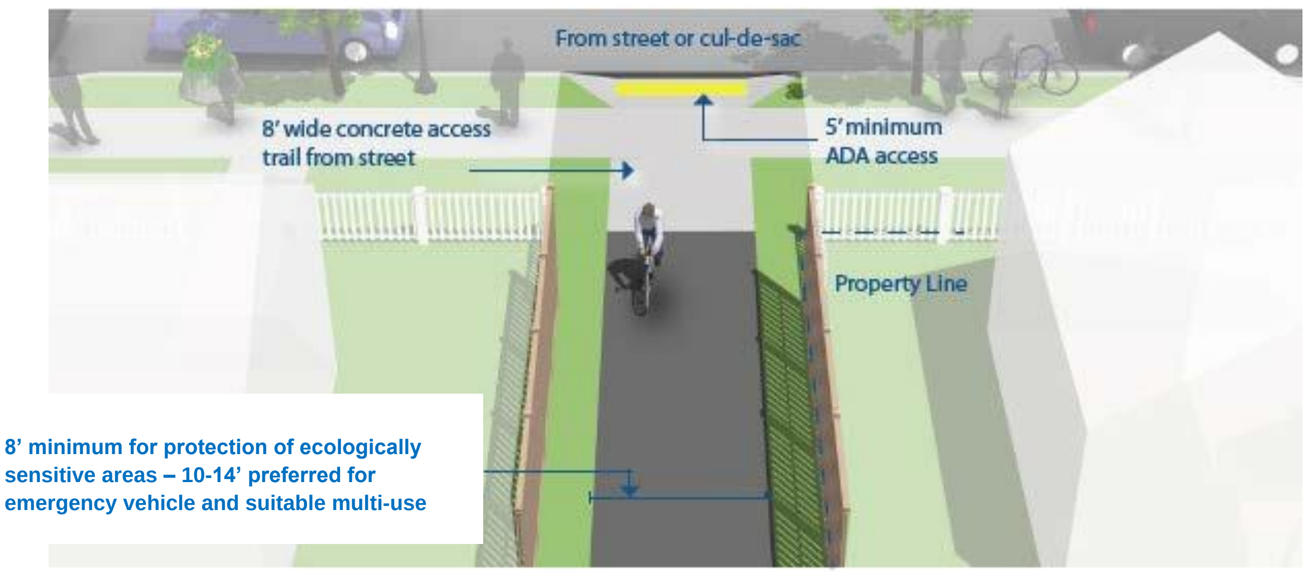
### 14.6.3 – Local Neighborhood Accessways

Neighborhood accessways provide residential areas with direct bicycle and pedestrian access to parks, trails, greenspaces, and other recreational areas. They most often serve as small trail connections to and from the larger trail network, typically having their own rights-of-way and easements.

Additionally, these smaller trails can provide bicycle and pedestrian connections between dead-end streets and cul-de-sacs as well as access to nearby destinations not provided by the street network.

**Guidance**

- Neighborhood accessways should remain open to the public.
- Trail pavement should be 10 to 14-feet wide to accommodate emergency and maintenance vehicles, meet ADA requirements, and be considered suitable for multi-use.
- Trail widths should be designed as less than 8-feet wide only when necessary to protect large, mature native trees over 18 inches in caliper, wetlands, or other ecologically sensitive areas.



## 14.7 – Bicycle Support Facilities

For cycling to serve as an attractive form of transportation, a system of support facilities is essential to complement the bikeway network. Useful complementary facilities include such items as convenient bicycle parking, transit access, wayfinding signage with clearly marked bike routes and destination information, and roadway features that consider the characteristics of a bicycle.


- **Bicycle Parking** – Bicyclists expect a safe, convenient place to secure their bicycle when they reach their destination. This may be for the short term (i.e., parking of two hours or less) or the long-term (e.g., parking for employees, students, residents, and commuters).

- **Access to Transit** – Safe and easy access to bicycle parking facilities encourages commuters to access transit via bicycle.

  Providing bicycle access to transit and space for bicycles on buses and rail vehicles can increase the feasibility of transit in lower-density areas where transit stops are beyond the walking distance of residences. People are often willing to walk only a quarter- to half-mile to a bus stop, while they might bike as much as two or more miles to reach a transit station.

  Chapter 15 of this manual provides additional transit information.

- **Roadway Considerations** – The safety of all roadway users should be considered during road construction and repair. Wherever bicycles are allowed, measures should be taken to provide for the continuity of a bicyclist's trip through a work zone.

  Work-zone maintenance and protection of traffic considerations are provided in Chapter 9 of this manual; rumble strip and other roadway considerations are provided in Chapter 12.

## 14.7.1 – Bicycle Parking

Short-term bicycle parking is meant to accommodate visitors, customers, and others expected to depart within two hours. The facility should have a locally-approved standard rack, appropriate location and placement, and weather protection. A maintenance agreement may be required for these facilities.

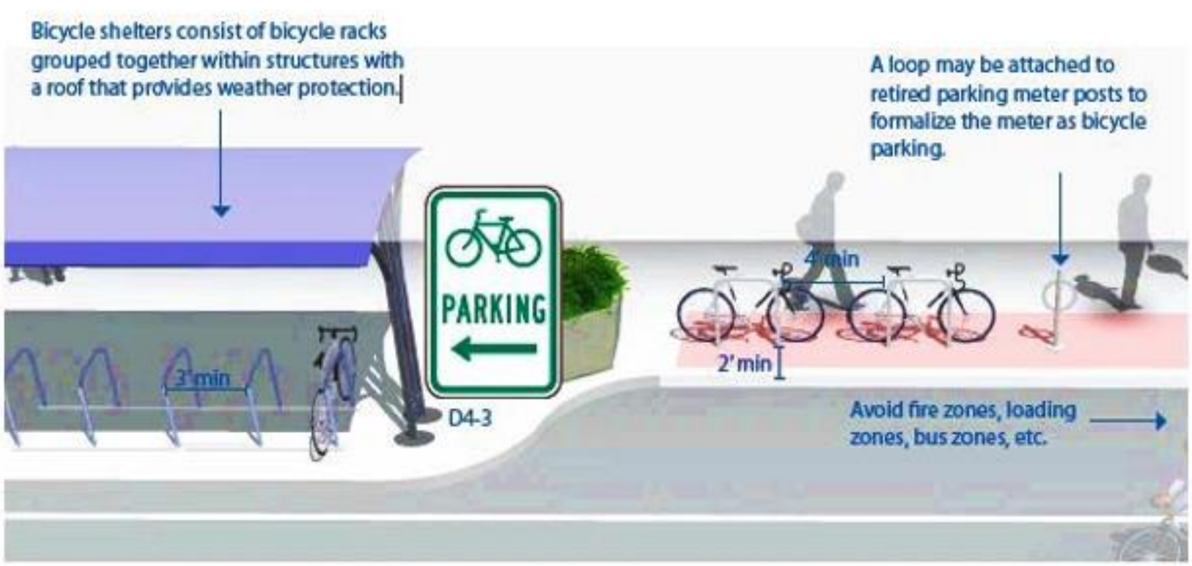
The Association for Pedestrian and Bicycle Professionals (APBP) recommends selecting a bicycle rack that:

- Supports the bicycle in at least two places, preventing it from falling over.
- Allows locking of the frame and one or both wheels with a U-lock.
- Is securely anchored to the ground.
- Resists cutting, rusting, and bending or deformation.

**Guidance**

- Parking should be placed at a 2-foot minimum from the curb face to avoid dooring.
- Parking should be close to destinations, with a 50-foot maximum distance from main building entrances.
- A minimum clear distance of 6 feet should be provided between the bicycle rack and the property line.
- Parking should be highly visible from adjacent bicycle routes and pedestrian traffic. Pavement markings may be added to enhance visibility
- Racks should be located in areas that bicyclists are most likely to travel.

Where it is not possible to place racks on sidewalks (due to narrow sidewalk width, sidewalk obstructions, trees, or other barriers), bicycle parking can be provided in the street through on-street bicycle corrals in locations where on-street vehicle parking is allowed.



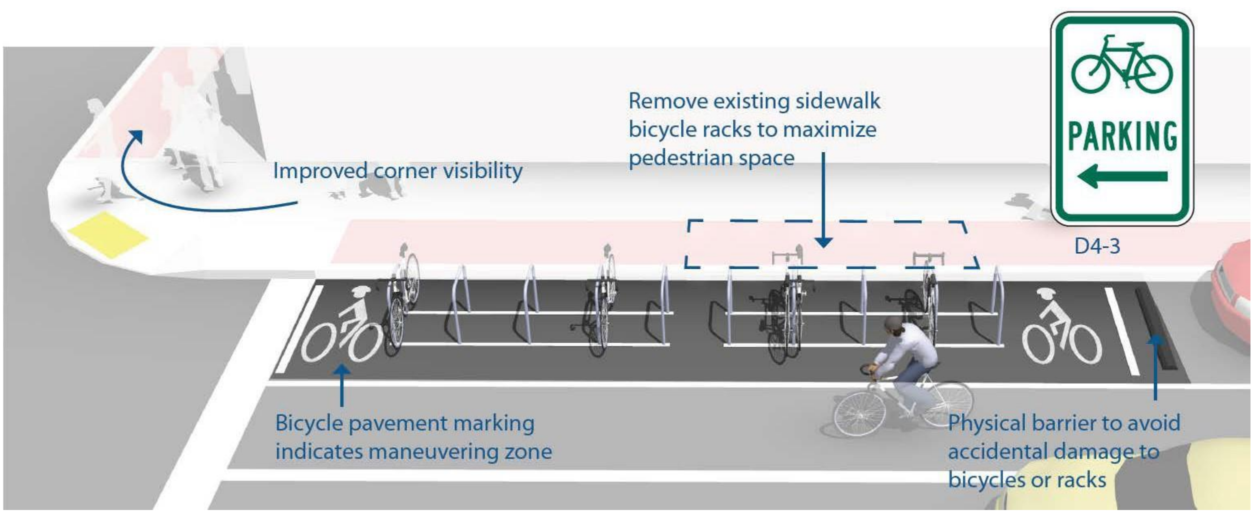
## 14.7.2 – On-Street Bicycle Corrals

Bicycle corrals (also known as on-street bicycle parking) are bicycle racks grouped together in a common area traditionally used for automobile parking within the street. Bicycle corrals are reserved exclusively for bicycle parking and provide a relatively inexpensive solution to high-volume bicycle parking. Bicycle corrals can be implemented by converting one or two on-street motor vehicle parking spaces into on-street bicycle parking. Each motor-vehicle parking space can be replaced with approximately six to ten bicycle parking spaces.

**Guidance**

- Bicycle corrals should have an entrance width from the edge of roadway of between 5 and 6 feet.
- Bicycle corrals can be used with parallel or angled parking.
- Parking stalls adjacent to curb extensions are good candidates for bicycle corrals since the concrete extension serves as delimitation on one side.

Bicycle corrals (which require a Highway Occupancy Permit and possible maintenance agreement) move bicycles off the sidewalks, leaving more space for pedestrian and sidewalk activities. Because bicycle parking does not block sight lines (as large motor vehicles do), it may be possible to locate bicycle parking in no-parking zones near intersections and crosswalks.



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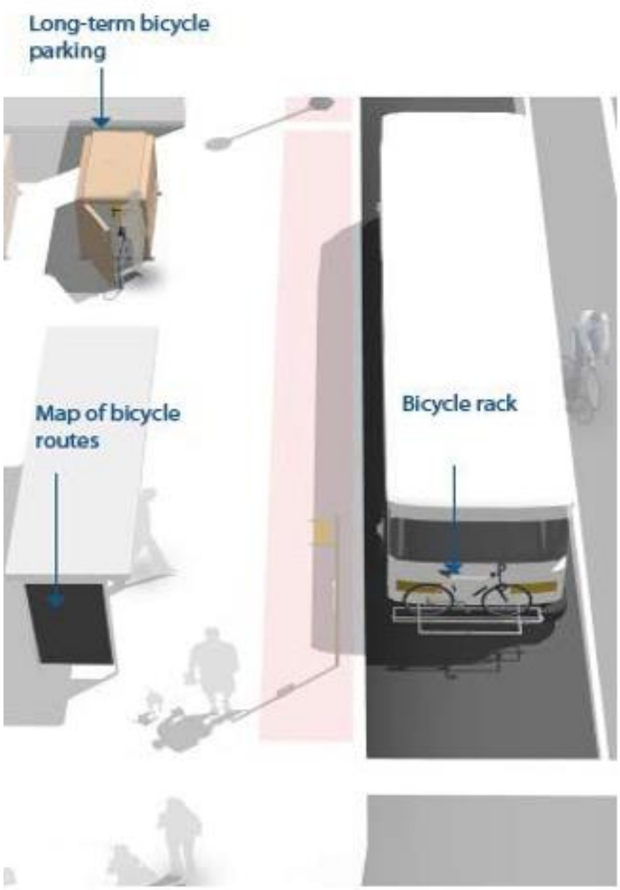
### 14.7.3 – Bicycle Access to Transit

Safe and easy access to transit stations and secure bicycle parking facilities is necessary to encourage commuters to access transit via bicycle. Bicycling to transit reduces the need to provide expensive and space-consuming vehicle parking spaces.

Many people who ride to a transit stop will also want to bring their bicycles with them on public transportation. Buses and other transit vehicles should be equipped accordingly.




**Guidance**

**Access**

- The design should provide direct and convenient access from the bicycle and pedestrian networks to transit stations and stops.
- The design should provide maps at major stops and stations showing nearby bicycle routes.
- The design should provide wayfinding signage and pavement markings from the bicycle network to transit stations.
- The design should ensure that connecting bikeways offer proper bicycle actuation and detection.

**Bicycle Parking**

- The route from bicycle parking locations to station/stop platforms should be well-lit and visible.
- Signing should note the location of the bicycle parking, rules for use, and instructions, as needed.
- Parking should be easy to use and well maintained. Long-term parking should be safe and secure, with features such as bicycle lockers at transit hubs.

## 14.7.4 – Roadway Considerations

### 14.7.4.a – Drainage Grates

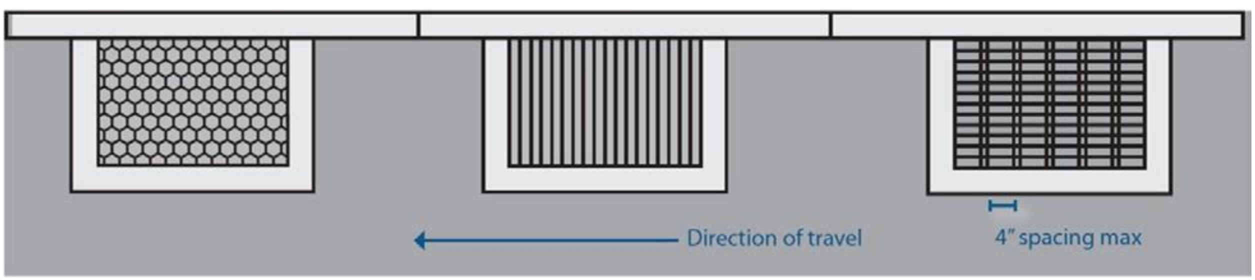
Drainage grates are typically located in the gutter area near the curb of a roadway. They contain slots through which water drains into the municipal storm sewer system.

Many older grates were designed with linear parallel bars spread wide apart, which can catch a bicyclist's front tire. This may cause the bicyclist to tumble over the handlebars and sustain potentially serious injuries.

Beyond grates, potential cyclist safety issues also include those presented by gutters (and their joints if a pavement differential exists), bus pads, historical pavements (such as cobblestones or bricks), and flush curbs.

**Guidance**

- Where bikes are allowed, all new drainage grates must be bicycle-friendly, incorporating horizontal slats when necessary, so that bicycle tires and assistive devices do not fall through the vertical slats.
- See RC-45M for approved inlet grates




### 14.7.4.b – Landscaping

Bikeways can become inaccessible due to overgrown vegetation. All landscaping design should ensure compatibility with the use of the bikeways. Publication 461, *Roadside Planting Guide,* and Publication 461A, *Roadside Beautification Overview and Application,* provide landscaping design details.

### 14.7.4.c – Signing and Pavement Markings

Bike lanes, shared shoulders, bicycle boulevards, and paths require different wayfinding and regulations signage. The examples provided in this chapter are intended to provide general guidance only. Messages and installation of bicycle guide signs should follow the Tourist Oriented Directional Signs Policy described in Publication 46, *Traffic Engineering Manual*.


### 14.7.4.d - Bicycle Signals at Signalized Intersections

Bicycle signals are additional signals at signalized intersections used to clarify when to enter an intersection and by restricting conflicting vehicle movements.

Bicycle signal heads are similar to conventional traffic signals, but use red, yellow, and green lenses incorporating a stenciled bicycle icon. AASHTO's *Guide for the Development of Bicycle Facilities* adds that a standard three-lens signal head with a supplemental SIGNAL plaque (i.e., R10-10b) could be used.

Bicycle signals should only be used in combination with an existing, conventional traffic signals. Bicycle signals would not be used at a unsignalized intersection or crossing. Bicycle signal heads may be installed at signalized intersections to indicate bicycle signal phases and other bicycle-specific timing strategies.

Signage and pavement markings may be used to supplement these facilities for both bicyclists and motorists. An R10-10b sign shall be installed immediately adjacent to every bicycle signal face that is intended to control only bicyclists, including signal faces with bicycle symbol signal indications, all-arrow signal indications, and every combination thereof. The purpose of the sign is to inform motor vehicle drivers who can see the signal face that these signal indications are intended only for bicyclists.


** Details for the R10-10b sign are provided in the Interim Approval for Optional Use of a Bicycle Signal Face (IA-16)

Signals may be necessary as part of a protected bicycle facility (such as a protected bike lane with potential turning conflicts) or to decrease vehicle or pedestrian conflicts at major crossings. An intersection with bicycle signals may also reduce delays for a crossing bicyclist and discourage illegal and unsafe crossing maneuvers.

A bicycle signal should be considered in the following scenarios:

- At intersections with bicycle-specific movements, such as a contraflow bicycle lane or track, where a bicycle signal may be necessary to indicate right-of-way to the bicyclist.
- At intersections where bicycle movements need to be separated in time from a conflicting vehicular movement, such as locations with a high volume of left or right turns. Bicycle signals at these intersections can allow for a separate bicycle phase or movement.
- At locations with high vehicle turning volumes, where bicyclists could benefit from a bicycle signal with a Leading Bicycle Interval (LBI), similar to a leading pedestrian interval. An LBI gives bicyclists a head start at intersections by giving them several seconds of green time before the concurrent vehicular movement receives the green indication. This provides bicyclists an opportunity to make a lane change or left turn and reduces the risk of conflicts between bicyclists and turning traffic.
- At intersections with high bicycle volumes, such as shared-use path crossings, where bicyclists would otherwise follow the pedestrian indication. At these locations, a bicycle signal can reduce confusion.
- At intersections where bicyclists would normally follow the vehicular indication. At these locations, a bicycle signal provides a longer clearance interval more suitable to bicyclist speeds, potentially preventing them from getting caught in the path of an oncoming vehicle.

**Guidance**

Locations where bicycle signals have had a demonstrated positive effect include:

- Those with a high volume of bicyclists at peak hours.
- Those with a high number of bicycle/motor vehicle crashes, especially those caused by turning vehicle movements.
- At T-intersections with major bicycle movement along the top of the "T".
- At the confluence of an off-street bike path and a roadway intersection.
- Where separated bike paths run parallel to arterial streets.

The designer should consider the following when installing bicycle signal heads:

- The bicycle signal shall be placed in a location clearly visible to oncoming bicyclists, who will have varying lateral positions on the bicycle facility.
- There shall be no right turn on red where bicycle signals are used to separate bicycle through movements from vehicular turning movements or to provide an LBI.
- The bicycle signal shall have an adequate clearance interval, which is generally determined by considering intersection width and bicyclist travel speed.
- If the bicycle phase is not set to recall each cycle, bicycle signals must be installed with appropriate detection and actuation, preferably passive (e.g., the bicyclist does not have to dismount and use a pushbutton).
- Use of smaller heads, programmable lenses, tunnels, and louvers can prevent confusion caused when motor-vehicle drivers misinterpret green bike face signals.

The FHWA Interim Approval MUTCD IA-16 provides guidance on the use of a bicycle signal face, including the meaning of bicycle signal indications, application parameters, design and location of bicycle signal faces, operation, and regulatory signing requirements. Additionally, the guidance outlines prohibitions to the use of a bicycle signal face without request to experiment.

# Appendix 14A: Bike Facilities Maintenance and Bike Lane Requests

## Operation and Maintenance of on Road Bicycle Facilities

The costs involved with the operation and maintenance of bicycle facilities should be considered and budgeted for when planning a facility, since neglected maintenance can render bicycle facilities unrideable and the facilities can become a liability.

In suburban and rural areas, on-road bike lanes generally consist of pavement markings, line striping, and signing. They are not physically separated from other traffic and utilize/share shoulder space.

Publication 23 – *Maintenance Manual* sets forth the Department's policies and practices for roadway maintenance. It includes guidance on winter services and roadside management that relate to bicycle lane (shoulder) maintenance and operations.

As a matter of current policy, the Department will remove the snow from the state road and shoulder in anticipation of further snow events and to provide an option for safe refuge for disabled vehicles. This includes non-separated bike lanes that are part of roadway/shoulder.

The Department also removes overgrown vegetation and other debris, sweeps after winter operations, responds to issues with pavement quality, and replaces pavement markings and line striping as part of restriping or resurfacing projects on state roads.

The 'local' maintenance requirement for these types of bike lanes essentially involves replacing bike lane signs that are damaged or destroyed and replacing pavement markings in between Department restriping/resurfacing work. These responsibilities shall be included in a maintenance agreement that must be signed prior to the inclusion of the bicycle facility into the overall project design.

More complex designs in suburban, urban, or urban core areas involving physical separation with vertical and horizontal elements, signalization, changes to drainage or other elements will require a substantially more complex maintenance agreement that will identify and address the issues particular to the project. The project manager should coordinate with the District Planner, District Bicycle and Pedestrian Coordinator, and the Statewide Bicycle and Pedestrian Coordinator, to ensure the agreement is fully vetted. In no case should the bicycle facility proceed to construction before a fully executed agreement is in place.

## Sharrows

Projects which contain sharrows must have a written request letter from the municipality on municipal letterhead prior to the project's advertisement for construction. This letter must request the sharrows, commit to maintaining the sharrows and to follow all municipal procedures as outlined in Section 6109 of Title 67 as applicable. Subsequently, if PennDOT agrees in coordination with the District traffic unit, then an approval letter must be sent to the municipality from the District ADE-Design. Approvals are per **67 Pa. Code § 212.5**. Sample request and approval letters for sharrows can be found in the ECMS File Cabinet under the Resources tab.

## Bike Lane Requests

Bike lanes designate a portion of a roadway, by striping, signing and pavement markings, for the preferential or exclusive use of bicyclists. The Bike Lane Request/Approval Letters in this section are not for use with Separated Bike Lanes, which require an executed maintenance agreement prior to construction. **67 PA Code § 212.5(b)1(v)** requires municipalities to maintain signage and pavement markings along bike lanes. PennDOT will remove snow from approved bike lanes that are part of the roadway on state roads (i.e. non-separated) and perform other routine roadway maintenance, such as sweeping and vegetation trimming, in accordance with normal operations.

Municipalities interested in creating bike lanes shall contact the PennDOT District Bicycle/Pedestrian (BP) Coordinator during the project scoping process so PennDOT can advise in the conceptual stage of the project. As the bike lane plan develops, at some point it will be necessary for the Municipality to request approval from the District. The Municipality shall request approval for the Bike Lane. The request can be submitted via mail or electronically. An example letter is provided in **Exhibit 14.A.1**. PennDOT will not install bike lanes without a municipal request.

The request for approval will include a detailed description of the proposed bike lane. If the information provided with the request letter is not adequate for the Department to make an informed decision, PennDOT will use the approval letter to notify the municipality that approval is denied pending the submission and approval of additional information. The letter will detail the additional information required.

PennDOT will evaluate the bike lane request based on AASHTO's *Guide for the Development of Bicycle Facilities*. The Department will consider, among other things, the following:

- Bike lane width (5' minimum preferred), motor vehicle lane width (minimum width is not necessarily desirable), roadway speed, and adjacent parking.
- Pavement condition and smoothness, rumble strips, inlets, flush utility covers, and adequate drainage.
- Bridge railing height and expansion joints.
- Right edge of the Bike Lane, such as curb, gutter, or guiderail.
- Conflicts at intersections, driveways, and railroad crossings.
- Signal timing and turning maneuvers.
- Transit stops and pedestrian crossings along the length of the bike lane.

The bike lane description shall include state routes and/or local roads listed in sequential order, starting from one end and progressing to the other end of the bicycle lane. In addition to the listing of the routes, the limits and identification of segments of each route in the bicycle lane must be indicated. The design should indicate if the bicycle facility is a bike lane or a buffered bike lane. The description and location shall specify the bicycle lane width, which side or sides of the roadway are involved, whether pavement or a portion of the shoulder is utilized, and any other pertinent information necessary to properly locate the bicycle lane.

Drawings detailing the proposed bike lane shall also be included. If the bike lane is part of a PennDOT project, the municipality should coordinate with PennDOT for drawings and description details.

Bicycle signals require an approved signal permit. If bicycle signals are required, or required to be relocated, for the proper function of the bike lane, an approved signal permit will be required prior to approval. If the requested bike lane is not part of a PennDOT project, the municipality must provide an Engineering Study for the proposed bike lane, with a P.E. Seal, detailing the considerations outlined above.

The District Bicycle/Pedestrian Coordinator will review the request with appropriate PennDOT staff. A template approval letter is shown in **Exhibit 14.A.2**. PennDOT approval is required from the District ADE for Design. If the Bike Lane is not approved, a letter will be sent to the municipality explaining why.

**Exhibit 14.A.1 Example Bike Lane Request Letter**

DATE

District Bicycle/Pedestrian Coordinator
Street Address
City, State, Zip Code

**Subject: Municipal Request for a Non-Separated Bicycle Lane**
County:
Municipality Name:
SR, Section:
Project Length:
Project Name:

Dear Bicycle/Pedestrian Coordinator:

(Municipality Name's) would like to request a (Bike Lane and associated pavement markings) on SR (1234). The proposed bicycle facility is described below:

[Provide a description of the proposed bike route. Include location map and relevant drawings detailing the routing, pavement markings and signage. The State Routes and/or local roads should be listed in sequential order starting from one end and progressing to the other end of the bicycle lane routing. In addition to the listing of the routes, the limits and identification of segments of each route in the bicycle lane routing should also be indicated. The description and location should specify the bicycle lane width, which side or sides of the roadway are involved, whether pavement or a portion of the shoulder is utilized and any other pertinent information necessary to properly locate the bicycle facility.]

(Municipality Name) is aware of its responsibility to install and maintain all Bike Route Signs and Pavement Markings associated with the bicycle lane per **67 PA Code § 212.5(b)1(v).** (Municipality Name) will coordinate with the PennDOT in advance of any work in the right-of-way. (Municipality Name) is also responsible to remove debris from the bike lane as needed. PennDOT will remove snow from Non-Separated Bike Lanes on State Roads and perform other routine roadway maintenance such as sweeping and vegetation trimming, in accordance with normal operations. This letter authorizes the Municipality to remove all Bike Lane Signs and Pavement Markings upon written notification to PennDOT. PennDOT also reserves the right to remove all Bike Lane Signs and Pavement Markings and will notify Municipality of such removal.

Please contact (Municipal Contact) to discuss the proposed bikeway:
Municipal Contact
Address
Telephone: (xxx) xxx-xxxx
E-mail:

Sincerely,

Name
Municipal Official

**Exhibit 14.A.2 Example Bike Lane Approval Letter**

DATE

Municipal Contact Person
Municipality Name
Street Address
City, State, Zip Code

**Subject: Municipal responsibilities for Non-Separated bicycle lane facilities under 67 PA Code § 212.5**
County:
Municipality Name:
SR, Section:
Project Length:
Project Name:
MPMS Number:

Dear Municipal Contact Person:

The Pennsylvania Department of Transportation (PennDOT) concurs with (Municipality Name's) plan to install a bicycle lane along SR (1234). The proposed bicycle lane is described below:

[Provide a description of the proposed bike route. Include location map and relevant drawings detailing the routing, pavement markings and signage. Approved documents submitted by the Municipality can be used to describe the bike lane.]

The purpose of this letter is to inform (Municipality Name) of its responsibility to install and maintain Bike Lane Signs and Pavement Markings for bicycles. Please see **67 PA Code § 212.5(b)1(v).** (Municipality Name) is responsible to install and maintain all signage and pavement markings associated with the bicycle lane described above. (Municipality Name) will coordinate with the PennDOT in advance of any work in the right-of-way. (Municipality Name) is also responsible to remove debris from the bike lane as needed. PennDOT will remove snow from Non-Separated Bike Lanes on State Roads and perform other routine roadway maintenance such as sweeping and vegetation trimming, in accordance with normal operations. This letter authorizes the Municipality to remove all Bike Lane Signs and Pavement Markings upon written notification to PennDOT. PennDOT also reserves the right to remove all Bike Lane Signs and Pavement Markings and will notify Municipality of such removal.

Please direct all correspondence to the following contact:

PennDOT Engineering District X-X
Contact Person
Address
Telephone: (xxx) xxx-xxxx
Email: xxxxx@pa,gov

Sincerely,

Name
Assistant District Executive for Design

# Chapter 15 – Transit Facilities (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 16 – Freight Facilities (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 17 – Plain People Community Considerations (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 18 – Traffic Calming (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 19 – Parking (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 20 – Lighting (To be Added Later)

This chapter will be published in the future.  Until it is published, please refer to relevant topic in Publication 13M.

# Chapter 21 – Wildlife Crossings

In this chapter there are references to future chapter that are currently not included in this Publication 13.

Until they are included in this Publication, please refer to relevant topics in Publication 13M.

# Chapter 21 – Wildlife Crossings

## 21.0 – Introduction

Wildlife needs to move to meet their basic habitat requirements. In view of this, it is important to consider mitigation efforts along transportation corridors that can facilitate wildlife in meeting these needs.

This chapter provides guidance when considering the appropriateness of designing and constructing a wildlife crossing or an exclusionary device, such as preventative fencing, to provide safe access for various wildlife and help to reduce vehicle/animal collisions on roadways throughout the Commonwealth.

Wildlife crossing
(U.S. 219 PennDOT District 9)

This guidance is for information purposes only; PennDOT does not require the use of wildlife crossings. However, an evaluation should be conducted to consider the use of wildlife crossings and preventive fencing on all non-urban transportation projects based on the defined determination criteria in Section 21.4. Urban and suburban projects might also be evaluated where these projects cross significant open space, park land or streams that could have potential for the presence of wildlife.

**Important context questions to ask:**

- What are the wildlife species groups to consider when designing a wildlife crossing?
- When should wildlife crossings be considered and where should they be located?
- What are the types of wildlife crossings?
- What are the appropriate dimensions of wildlife crossings to accommodate specific species groups?
- When should fencing be considered for wildlife crossings?

**Key design components:**

- Generally, the Engineering District should consider designing a wildlife crossing feature for the safe passage of wildlife across a roadway corridor at locations where a high volume of crossings has been documented historically and/or where excessive vehicle/animal collisions have occurred.
- When designing a wildlife crossing consideration should be given to the type, size and location of a crossing that best accommodates the appropriate specie(s) design group.
- Guide fence is an important component of most types of wildlife crossing designs as an exclusionary device to help safely direct wildlife to the location of the crossing.

### 21.0.1 – Resources and References


- Beckerman, J., A. Clevenger, M. Huijser, and J. Hilty, *Safe Passages: Highways, Wildlife and Habitat Connectivity*, 2010.
- California DOT, *Wildlife Crossings Guidance Manual*, 2007. http://www.conservewildlifenj.org/downloads/cwnj_278.pdf
- D.C.Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine, and T.C. Winter, *Road Ecology: Science and Solutions*, 2003.
- Defenders of Wildlife, *Getting Up to Speed: A Conservationist's Guide to Wildlife and Highways*, 2007. https://defenders.org/sites/default/files/publications/getting_up_to_speed.pdf
- FHWA, *Critter Crossings: Linking Habitats and Reducing Roadkill*, 2002. https://permanent.fdlp.gov/lps11043/www.fhwa.dot.gov/environment/wildlifecrossings/intro.htm
- FHWA, *Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report*, 2007. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/07033/07033.pdf
- FHWA, *Eco-logical: An Ecosystem Approach to Developing Infrastructure Projects*, 2006. https://www.environment.fhwa.dot.gov/env_initiatives/eco-logical/report/eco_index.aspx
- FHWA, *Wildlife Crossing Structure Handbook Design and Evaluation in North America*, 2011. https://www.fhwa.dot.gov/clas/ctip/wildlife_crossing_structures
- Massachusetts DOT, *Project Development & Design Guide*, 2006. https://www.mass.gov/doc/2006-project-development-and-design-guide
- National Cooperative Highway Research Program Transportation Research Board of The National Academies, *Evaluation of the Use and Effectiveness of Wildlife Crossings NCHRP 25-27*, 2007. http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/25-27_FR.pdf
- PennDOT, Publication 546, *Threatened and Endangered Desk Reference.*

## 21.0.2 – Glossary

- **Fragmentation.** Splitting up or separation of a habitat, landscape, or ecosystem into smaller parcels.
- **Habitat Connectivity.** The state of structural landscape features being connected, enabling access between places via a continuous route.
- **Large Mammals.** Includes bear and ungulates (a large group of mammals all of which have hooves, e.g., Deer and Elk) that pose a threat to motorists' safety.
- **Listed Species.** Species that are listed as either threatened or endangered, nationally, or statewide, sometimes referred to as "T&E species."
- **Target Species.** The primary species the crossing is designed to accommodate. Target species are often large mammals or listed species.
- **Travel Corridors.** Features that connect two or more otherwise isolated patches of habitat that allow animals to travel safely from one area to another but may also provide food or other necessities as well.
- **Wildlife Crossing.** Structures that allow animals to cross human-made barriers safely.
- **Wildlife Fencing.** Fences designed to keep animals from accessing right-of-way habitat and road surface, or to funnel animal movement to safe crossing locations (e.g., wildlife crossing structures).

## 21.1 – Background

Wildlife crossings are structures that allow animals to cross human-made barriers safely. Wildlife crossings may include underpass structures, viaducts, and overpasses (mainly for large animals such as bears or herd-type ungulates), culverts (for small mammals such as raccoons, possums, and porcupine); and amphibian and reptile tunnels (for frogs, turtles, and snakes). Wildlife crossings allow connections or reconnections between habitats and assist in avoiding collisions between vehicles and animals.

Each year on average in the United States, the National Highway Traffic Safety Administration (2019) estimates that 200 human deaths and 29,000 injuries result from vehicle crashes involving animals, i.e., deaths from a direct motor vehicle/animal collision or from a crash in which a driver tried to avoid an animal and ran off the roadway. In 2019, Pennsylvania reported 5,747 crashes including 1,106 motorist injuries and 6 motorist fatalities involving wildlife on Pennsylvania roadways (PennDOT Crash Data). Also, Pennsylvania ranks third highest nationally over the ten-year period 2010-2019 for the number of fatalities caused by vehicle crashes with animals (Insurance Institute for Highway Safety (IIHS)). According to the Federal Highway Administration, wildlife/vehicle collisions cost American taxpayers more than $8 billion per year and the insurance industry estimates the average vehicle damage claim is over $4,000.

Studies have also shown that animal mortality from vehicles is a threat to wildlife populations when some population numbers are already low or when vital habitats occur near roadways due to fragmentation. The long-term cost savings benefits gained from reduced animal/vehicle collisions by constructing a wildlife crossing structure when appropriate should be considered for all non-urban projects, as well as for urban and suburban projects surrounded by significant open space, park land or streams with identified or potential wildlife when animal/vehicle collisions are documented. Note that consideration for wildlife crossings may be based on ecological benefits only.

PennDOT recognizes the importance of reducing impacts to wildlife and improving or maintaining habitat connectivity. However, the emphasis on public safety is paramount and cannot be overstated. As a transportation agency, the function of PennDOT is first and foremost to provide a safe and efficient transportation infrastructure for the traveling public.

## 21.2 – Crossing and Exclusion Considerations

All transportation projects within non-urban areas in particular, should be evaluated to consider providing a wildlife crossing and/or exclusionary fencing where appropriate. The decision to incorporate wildlife crossings and/or exclusionary fencing into the highway design is not a straightforward and simple formula but a combination of these factors:

- Public Safety (injuries and fatalities)
- Cost to implement (e.g., design, construction, maintenance)
- Vehicle repair costs and associated costs (insurance, cleanup, EMS, etc.)
- Environmental Benefits

These areas are interrelated when it comes to wildlife crossings and the weight assigned to each may fluctuate. Factors such as public opinion, ADT, crash data, future land use and species concerns can shift the values one way or the other. The value of each factor varies from project to project and must be considered according to the circumstances present. Data collected or provided to address the above guidelines should serve as the basis of decision for determining whether a wildlife crossing, and/or exclusionary devices are appropriate. The specific design (type, size, and location) of the crossing should be determined by the District with Coordination from the Pennsylvania Game Commission (PGC), Pennsylvania Fish and Boat Commission (PF&BC), U.S. Fish and Wildlife Service (USFWS) and FHWA when appropriate.

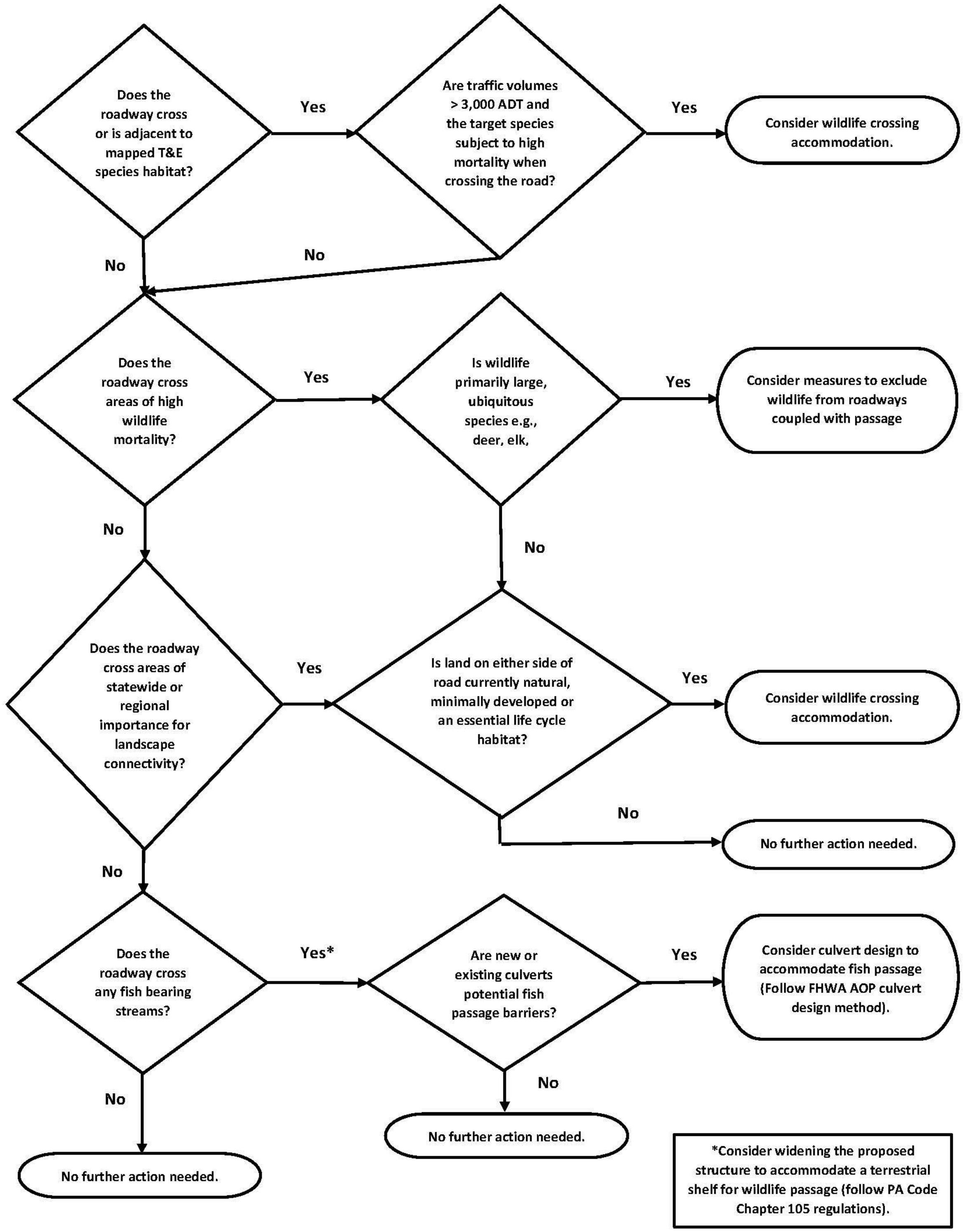
## 21.3 – Wildlife Crossing Determination

Criteria listed in this section, including **Exhibit 21.3.1**, should be used when determining whether to include a wildlife crossing within a transportation project in conjunction with existing data sources. Some useful data sources include: PennDOT Crash Information Tool, PA habitat connectivity mapping, PA National Heritage Program-Conservation Explorer (PNHP), and the PA National Diversity Inventory-Environmental Review Tool (PNDI-ER).

Since all potential mitigation areas are different, it is not mandatory to meet all criteria when determining a wildlife crossing. Appropriate data, agency collaboration and professional judgement should be applied in the evaluation process to come to a reasonable conclusion.

Exhibit 21.3.1 can assist in making the determination whether a wildlife crossing, and/or exclusionary device is appropriate.

## Exhibit 21.3.1 - Wildlife Accommodation Scenarios



Wildlife crossings and exclusionary devices, such as fences, walls, or earth mounds, should be considered when the project is a new roadway or bridge or a new alignment where the centerline deviates from the existing one enough that vertical and horizontal design controls for new construction are used to at least some degree, and the following conditions exist:

- The project has the potential to inhibit movement of target species between critical life requisite habitats or prohibits movement of target species along documented travel corridors.
- Projected traffic volumes are ≥ 3,000 ADT and the target species is subject to high mortality when crossing the road (if applicable).
- Target species have been documented to utilize habitat impacted by the project to fulfill its need for food, structure, water, and ability to reproduce. or the project is within the primary or secondary range of a listed species. Additional information is available through the Pennsylvania Natural Heritage Program.
- Public lands or lands under conservation easement are present in enough amounts, on both sides of the road, where the crossing will be located to ensure future land use is compatible with the target species' needs.
- The project crosses areas where drainage ways are present.
- The project crosses areas that present minimal grade separations requiring little cut or fill to install the crossing.

On projects where multiple locations meet these criteria, the number and spacing of wildlife crossings will be determined by the District (Project Manager, Assistant District Executive for Design) after consultation with the natural resource agencies and PennDOT Bureau of Design and Delivery.

Wildlife crossings and exclusionary devices should be considered when the project is a bridge replacement, drainage improvement, or reconstruction project if the following conditions are met:

- The project meets the criteria in Exhibit 21.3.1 above.
- There are documented road kills of target species within the project area.

A request can be made from an organization/agency (other than those referenced below) if the requesting organization/agency is prepared to participate as a funding partner and adequate funding is available (when applicable).

PennDOT will consider the need for a wildlife crossing or exclusionary device when the PGC, PF&BC or USFWS have expressed a science-based need for a wildlife crossing, in conjunction with PennDOT, for a target species.

All requests for wildlife crossings and/or exclusionary devices will be made in accordance with the Pennsylvania Department of Transportation Natural Resources Assessment and Mitigation Agency Partnering Policy (Publication 546, *Threatened and Endangered Species Desk Reference*). This policy requires the requesting entity to provide documentation or studies to substantiate their requests and it requires an analysis to determine whether the resource is a Natural Resource Meriting Compensation and further whether the compensation is a reasonable expenditure of public funds. In cases where supporting data does not exist, PennDOT will not conduct studies, nor will it generate data for such purposes.

## 21.4 – Wildlife Crossing Design

Each project site has different conditions that require consideration in the design of a wildlife crossing system or exclusionary device. During the project development process, direct coordination is recommended between PennDOT and PGC, PF&BC and/or USFWS, to establish the design considerations for each specific crossing and site. This coordination should occur as early as practical during the design phase to ensure that all project objectives are met. Conditions which should be utilized in the determination of a crossing design should include but are not limited to:

- The crossing cannot compromise state or federal design criteria.
- The crossing cannot restrict property access rights-of-way to adjacent properties.
- The crossing should not negatively impact adjacent properties (e.g., provide direct access for wildlife to private properties where none presently exist).
- The crossing should not negatively impact existing drainage patterns or increase flow to off-site properties.
- Construction of the crossing should not negatively impact the habitat.
- The addition of the crossing should not result in significant modifications to the proposed project (e.g., excessive increases in roadway grades, significant increases in required right-of-way).

## 21.4.1 – Species Design Groups

Planning and designing wildlife crossings will often be focused on a certain species of conservation interest (e.g., threatened or endangered species), a specific species group (e.g., amphibians) or abundant species that pose a threat to motorist safety (e.g., deer, elk).
This guidance looks at wildlife and species groups when discussing the appropriate wildlife crossing designs. The eight groups mentioned below are general in composition. However, recommendations will be provided, if it is available, for species-specific design requirements (See **Exhibit 21.4.1** through **21.4.3**). Their ecological requirements and how roads affect them are described along with some sample wildlife species for each group.

- **Large Mammals (Deer, Elk, Bears).** Species with large area requirements and potential migratory behavior; large enough to be a motorist safety concern; traffic related mortality may cause substantial impacts to local populations; susceptible to habitat fragmentation by roads.
- **High Mobility Medium-Sized Mammals (Lynx, Coyote, Fox).** Species that range widely; fragmentation effects of roads may impact local populations.
- **Low Mobility Medium-Sized Mammals (Raccoon, Skunk, Hare, Groundhog).** Species with smaller area requirements; common road related mortality; relatively abundant populations.
- **Semi-arboreal Mammals (Marten, Red Squirrel, Flying Squirrel).** Species that are dependent on forested habitats for movement and meeting life requisites; common road-related mortality.
- **Semi-aquatic Mammals (River Otter, Mink, Muskrat).** Species that are associated with riparian habitats for movement and life requisites; common road-related mortality.
- **Small Mammals (Ground Squirrels, Voles, Mice).** Species that are common road-related mortality and relatively abundant populations.
- **Amphibians (Frogs, Toads, Salamanders).** Species with special habitat requirement; relatively abundant populations at the local scale; populations are highly susceptible to road mortality.
- **Reptiles (Snakes, Lizards, Turtles).** Species with special habitat requirement; road environment (e.g., warm pavement, water, and feed vegetation) tends to attract individuals; relatively abundant populations

## 21.4.2 – Identifying Locations for Wildlife Crossings

These basic principles will help guide the determination of how to locate wildlife crossings to get the greatest long-term conservation value.  There is no simple formula to determine the recommended location. The specific location of a wildlife crossing should be determined by the

District in coordination with the PGC, PF&BC, USFWS and FHWA when appropriate. Wildlife crossings are seldom effective without fencing.

- **Topographic features.** Wildlife crossings should be placed where movement corridors for the target species are associated with dominant topographic features (riparian areas, ridgelines, etc.). Sections of roadway can generally be ignored where terrain (steep slopes) and land cover (built areas) are unsuitable for wildlife and their movement.
- **Multiple species**. Crossings should be designed and managed to accommodate multiple species and variable home range sizes. A range of wildlife crossing types and sizes should be provided at frequent intervals along with necessary microhabitat elements that enhance movement, e.g., root crowns for cover. Unlike the physical structure of wildlife crossings, microhabitat elements are movable and can be modified over time as conditions and species distributions change.
- **Adjacent land management.** How well a wildlife crossing structure performs is partly dependent upon the land management that surrounds them. Transportation and land management agencies need to coordinate in the short and long term to ensure that tracts of suitable habitat adjacent to the crossings facilitate movement to designated wildlife crossings.

## 21.4.3 – Wildlife Crossing Types (for description purposes only)

Follow PennDOT Publication 15M, Design Manual Part 4, *Structures* (DM-4) and *Wildlife Crossing Structure Handbook Design and Evaluation in North America* (2011), when choosing the appropriate type. Note that wildlife crossings are seldom effective without wildlife fencing.

### 21.4.3.a – Overpass Design

- **Landscape Bridge.** Designed exclusively for wildlife use. Due to their large size, they are used by the greatest diversity of wildlife and can be adapted for amphibian and reptile passage.
- **Wildlife Overpass.** Smaller than landscape bridges, these overpass structures are designed exclusively to meet needs of a wide range of wildlife from small to large.
- **Multi-use Overpass.** Generally, the smallest of the wildlife overpasses. Designed for mixed wildlife and human use. This wildlife crossing type is best adapted in human disturbed environments and will benefit generalist type species adapted to regular amounts of human activity and disturbance.

Overpass Crossing

## 21.4.3.b – Underpass Design

- **Viaduct or Flyover.** This wildlife passage design is the largest of underpass structures. The large span and vertical clearance of viaducts allow for use by a wide range of wildlife. Structures can be adapted for amphibian and reptiles, semi-aquatic and semi-arboreal species. These work well because of the large open natural areas. This design should not be constructed exclusively for wildlife movement. The Viaduct or Flyover may be included in the design of a transportation project if warranted to meet the project's transportation needs based on the topography of the area while additionally providing benefit to wildlife.

Viaduct Underpass
(U.S. 219 PennDOT District 9)

- **Large Mammal Underpass.** Not as large as most viaducts, but the largest of underpass structures designed specifically for wildlife use. Designed for large mammals but small- and medium-sized mammals use readily as well. The large mammal underpass should be included in the design of a transportation project if warranted based on the topography of the area.

Examples of Large Mammal Underpasses

- **Multi-Use Underpass.** Design similar to large mammal underpass; however, management objective is co-use between wildlife and humans. Design is generally smaller than a large mammal underpass because of type of wildlife using the structures along with human use. These structures may not be adequate for all wildlife but usually results in use by generalist species common in human-dominated environments (e.g., urban or suburban habitats). Large structures may be constructed to accommodate the need for more physical space for humans and habitat generalist species.

- **Underpass with Water Flow.** An underpass structure designed to accommodate the needs of moving water and wildlife. These underpass structures are frequently used by some large mammal species, but their use depends largely on how it is adapted for their specific crossing needs. Small- and medium-sized mammals generally utilize these structures, particularly if riparian habitat or cover is retained within the underpass.

  Consider incorporating wildlife underpass crossings when designing bridges. Wildlife crossings may be more easily added by increasing the bridge span to accommodate a wildlife passage dry shelf that would permit various types of animal movement. This can apply to large mammal, multi-use and water flow type underpass structures. Consideration should be made to provide a dry shelf on both sides of the waterway so that wildlife would not be forced to cross water upstream or downstream.

Wildlife Underpass Dry Shelf (Terrestrial) Crossing
(Route 22 PennDOT District 8)

- **Small- to Medium-Sized Mammal Underpass.** One of the smaller wildlife crossing structures. Primarily designed for small- and medium-sized mammals, but species use will depend largely on how it may be adapted for their specific crossing needs.

Example of Medium-Sized Mammal Underpass

- **Amphibian and Reptile Tunnels**. Crossing designed specifically for passage by amphibians and reptiles such as turtles, frogs, and snakes, although other small-and medium-sized vertebrates may use as well. Many different amphibian and reptile designs have been used to meet the specific requirements of each species or taxonomic group. Main conflicts with amphibians are where roads intercept periodic migration routes to breeding areas (ponds, lakes, streams, vernal pools, or other aquatic habitats). For some species the migration to these critical areas, including the dispersal of juveniles to upland habitats, is synchronized each year. This large movement event results in a massive migration of individuals in a specific direction during a short period of time. Amphibian/reptile tunnels should be in these key sections of road that intercept their movements year after year. Crash data, (e.g., PennDOT PCIT Crash Data) and migration data from regional herpetological organizations can be used to help identify highly active amphibian (e.g., turtles) and reptile crossing locations to consider the installation of a protective wildlife crossing.

Examples of Amphibian and Reptile Tunnels

**Exhibit 21.4.1 General Guidelines for Minimum and Recommended Dimensions of Wildlife Overpass Designs**

| Type | Usage | Species and Group | Dimensions Minimum | Dimensions Recommended[1] |
|---|---|---|---|---|
| Landscape Bridge | Wildlife Only | All wildlife species<br>Amphibians (if adapted) | **W: 230 ft** | **W: >330 ft** |
| Wildlife Overpass | Wildlife only | Large mammals<br>High-mobility medium-sized mammals Low mobility medium-sized mammals<br>Small mammals<br>Reptiles<br>Amphibians (if adapted) | **W: 130-165 ft** | **W: 165-230 ft** |
| Multi-use Underpass | Mixed use: Wildlife & Human activities | Large mammals<br>High-mobility medium-sized mammals Low mobility medium-sized mammals. Small mammals<br>Amphibians (if adapted)<br>Reptiles | **W: 32 ft** | **W: 50-130 ft** |

[1]These dimensions are recommendations and may vary based on site conditions and species needs.

Source: FHWA, *Wildlife Crossing Structure Handbook Design and Evaluation in North America*, 2011.

**Exhibit 21.4.2 General Guidelines for Minimum and Recommended Dimensions of Wildlife Underpass Designs**

| Type | Usage | Species and Group | Dimensions Minimum | Dimensions Recommended[1] |
|---|---|---|---|---|
| Viaduct or Flyover | Multi-purpose | All wildlife species | There are no minimum dimensions. Structures are generally larger than the largest wildlife underpass structures | There are no minimum dimensions. Structures are generally larger than the largest wildlife underpass structures |
| Large Mammal Underpass | Wildlife only | Large mammals<br>High-mobility medium-sized mammals<br>Low mobility medium-sized mammals<br>Semi-arboreal & semi-aquatic<br>Mammals (adapted)<br>Small mammals<br>Amphibians (adapted)<br>Reptiles | **W: 23 ft**<br>**Ht: 13 ft** | **W: >32 ft**<br>**Ht: >13 ft** |
| Multi-use Underpass | Mixed use: Wildlife & Human activities | Large mammals<br>High-mobility medium-sized mammals<br>Low mobility medium-sized mammals<br>Semi-arboreal & semi-aquatic<br>Mammals (adapted)<br>Small mammals<br>Amphibians (adapted)<br>Reptiles | **W: 16.5 ft**<br>**Ht: 8.2 ft** | **W: >23 ft**<br>**Ht: >11.5 ft** |

| Type | Usage | Species and Group | Dimensions Minimum | Dimensions Recommended[1] |
|---|---|---|---|---|
| Underpass with Water Flow | Wildlife and drainage | Large mammals<br>High-mobility medium-sized mammals<br>Low mobility medium-sized mammals<br>Semi-arboreal mammals (adapted)<br>Semi-aquatic mammals<br>Small mammals & amphibians<br>Semi-arboreal mammals & reptiles (adapted) | **W*: 6.5 ft dry pathway**<br>**Ht: 10 ft**<br>*Width will be dependent on width of hydrologic channel in crossing | **W*: >10 ft dry pathway**<br>**Ht: >13 ft**<br>*Width will be dependent on width of hydrologic channel in crossing |
| Small to Medium Sized Mammal Underpass | Wildlife and seasonal drainage | High-mobility medium-sized mammals (adapted)<br>Low mobility medium-sized mammals<br>Semi-aquatic mammals (adapted)<br>Small mammals<br>Amphibians (adapted)<br>Reptiles | **Same as recommended dimensions**<br>Size selection is based on the target species needs or connectivity objective at the site | **W: 1-4 ft**<br>**Ht: 1-4 ft**<br>OR<br>**1-4 ft dia.** |
| Amphibian and Reptile Tunnel | Wildlife only | Amphibians<br>Low mobility medium-sized mammals (adapted)<br>Semi-aquatic (adapted)<br>Small mammals & reptiles (adapted) | Dimensions vary depending on target species or taxa or local conditions<br>Tunnels range from 1-3 ft in diameter | Dimensions vary depending on target species or taxa or local conditions<br>Tunnels range from 1-3 ft in diameter |

[1]Note: The height of the wildlife underpass is generally the distance between the pathway surface and the underside of the structure over the pathway surface.

Source: FHWA, *Wildlife Crossing Structure Handbook Design and Evaluation in North America*, 2011.

## Exhibit 21.4.3 Suitability of Wildlife Crossing Design Types for Distinct Wildlife Species and Taxa

| | Landscape bridge | Wildlife overpass | Multi-use overpass | Viaduct or flyover | Large mammal underpass | Multi-use underpass | Underpass with water flow | Small- to medium-sized mammal underpass | Amphibian and reptile tunnel |
|---|---|---|---|---|---|---|---|---|---|
| **Ungulates** | | | | | | | | | |
| Elk | ● | ● | ● | ● | ● | ● | ● | ⊗ | – |
| White-Tailed Deer | ● | ● | ● | ● | ● | ● | ● | ⊗ | – |
| **Carnivores** | | | | | | | | | |
| Black Bear | ● | ● | ⊗ | ● | ● | ⊗ | ● | ⊗ | – |
| Coyote | ● | ● | ● | ● | ● | ● | ● | ● | – |
| Fox | ● | ● | ● | ● | ● | ● | ● | ● | – |
| Bobcat | ● | ● | ● | ● | ● | ● | ● | ⊗ | – |
| Fisher | ● | ● | ● | ● | ○ | ● | ○ | ● | – |
| Marten | ● | ● | ● | ● | ○ | ● | ○ | ● | – |
| Weasel | ● | ● | ● | ● | ○ | ● | ○ | ● | – |
| River Otter | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ⊗ |
| **Low mobility medium-sized mammals** | ● | ● | ● | ● | ● | ● | ● | ● | ○ |
| **Semi-arboreal mammals** | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ⊗ | ⊗ |
| **Semi-aquatic mammals** | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ |
| **Small mammals** | ● | ● | ● | ● | ● | ● | ● | ● | ○ |
| **Amphibians** | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| **Reptiles** | ● | ● | ● | ● | ● | ● | ○ | ● | ○ |

● Recommended/Optimum solution; ○ Possible if adapted to local conditions; ⊗ Not recommended; – Not applicable

Source: FHWA, *Wildlife Crossing Structure Handbook Design and Evaluation in North America*, 2011.

## 21.5 – Wildlife Fencing

The use of fencing in conjunction with wildlife crossings is critical. Most wildlife is extremely wary and will avoid confinement or unnatural situations. Given the choice between going through unfamiliar wildlife crossing structures and crossing highway pavement, many will choose the latter. Fence guides the wildlife to use the crossing and over time will become comfortable. Without fencing, most wildlife may not use the structure. Wildlife fencing can also act as a protective barrier to prevent wildlife from crossing roadways reducing opportunities for vehicle/animal collisions.

Area View of Wildlife Crossing with Channeling Guide Fence
(I-99 PennDOT District 2)

When designing a wildlife passage, the fencing should be designed to minimize the corral or chute effect. This is done by constructing fencing to the top of the wildlife crossings, rather than the bottom, making approach to the wildlife crossing as wide as possible. The structure length and approaches should be dependent on the target species, making it more encouraging for wildlife usage.

For large mammals, a 6 to 8 foot woven-wire fence presents a formidable barrier when properly constructed and maintained. The 20-year life span of a well-built fence can justify its cost. Major materials include sturdy, rot-resistant wooden corner posts set in concrete (optional), wooden or studded steel T line posts, woven-wire fencing, and gates. If needed, extensions can be attached to the top of the fence to prevent deer or elk from jumping over. Bears, coyotes, and other carnivores may try to dig under or climb over. Burying fencing underground reduces the possibility of wildlife digging under the fence and also increases the lifetime of the fencing reducing maintenance costs. Fencing is also important for medium to small mammals, reptiles, and amphibians as well. For many of these species, Type 2 right-of-way highway fencing (4 foot wire mesh) should be adequate. Variable mesh fencing that has small-sized mesh openings at the bottom and the standard mesh size at the top should be used where small mammals, reptile and amphibians are anticipated.

Examples of Wildlife Fencing

If wildlife becomes trapped inside the fenced area, they need to be able to safely exit the highway area. The most effective means of escape are through earthen ramps (or "jump-out" structures). Earthen ramps or jump-outs allow wildlife (large and small) to safely exit rights-of-way by jumping down to the opposite side of the fence. Earthen escape ramps are mounds of dirt placed against a smooth backing material and constructed on the right-of-way side of the fence. The landing spot around the outside wall must consist of loose soil, sand, or other soft material to prevent injury to animals.

Example of "Jump-out" Structure

## 21.6 – Fish Passage

Consideration for the safe passage of fish and other aquatic wildlife within creeks, streams or other small watercourses that cross under roadways is also important in limiting the fragmentation of aquatic habitat. Culvert installations can significantly decrease fish movement if not designed for proper fish passage. Velocities resulting from traditionally sized culverts may exceed fish swimming ability and scour at culvert outlets may prove too excessive for fish to leap into the structure. Common obstructions to fish passage include:

- Excessive water velocities
- Drops at culvert inlets or outlets
- Physical barriers such as weirs
- Improperly designed baffles, or debris caught in the culvert barrel
- Excessive turbulence caused by inlet contraction
- Low flows or sheet flows that provide too little depth for fish to swim

Consider appropriate structure design to allow for the adequate conveyance of aquatic wildlife. The specific location of aquatic wildlife crossings should be determined by the District in coordination with the PGC, PF&BC, USFWS and FHWA when appropriate.

For additional information regarding the design of fish passages, refer to Chapter 10, *Drainage*.

Examples of culverts designed to allow aquatic wildlife

## 21.7 – Determining Effectiveness

Monitoring of wildlife crossings may be conducted by PennDOT, the agency with jurisdiction of the species, and/or any partnering organization to determine the success of the accommodation and to help in the improved design and placement of future crossings. Measures of effectiveness should be developed during the design phase and monitored post-construction. "Effectiveness" may be defined as:

- Number of animal/vehicle collisions
- Number of crossings by target species
- Connectivity maintained to sustain populations, communities, ecosystem functions
- Population increases of the target species

It may be useful to compare statistics for similar stretches of roadway as a “control”. Understanding changes in average traffic volumes and changes in target species populations may help to determine how effective the crossings are in reducing animal-vehicle collisions.

## 21.8 – Maintenance Consideration

The designer should take into consideration that existing and newly installed wildlife crossing structures must be periodically maintained to continue to provide safe passage as, in the absence of routine maintenance, these structures may be avoided or become unusable by the species that they were intended to benefit.

Maintenance staff should be involved in the wildlife crossings planning to provide input on design considerations and their impacts on maintenance needs as well as in post-project assessments to consult on any maintenance concerns that may have arisen. It cannot be assumed that wildlife crossing structures, once in place, will remain effective without periodic maintenance, and maintenance crews must be informed of the procedures necessary to keep crossing structures accessible and to function as intended.
Maintenance activities may include but are not limited to:

- Cleaning of vegetation and maintenance of aprons of culverts. If scouring following storms prevents access, the scoured rocks or soil should be replaced with like materials to eliminate “hanging culverts” and not replaced with boulders, riprap or other substrates unsuited to the animal specie the culvert was intended to benefit.
- Maintaining cover material for smaller species (including but not limited to pipes, rocks, and root balls).
- Fences should be cleared of accumulated debris and repaired if they are torn or displaced from their original positions.

Over and under-crossings should be kept free of vegetation that inhibit passage of the target animals while native plants are encouraged to provide cover or forage.

It is recommended that a Maintenance Plan (Narrative, Planting Plans, etc.) be developed and kept on file at the county maintenance office for future care to be properly ensured. If nothing is documented or the Maintenance staff changes, the information passed on during the planning likely will not be passed on to new staff.

Refer to PennDOT Publication 23, *Maintenance Manual,* for additional maintenance activities.

# Chapter 22 – Landscape Planting

In this chapter there are references to future chapter that are currently not included in this Publication 13.

Until they are included in this Publication, please refer to relevant topics in Publication 13M.

# Chapter 22 – Landscape Planting Design

## 22.0 – Introduction

The roadside environment provides opportunities to enhance the aesthetic experience of the highway. Proper plantings will ensure a more visually enjoyable experience for users of the roadway, while not creating any detriment to safe operation. When choosing proper plantings, items such as size and scale of the planting, the relative resilience of the planting to the local environment, coordination with stormwater management, as well as the long-term maintenance impacts all factor into selection of the appropriate planting. This chapter presents some best practices for designers to consider, as well as defining appropriate planting locations at key roadway decision points to ensure operational safety.

**Important context questions to ask:**

- Is the planting appropriate for the specific project area?
- Is the selected planting of appropriate size and scale for the typology of the facility?
- Will the location of the planting potentially be a safety hazard for roadway users?
- Could the planting interfere with components of the facility (drainage, guiderail, utilities)?
- Will maintenance operations (particularly treatment for winter weather events) negatively impact the planting?
- Can full-width mowing reduction be achieved by the planting selection?
- Is the selected planting going to create excessive need for maintenance?
- Was resiliency, biodiversity, use of native plants and establishment of pollinator habitats considered in the planting design?
- Will the shade created by the planting cause icing issues?

**Key design components:**

- Size, Scale, and Sustainability of the selected planting.

  Relative to typology and footprint of the facility, consideration needs to be given to the size of the planting, and the visual scale that it will project. Mismatches between the planting selection and roadway facility will create undesired visual contrasts, the appearance of overgrowth, or other impacts deemed visually detrimental. Improperly sized plantings may also overtake the space provided or leave the appearance of empty space. Any planting selected should be able to thrive in the soil conditions and climate of the area.

- Short- and Long-Term Maintenance Demands of the Plantings.

Consideration during the design phase should include both the maintenance demands of the planting (in the short and long term), opportunities for reductions in mowing requirements, as well as the resiliency of the planting against typical maintenance operations, in particular winter treatment and maintenance.

- User Safety is always the primary concern.
- Plantings that are selected should be considered regarding risk of overgrowth. Plantings with the potential for expansion and overgrowth should not be located adjacent to key roadway safety devices, such as guiderail. Applicable intersection sight distances and other required sight lines are not to be obstructed. Trees greater than 4” in diameter should not be located within or near the clear zone. Visibility to all signs and traffic signals also needs to be maintained.
- Avoid conflict with underground design components and other stakeholders’ facilities.

  Some plantings and trees have root structures that can extend both out diametrically from the plant structure as well as to depths several feet underground. With these plantings, their location should be coordinated with any underground aspects of the roadway design (sign and signal foundations, drainage pipes, etc.) to avoid conflicts that would impact the function of these items.

## 22.0.1 – Resources and References

Beyond the planting design guidance provided in this chapter, designers should consult the various PennDOT Publications that address related topics that influence successful plantings, such as PCSWM and ESC design. Specific construction details for plantings are provided in Publication 72M, *Roadway Construction Details*. Additional information can be found in the following references.

- AASHTO, *A Guide for Transportation Landscape and Environmental Design,* 1991.
- FHWA, *Roadside Best Management Practices that Benefit Pollinators: Handbook for Supporting Pollinators through Roadside Maintenance and Landscape Design,* 2015.
- NACTO, *Leading Landscape Design Practices for Cost-Effective Roadside Water Management,* 2018.

## 22.1 – Required Agency and Municipal Coordination

Often in the design process, landscape design or roadside development is considered as part of the Post-Construction Stormwater Management for the project. Subsequently, the planting design is reviewed by the local stormwater agencies as part of the waterway permitting process. These agencies can also assist, from their extensive past experience, in determining plantings that have performed adequately in the local area, as well as those that have not taken to the local environment.

The selection of plantings needs to be coordinated with the local government as they will typically be responsible for maintaining them. Plantings may also be included in the center of roundabouts. Installation of plantings in these areas should balance a desire to dissuade pedestrians from trying to cross the roundabout travel lanes to the center, while also providing plantings that will not impede truck movements using the apron. Plantings should also be provided in these areas that will minimize the local entity's maintenance burden. Before installation of the plantings, a maintenance agreement shall be in place with the local agency to confirm maintenance responsibilities for the local stakeholder. This should be coordinated with the Environmental Policy Development Division of the Bureau of Design and Delivery to work out details on what needs to be included within the maintenance agreement. A Maintenance Agreement Template can be obtained from the Environmental Policy Development Division of the Bureau of Design and Delivery.

Landscape designs and roadside development features may fall within or beyond highway right-of-way. Dependent on the reason for, or commitment of plantings on a project, the Department or local government may be responsible for their maintenance post-construction. For instance, plantings within highway right-of-way may include plantings within interchange loop ramps or along highway roadsides or medians, for instance. These plantings will typically be maintained by the Department. Plantings resulting out of coordination with, or commitments to other agencies, may include plantings along urban roadway 'park-like' corridors, or within the center of roundabouts. These plantings will likely be owned/maintained by local government. It is essential to coordinate at a minimum, all planting designs that will be maintained by others, with the owning/maintaining agency.

## 22.2 – Landscape Planting Design Guidelines

All roadside landscape planting design should conform to the general principles of the latest edition of the AASHTO publication, *A Guide for Transportation Landscape and Environmental Design*. Roadside planting and roadway design should be correlated to achieve an overall unified plan. Roadside landscape planting design is a specialized field and should be assigned to personnel skilled in the use of plant material and experienced in the practice of Landscape Architecture. Landscape planting design should be completed under the direction of a Pennsylvania Registered Landscape Architect. Prepare the landscape planting design in conformance with the criteria presented in this Chapter.

### 22.2.1 – Planting Design

There are few mandatory rules for landscape planting design. The 1994 Presidential Executive Order on Environmentally Beneficial Landscaping provides guidance for implementing cost-effective, environmentally sound landscaping practices. Good design depends upon the knowledge and creativeness of the designer; however, a few basic guidelines do apply:

- The designer should first gather knowledge of any special problems that may affect the location or survival of the plant material (soil data, utilities, water table, contour grading plan, etc.).
- Highway planting should achieve a mass effect to be in scale for the viewer traveling at the design speed of the highway. Planting design should also achieve a well-balanced combination of both planted area and open spaces.
- Planting should be both functional and aesthetic to serve some definite purpose such as traffic delineation, screening, erosion control, etc.
- Where possible, especially in rural areas, planting designs should reflect the naturalistic conditions with informal flowing arrangements of material ecologically adapted to the site and purpose of the design. Avoid symmetrical, straight-line arrangements.
- Contrasts of sizes, foliage, bark color, flower or fruit should be considered to add interest. For further information, please refer to Publication 461A, *Roadside Beautification Overview.*
- Form and shape should be utilized for harmony as well as for contrast. Round headed or spreading plants form more desirable masses, while columnar or conical shapes add greater visual emphasis. Plants as they mature change size and can quickly overgrow a particular planting site. Avoid planting trees too close together that would limit the potential width or height development of either plant.
- Shrub use should be limited because of high maintenance costs, their relatively short life, and large quantities of plants necessary to achieve large masses. Small flowering trees generally require less maintenance, have a longer life potential and can create larger and taller plant masses.

**Plant Selection Characteristics to Consider**

- Cold hardiness
- Salt spray tolerance
- Soil moisture requirements
- Drought tolerance
- Insect susceptibility
- Disease resistance
- Native plant classification
- Ease of transplant
- Sunlight or shade tolerance
- Off-site invasive characteristics
- Availability
- Predation
- Avoid vegetation used for grazing

- Plant selection should be based on the plant's adaptability to various environmental, climate and soil conditions both in relation to surrounding conditions, as well as other potential factors such as maintenance needs. When determining appropriate plants, please refer to Publication 756, *Invasive Species Best Management Practices.*
- Plant selection should emphasize the use of native plants to the highest extent possible. Efforts should be taken, when appropriate, to use regionally native plants for landscaping. However, the design should also strive to utilize the best plant selection possible for the prospective site and design concept. For example, White Pine (Pinus strobus) is a very nice native evergreen tree for use in many situations, but it is sensitive to salt spray damage. Therefore, white pine use in plantings along highways should be extremely limited to protected areas well away from potential salt spray damage zones. Japanese Black Pine (Pinus thunbergia) is a non-native evergreen tree, but it is well suited to be used in areas subjected to salt spray.

**Pollinator Habitat Design Elements**

- Use proper site selection criteria (soil quality, water availability, proximity to other pollinator habitats).
- Prior to planting, ensure that invasive species have been eliminated or controlled to less than 5% cover to allow native species to become established.
- Consider restoration and management as part of the design and time commitment that establishing the habitat (3-5 years) requires.
- Consider food sources and plants for a wide variety of pollinator species.
- Ensure that invasive species can be controlled during future maintenance.
- Consider mowing requirements in conjunction with supporting the pollinator habitat.
- “Integrated Vegetation Management” approaches serve to aid in controlling populations of invasive plant species below threshold levels.

- Avoid selecting plants that have the potential to spread (invade) to areas adjacent to the highway right-of-way and adversely harm other existing plant communities. For additional guidance on planting management, please refer to Publication 370H, *Vegetation Management*.
- Creating naturalized plant areas using native plant species including bunch grasses, decorative shrubs, perennial bulbs, daylilies, and wildflowers can be effective in providing colorful special focal areas along the highway and provides native habitat for pollinator species and supports biodiversity.
- Avoid placing trees and shrubs over underground utility lines and drainage pipes. Avoid planting trees under overhead utility lines unless the mature tree size is recognized as a tree type recommended for this purpose. Avoid placing trees and shrubs in the center of proposed drainage swales and in front of drainage pipe discharges.

- The use of non-standard herbaceous seed mixtures containing native warm-season grasses and perennial wildflowers is encouraged for disturbed soil areas which may extend beyond the highway constructed slope limits. These herbaceous mixtures are well suited for revegetating areas for wildlife habitat mitigation and upslope areas for wetland replacement mitigation. All non-standard seed mixtures shall be approved by the Environmental Policy Development Division of the Bureau of Design and Delivery on a project-by-project basis.

  See Chapter 11, *Erosion and Sediment Pollution Control*, for additional guidance on these seed mixtures.

> **Pollinator Habitat Establishment - Details to Include:**
>
> - Project Description
> - Perennial Establishment
> - Establishment Overview
>   - Site Preparation and Planning
>   - Seeding Dates
>   - Maintenance During Establishment
> - Seeding Specifications
> - Schedule of Operations
> - Practice Implementation and Maintenance Agreement Contacts

- New construction projects should also include a provision to plant native wildflowers. The wildflower planting should be of a value of at least 1/4 of 1 percent of the total landscape planting cost, exclusive of planting items considered to be erosion and sedimentation control plantings.
- Pollinator habitats should be considered in developing the roadside planting design. The box above provides several items to consider if incorporating pollinator habitat. For additional Pollinator Habitat considerations, refer to PennDOT's Voluntary Prelisting Pollinator Conservation Program.
- Planting should not impede safe and efficient access or mobility for bicyclists and pedestrians. This should take into consideration plant growth so as to not inhibit or damage non-vehicular infrastructure.

For additional guidance related to designing with future maintenance considerations, refer to Publication 23, *Maintenance Manual.*

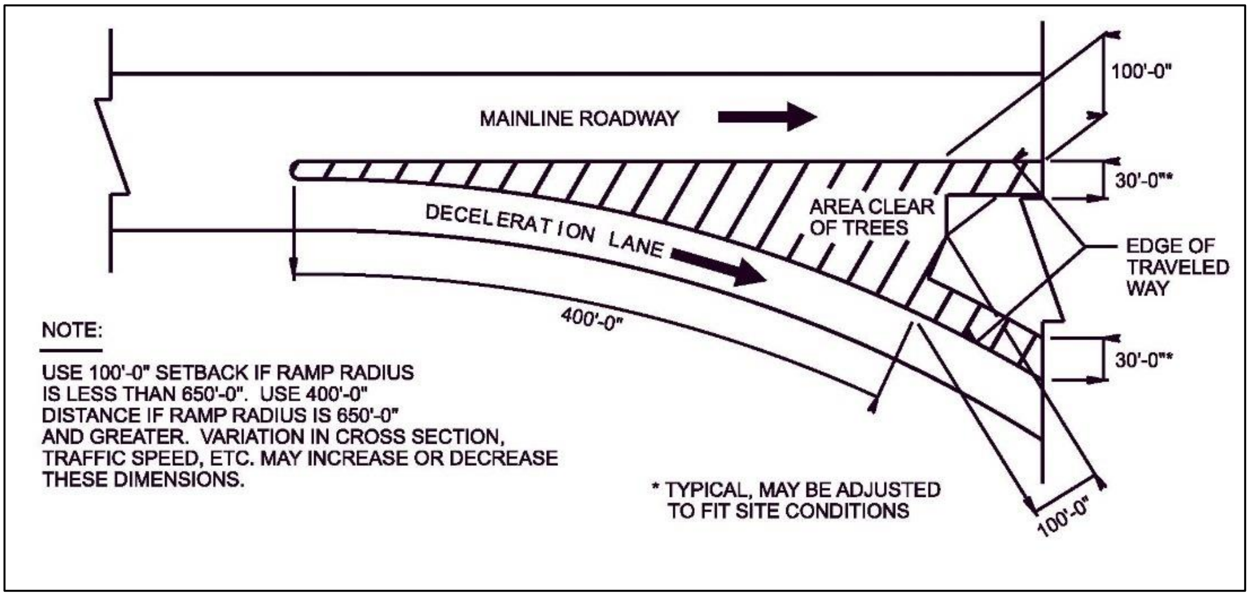
## 22.2.2 – Setback Distance

Major trees that can attain a trunk diameter greater than 4 inches should not be located within or near the proposed clear zone. The clear zone is the area measured from the edge of the travelled way available for safe use by errant vehicles and permits vehicular recovery. The clear zone widths are specified in Chapter 12, *Roadside Design*. The designer must consider site conditions and consider wider clear zones where practical. The values in are approximate values, not precise values. Major trees may be planted outside the proposed clear zone. Other considerations such as the potential maintenance problems of sign obstruction, roadway shading, leaf or other tree debris litter and the tree damage potential from winter maintenance chemicals shall be considered when planting trees close to the edge of traveled way. Additional guidance and discussion related to required/recommended sight distances for various classes and typologies of roadways can be found in the AASHTO Green Book.

Major trees that can attain a trunk diameter greater than 4 inches should not be located between a diverging ramp and the mainline roadway, as follows:

- For diverging ramps with a radius of less than 650 feet, the area between the mainline and the ramp shall be clear of trees to the intersection point of two lines measuring 100 feet on the perpendicular from the mainline and ramp traveled way edges as indicated in **Exhibit 22.2.1**.
- For diverging ramps with a radius greater than 650 feet, the area between the mainline and the ramp shall be clear of trees from a point 400 feet from the nose, measured along the ramp traveled way and a line perpendicular to the mainline as indicated in Exhibit 22.2.1.

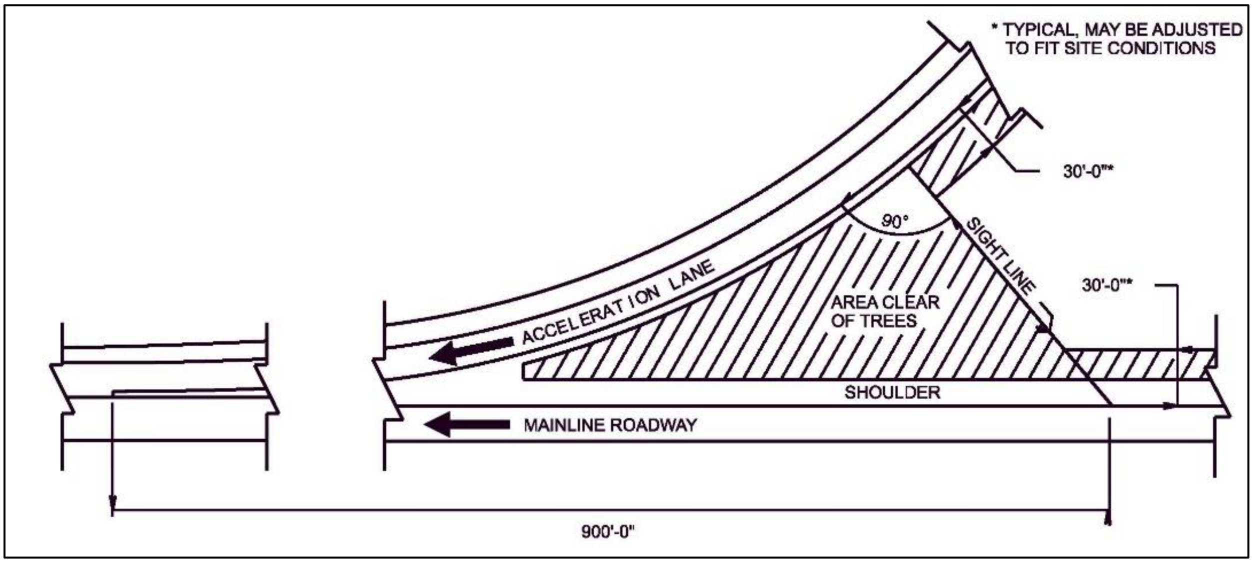
**Exhibit 22.2.1 Safety Set-Back for Interchange Tree Planting**



Trees and shrubs should not be located between converging ramps and mainline roadways, as follows:

- For converging ramps with standard acceleration lane tapers, the area between the mainline and the ramp shall be clear of all vegetation over 24 inches in height, from a point measured 900 feet from the end of the traffic separator and an intersecting line at a right angle to the left edge of traveled way of the converging ramp (see **Exhibit 22.2.2**).

**Exhibit 22.2.2 Clear Sight Distance Guide for Interchange Tree and Shrub Planting**




- For converging ramps where a structure or a deceleration ramp is less than the 900 feet or the right-angle clear area is less than what is shown in Exhibit 22.2.2, use an intersecting line at a right angle to the left edge of traveled way of the converging ramp to the furthest point available at the structure or the other deceleration ramp for the clear area limits (see **Exhibits 22.2.3** and **22.2.4**).

**Exhibit 22.2.3 Clear Sight Distance for Interchange Tree and Shrub Planting**

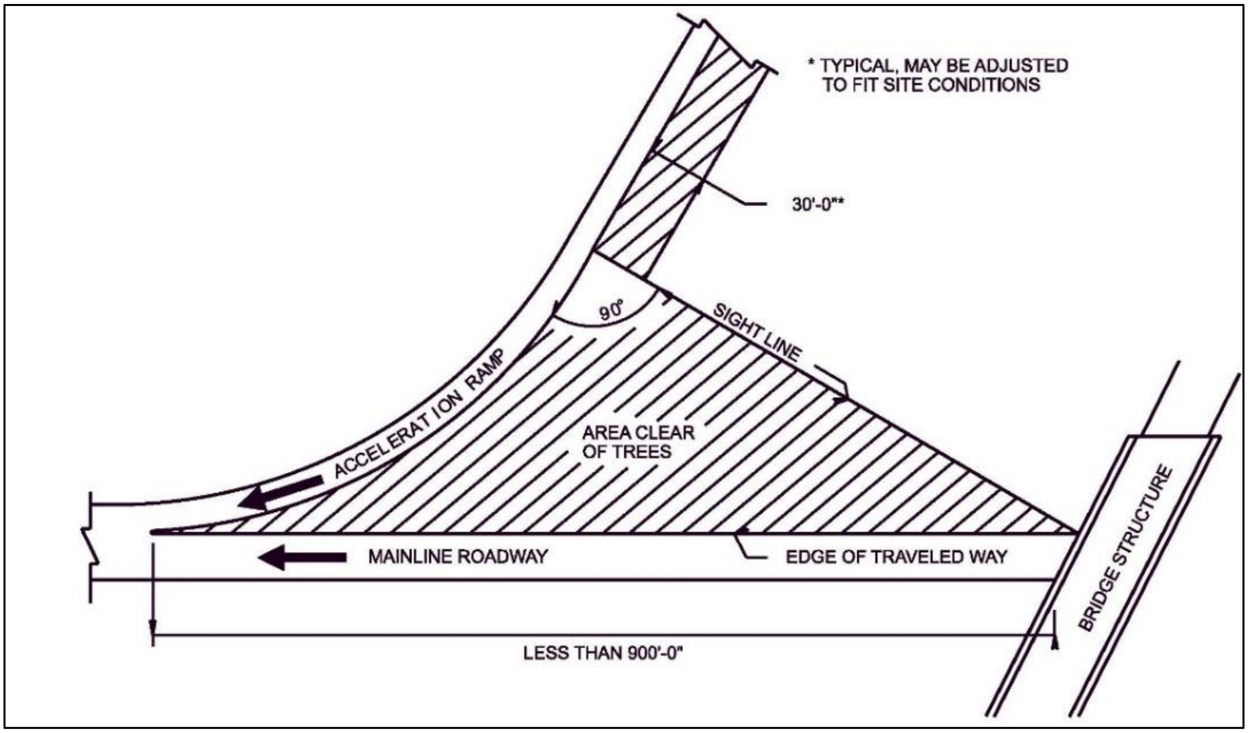
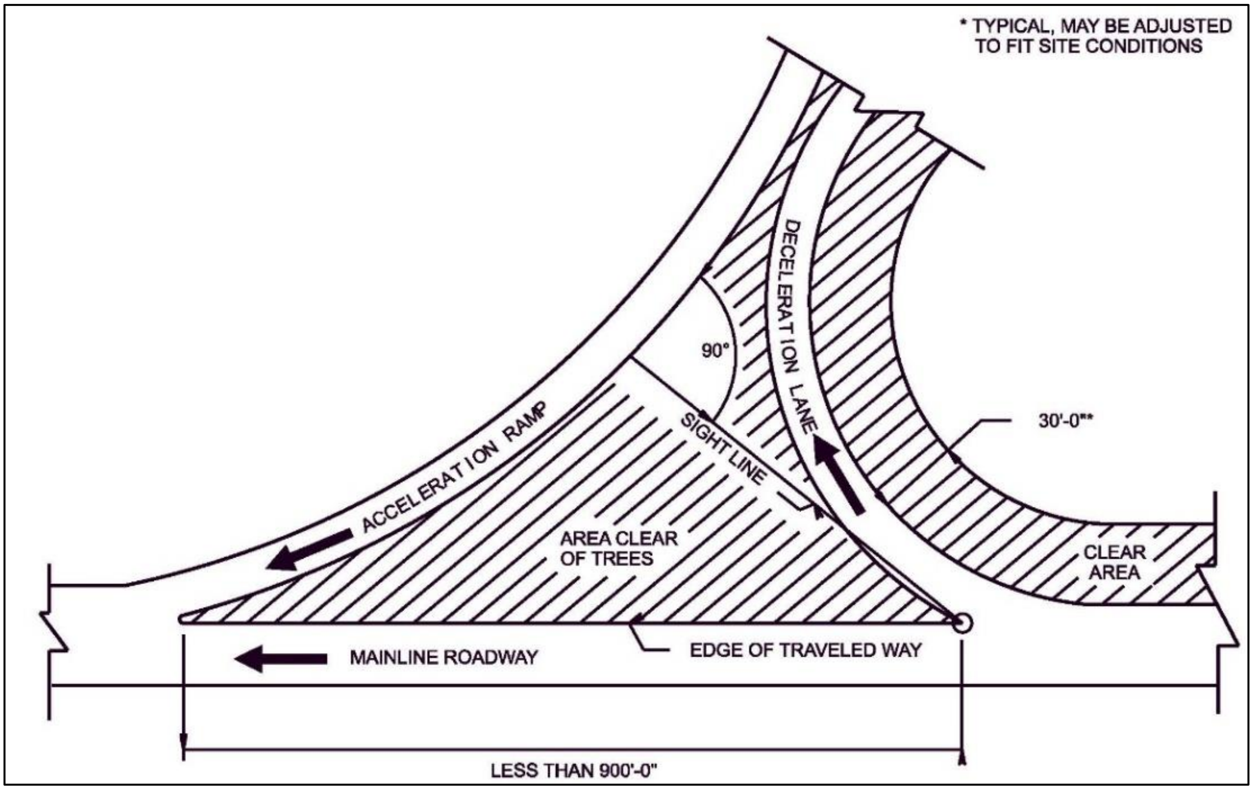


**Exhibit 22.2.4 Clear Sight Distance for Interchange Tree and Shrub Planting**



## 22.3 – Design Concerns for Long-Term Maintenance

Maintenance is another critical aspect in determining an appropriate planting design. When incorporating maintenance concerns into the design, the designer will minimize potential risk for overgrowth and intrusion on to aspects of the roadway facility, while also ensuring that the appropriate plantings are given an opportunity to establish themselves within the roadside environment. Below are some practices to consider when developing the roadside design. For additional guidance regarding maintenance, please refer to PennDOT Publication 23, *Maintenance Manual*.

### 22.3.1 – Mow Line Limit

Mow line limits are encouraged to be established in areas of mass planting to help natural vegetation regeneration, protect the new plant installations, and reduce mowing requirements and allow for implementation of conservation mowing seasonal restrictions. These limits and seasonal mowing restrictions can be indicated on the Landscape Planting (Roadside Development) Plans. For minor projects, a separate plan may not be required for the landscape plans. See Publication 14M, Design Manual Part 3, *Plans Presentation* (DM-3), for the recommended plan designation.

### 22.3.2 – Mulching

All tree pits and individual shrub pits are mulched with appropriate surface mulch as indicated on Publication 72M, *Roadway Construction Standards*, RC-91M. Mulch with or without weed barrier mat or weed control mat is measured on a square yard basis for any designated shrub bed areas.

### 22.3.3 – Staking and Guying

Trees are staked and guyed and this operation is incidental to the planting cost as indicated on Publication 72M, *Roadway Construction Standards*, RC-91M.

### 22.3.4 – Selective Tree Trimming and Removal

Selective tree removal and trimming work is accomplished in accordance with Publication 408, *Specifications*, Section 810. Calculate selective tree removal and trimming work as follows:

- In median or interior areas of interchanges where stands of trees are less than 100 feet in width, perform work as required on entire stand.
- Where the median or interchange areas are greater than 100 feet in width, perform work as required a minimum 50 feet from the grading limits.
- For outer areas, perform work as required a minimum of 25 feet or to the right-of-way line, whichever is less.

# Chapter 23 – Emergency Escape Ramps

In this chapter there are references to future chapter that are currently not included in this Publication 13.

Until they are included in this Publication, please refer to relevant topics in Publication 13M.

# Chapter 23 – Emergency Escape Ramps

## 23.0 – Introduction

An escape ramp is an emergency area located adjacent to a downgrade roadway, providing a location for large out-of-control vehicles to slow and stop away from other vehicles on the road. An escape ramp is generally located near the middle or the end of long steep downgrades.

Although several types of emergency escape ramps are used across the country, in Pennsylvania, only aggregate arrester bed ramps are used.

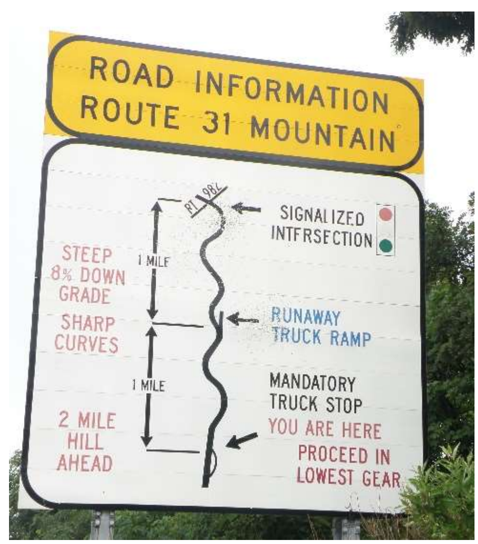
In some cases, static signing and stopping areas (turnouts or pull-off areas) are located before severe downgrades. These areas provide information to drivers regarding the downgrade and an opportunity for checking equipment operation prior to descent. The sections within this chapter address design considerations for emergency escape ramps, including:

- Locating emergency escape ramps.
- Selecting the appropriate arrester bed type.
- Designing all elements of the ramp.

Guide rail is shown above, but is not required on escape ramps.

### 23.0.1 – Resources and References

- Arizona DOT, *Truck Escape Ramp Study: Final Report*, 2005.
- National Cooperative Highway Research Program, Transportation Research Board, *Truck Escape Ramps: A Synthesis of Highway Practice*, 1992.
- Oregon DOT, *Energy Absorption of Gravel Mounds for Truck Escape Ramps*, 1978.
- Pennsylvania DOT, *A Field and Laboratory Study to Establish Truck Escape Ramp Design* Methodology: Final Report,1988.





pennsylvania
DEPARTMENT OF TRANSPORTATION

## 23.1 – Locating Emergency Escape Ramps

The combination of heavy vehicles, horizontal curvatures, and long, steep downgrades can increase the potential for runaway vehicles. While there are no widely accepted parameters for placing emergency escape ramps, they are mostly located in areas where there is a history of runaway vehicle crashes and where law enforcement, truck drivers, and the public have reported concerns.

The principal considerations in determining the need for an emergency escape ramp must be the safety of other traffic on the roadway, the driver of the runaway vehicle, and the residents along and at the end of the downgrade. When locating an emergency escape ramp, the designer must consider a variety of elements intrinsic to the escape ramp site. These include:

- Topography
- Length and percent of grade
- Potential speed
- Environmental impact
- Crash history

**Escape Ramp Location Considerations:**

- To intercept the greatest number of runaway vehicles, such as at the bottom of the grade or at intermediate points along the grade.
- At any practical location where the main road alignment is tangent.
- In advance of horizontal curves that cannot be negotiated by a runaway vehicle.
- In advance of populated areas.
- On the right side of the roadway.

Emergency escape ramps may be built at any practical location where the main road alignment is preferably on tangent or a relatively flat curve. The ramp should be in advance of horizontal curves that cannot be negotiated by an out-of-control vehicle without rolling over and in advance of populated areas. Escape ramps should exit to the right of the roadway.

Although crashes involving runaway vehicles can potentially occur along any downgrade, the designer must carefully analyze locations where multiple crashes have or might have occurred. Analysis of crash data includes evaluation of the highway section immediately uphill from the prospective site, particularly the amount of curvature traversed and the distance to and radius of the adjacent curve.

Runaway vehicle crashes generally result from brake failures, typically due to brakes overheating. Therefore, the need for an escape ramp should be considered in locations where vehicle brakes have failed (or are likely to fail) and where the potential for loss of life due to a runaway vehicle is significant.

## 23.2 – Types of Emergency Escape Ramps Used in Pennsylvania

Emergency escape ramps include three broad categories: sand pile, gravity, and arrester bed. Within these broader categories, four basic emergency escape ramp designs predominate.

These are the sand pile and three types of arrester bed (descending grade, level grade, and ascending grade). The Green Book illustrates each of these ramps.

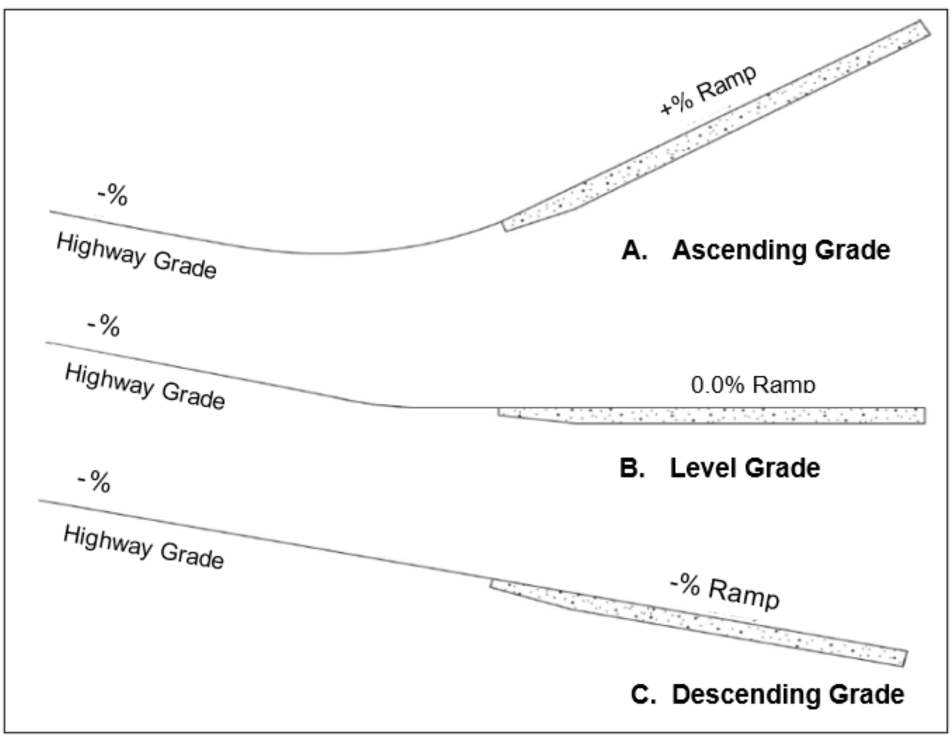
In Pennsylvania only aggregate arrester bed escape ramps are used. Sand pile escape ramps are not used because they are prone to freezing in Pennsylvania's climate. Gravity ramps are not used because of their inability to prevent a vehicle from rolling back down the ramp grade and jackknifing without a positive-capture mechanism.

## 23.2.1 – Arrester Bed Escape Ramps

As shown in **Exhibit 23.2.1**, arrester bed escape ramps are characterized as ascending grade, level grade, or descending grade, based on project-specific site conditions. The designer should select the type of arrester bed that is most compatible with location and topographic controls.

The most commonly used escape ramp is the ascending grade ramp. This type uses gradient resistance, supplementing the effects of the aggregate in the arrester bed and generally reducing the length of ramp needed to stop the vehicle. The loose material in the arresting bed increases the rolling resistance, as in the other types of ramps, while the gradient resistance acts in a downgrade direction, opposite to the direction of vehicle movement. The loose bedding material also serves to hold the vehicle in place after it has come to a stop.

**Exhibit 23.2.1 Arrester Bed Types**



Where the topography can accommodate it, a level grade escape ramp is another option. Constructed on a relatively flat gradient, the level grade ramp relies on the increased rolling resistance from the loose aggregate in the arrester bed to slow and stop the out-of-control vehicle, since the effect of gravity is minimal. This type of ramp is longer than the ascending grade arrester bed ramp, but shorter than a descending grade bed.

Descending grade escape ramps are constructed parallel and adjacent to the through-lanes of the highway. These ramps use loose aggregate in the arrester bed to increase rolling resistance, thus slowing the vehicle. The gradient resistance acts in the direction of vehicle movement. Descending grade ramps can be rather lengthy because the gravitational effect does not help to reduce the speed of the vehicle.

## 23.3 – Design Considerations

The combination of external and internal resistance forces (discussed in the Green Book) limits the maximum speed of an out-of-control vehicle. Although runaway vehicles rarely reach speeds more than 80 mph or 90 mph, an escape ramp should be designed for a minimum entering speed of 80 mph, with a 90 mph design speed preferred.

Lower design speeds may be used if roadway geometry limits the maximum entry speed. In these instances, the geometry's maximum truck speed must be mathematically determined.

Key design and construction components include:

- **Stopping an Out-of-Control Vehicle**. The length of the ramp along with any other energy absorbing features should be sufficient to dissipate the kinetic energy of the moving vehicle to come to a stop.
- **Alignment of the Escape Ramp**. The alignment of the escape ramp should be tangent or on very flat curvature to minimize the driver's difficulty in controlling the vehicle.
- **Width of the Arrester Bed**. Ramp Arrester beds should be wide enough to accommodate more than one vehicle entry because two or more vehicle entries may occur within a short time period. Therefore, a 30 to 40-foot width is preferred, but at locations where site constraints limit the available width, a 26-foot width may be used. In areas with extreme site constraints, a minimum width of 12 ft may be used. Note that for widths less than 26 ft, typically only one vehicle is accommodated because the first vehicle tends to occupy the center of the arrester bed.
- **Arrester Bed Material**. Pea gravel is to be used for the high rolling resistance value, overall performance, and for efficiency in the length of the arrester bed. PS&E packages for projects containing arrester beds are to specify the following:
    - The pea gravel should be smooth, rounded, uncrushed, clean, washed, and uniformly graded, i.e., predominately single-sized, and free from fine-sized material. Uniformly graded round material increases the volume of void space, which minimizes compaction and allows for adequate drainage. Thereby it

increases the rolling resistance and the arrester bed effectiveness. Crushed stone compacts quickly, decreases rolling resistance and therefore may not be used.

- Material for PennDOT arrester beds is to meet the following requirements:
  - Aggregate is rounded and uncrushed.
  - Aggregate meets the requirements Publication 408, *Specifications*, Section 703.2 (c) Table B, *Coarse Aggregate Quality Requirements*, Type C or better, with the exception of the crushed fragments requirement, and no clay lumps, coal or metallurgical slag or cinders are permitted.
  - Gradation for pea gravel conforms to that shown in **Exhibit 23.3.1**, below, with limited fines.

**Exhibit 23.3.1: Pea Gravel Arrester Bed Material Gradation**

| Sieve Size | Total % Passing |
|---|---|
| 1/2" | 100 |
| 3/8" | 85-100 |
| #4 | 10-30 |
| #8 | 0-10 |

- Material inside barrel attenuators and transverse gravel mounds must match the arrester bed material to avoid contamination of the bed.
- If pea gravel is not reasonably available, another aggregate with a different gradation may be used if it complies with the Green Book and is approved by the Highway Design and Technology Division Chief. Note that **Exhibit** 23.3.1 and **23.4.2**, and subsequent examples in this Chapter, are based on the rolling resistance of pea gravel. If another material is used, then these exhibits and examples are not applicable.

- **Depth of the Arrester Beds**. The minimum depth of aggregate in arrester beds is 3 feet. Contamination of the bed material can reduce the effectiveness of the arrester bed by creating a hard surface layer up to 12 inches thick at the bottom of the bed. Therefore, an aggregate depth of up to 42 inches is recommended.

  As a vehicle enters the arrester bed, its wheels displace the surface, and sink into the bed material increasing the rolling resistance. To assist in decelerating the vehicle smoothly, the depth of the bed should be tapered from a minimum of 3 inches at the entry point to the full depth of aggregate in the initial 100 feet to 200 feet of the bed.

- **Draining the Arrester Bed**. Provide positive means of draining the arrester bed to protect the bed from freezing and to avoid contamination of the arrester bed material. This is accomplished by grading the base to drain, intercepting water prior to entering the bed, using underdrain systems with transverse outlets or edge drains.

  The design can use a Class 4 Type A geotextile or paving between the subbase and bed materials to prevent infiltration of fine materials that may trap water. Where toxic contamination from diesel fuel or other material spillage is an environmental concern, the base of the arrester bed may be paved with concrete and holding tanks provided to retain the spilled contaminants.

- **Entrance to the Ramp**. The entrance should be designed so that a vehicle traveling at high speed can enter with as much sight distance as practical preceding the ramp for the driver to enter the arrester bed. The full length of the ramp should be visible to the driver.

  The angle of departure for the ramp should be small, usually 5 degrees or less. An auxiliary lane may be appropriate to assist the driver in preparing to enter the escape ramp.

  The main roadway surface should be extended to a point at or beyond the exit gore so that both front wheels of the out-of-control vehicle will enter the arrester bed simultaneously. This also provides the driver with preparation time before actual deceleration begins. The arrester bed should be sufficiently offset laterally from the through-lanes to preclude loose material being thrown onto the lanes.

- **Ramp Access**. Exit signing should clearly indicate access to the ramp, allowing the driver of an out-of-control vehicle time to react and to minimize the possibility of missing the ramp. Additionally, advance signing informs drivers of the ramp’s existence and prepares them well in advance of the decision point. This will allow them enough time to decide if they need to use the escape ramp. Descending grade ramps should have a clear and obvious return path to the highway, so that drivers who doubt the effectiveness of the ramp will feel that they are able to return to the highway at a reduced speed.

  Regulatory signs placed near the entrance discourage other motorists from entering, stopping, or parking at or on the ramp. The path of the ramp should be delineated to define ramp edges and provide nighttime direction. It is desirable to illuminate the approach and ramp. Refer to Chapter 20, *Lighting*, for more detailed criteria for illumination of escape ramps.

- **Service Road and Vehicle Retrieval**. The characteristics that make an escape ramp effective can also make it difficult to retrieve a captured vehicle. A service road located adjacent to the arrester bed permits tow trucks and maintenance vehicles to retrieve vehicles without trapping them in the bedding material. Preferably, the service road should be paved but may be surfaced with gravel. The road should be designed so that the driver of an out-of-control vehicle will not mistake the service road for the arrester bed. Refer to Section 23.5 for more specific criteria regarding service roads.

Anchor blocks secure a tow truck as it pulls a vehicle from the arrester bed. Local tow truck operators can be very helpful in properly locating anchor blocks. Refer to Section 23.5.1 for more specific criteria regarding the placement and use of anchor blocks.

- **Maintenance**. Refer to Publication 23, *Maintenance Manual*, Section 12.6, *Escape Ramps,* for maintenance procedures.

## 23.4 – Arrester Bed Ramp Design

Emergency escape ramps using arrester beds are designed in configurations that are length- and grade-dependent. This section provides design guidance for the other components of an emergency escape ramp, including:

- Arrester bed length.
- Ramp end treatments (i.e., positive attenuation or last chance device).
    - Barrels
    - Traverse gravel mounds.
- Ramp designs with combination beds, barrels, and mounds.

### 23.4.1 – Arrester Bed Length

To be effective, an arrester bed ramp must be able to stop the largest vehicle expected to use the ramp, typically a WB-67 design vehicle (fully loaded weighing 80,000 pounds). Other elements that affect the design include the initial (entering) velocity of the vehicle, rolling resistance of the bed material, and the grade of the ramp.

As a vehicle moves along an arrester bed it loses momentum and comes to a stop because of the effect of gravity (if on an ascending grade) and the rolling resistance of the bed material. **Exhibit 23.4.1** illustrates Equation 23.1 which is used to determine the approximate arrester bed length needed to bring a vehicle to a stop (with consideration of rolling resistance and gradient resistance). This equation can also be rearranged to solve for the final velocity as shown in the Green Book. Then if an arrester bed has more than one grade, the speed loss for each grade can be calculated.

**Exhibit 23.4.1 Arrester Bed Length Equation**

$$L = \frac{V_i^2 - V_f^2}{30(R \pm G)} \quad \text{Equation 23.1}$$

Where:

L = length of arrester bed, in feet
$V_i$ = initial (entering) velocity, mph
$V_f$ = final (exiting) velocity, mph
R = rolling resistance, expressed as equivalent percent gradient divided by 100
G = percent grade divided by 100

Exhibit 23.4.2 presents speed versus deceleration distance curves based on Equation 23.1 using pea gravel. Either Exhibit 23.4.2 or Equation 23.1 should be used to determine vehicle speed or distance traveled on an arrester bed.

Considerations regarding the equation include:

- **$V_i$** - Initial entering velocity in mph. An escape ramp should be designed for a minimum entering speed of 80 mph, with a 90-mph design speed preferred. However, lower design speeds may be used if roadway geometry limits the maximum entry speed.
- **$V_f$** - Final exiting velocity in mph. This is the speed of a runaway truck on an escape ramp at the end of a length of constant grade. On ramps that have more than one length of constant grade, use of a rearranged Equation 23.1 is repeated for each length of constant grade. The final velocity of the prior length of constant grade is entered into the equation as the initial velocity on the next length of constant grade. Then the calculation is repeated for each grade.
- **R** - Rolling resistance, expressed as equivalent percent gradient divided by 100. Rolling resistance is a general term used to describe the resistance to motion at the area of contact between a vehicle's tires and the roadway surface and is only applicable when a vehicle is in motion. It is influenced by the type and displacement characteristics of the surfacing material of the roadway. PennDOT's arrester bed material, pea gravel, has a rolling resistance of 250 pounds/1000 pounds gross vehicle weight (GVW) which is equivalent to a vertical grade of +25.0%. If material other than pea gravel is used, then the R value for that material must be determined. Refer to Section 23.3 for approval to use other materials.
- **G** - Percent grade of the ramp divided by 100. The grade of a roadway is a measure of its incline or slope. The grade indicates how much the arrester bed is inclined from the horizontal. The maximum allowable ascending grade for an escape ramp is +25%.

## Example 1: Arrester Bed Length

The topographic conditions at the site of an emergency escape ramp limit the ramp to an upgrade of 10% (G = +0.10). The arrester bed is constructed with pea gravel for an entering speed of 90 mph. The arrester bed length is computed using Equation 23.1 as shown here.

$V_i$ = 90 mph
$V_f$ = 0 mph
R = 250 lb / 1000 lb = 0.25
G = +10% / 100 = 0.10

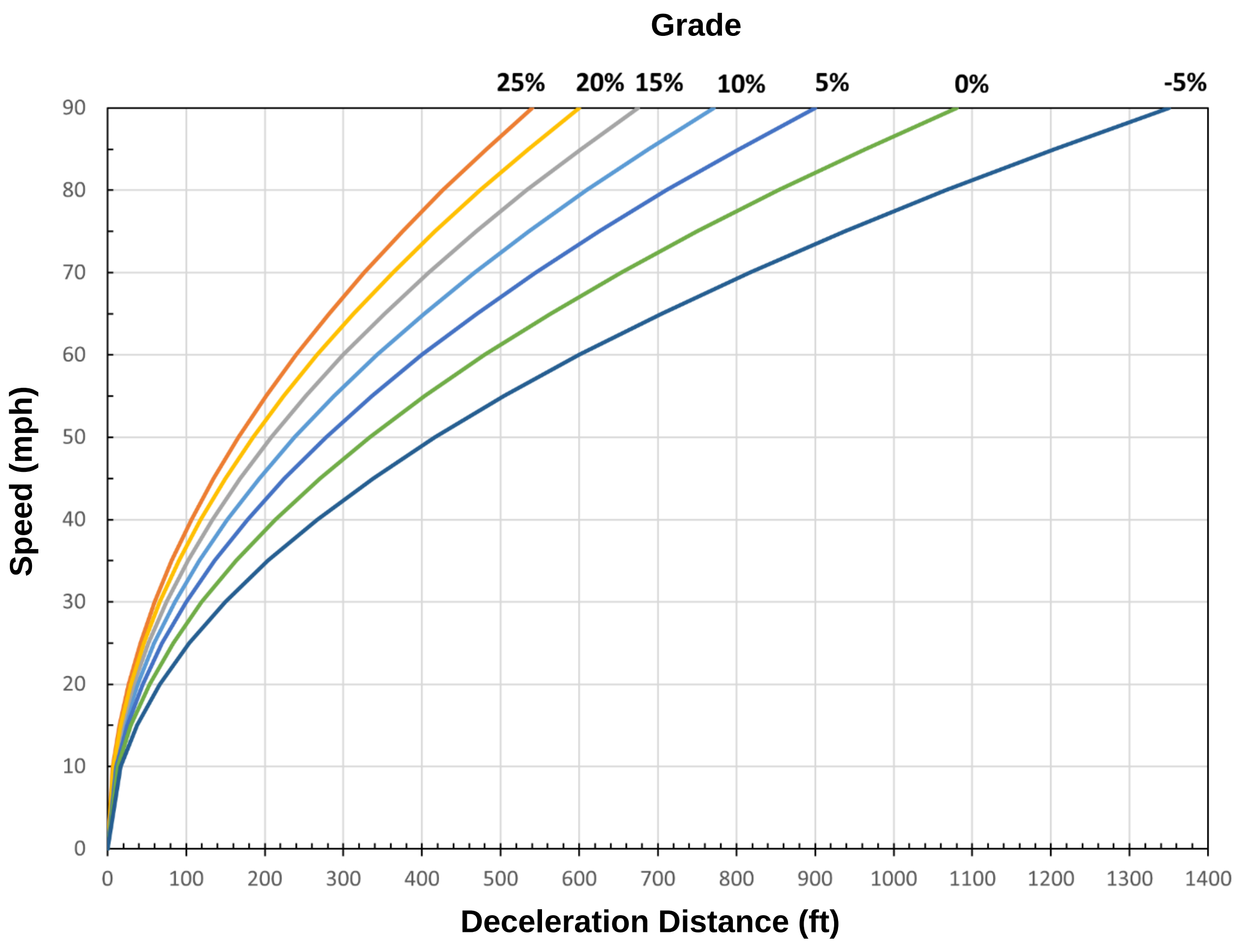
$$L = \frac{90^2 - 0}{30(0.25+0.10)} = 771.43$$

L = 771.43 feet, is rounded to 772 feet

Exhibit 23.4.2 is based on Equation 23.1 with pea gravel's rolling resistance of 250 lb / 1000 lb and illustrates the effect of grade on vehicle speed. The exhibit contains a series of seven distance-versus-speed curves for grades of +25% to -5% in increments of 5%. As a vehicle travels from right to left along the horizontal axis, it loses speed because of the combination of rolling resistance and grade. This indicates that the vehicle is quickly losing speed, largely due to the rolling resistance of the bedding material, and that the grades have far less effect than they did when the speeds were higher.

Exhibit 23.4.2 enables a designer to evaluate the effects of alternative grades on arrester bed length. Example 2 demonstrates how to use the exhibit in determining vehicle speeds at any point along an arrester bed.

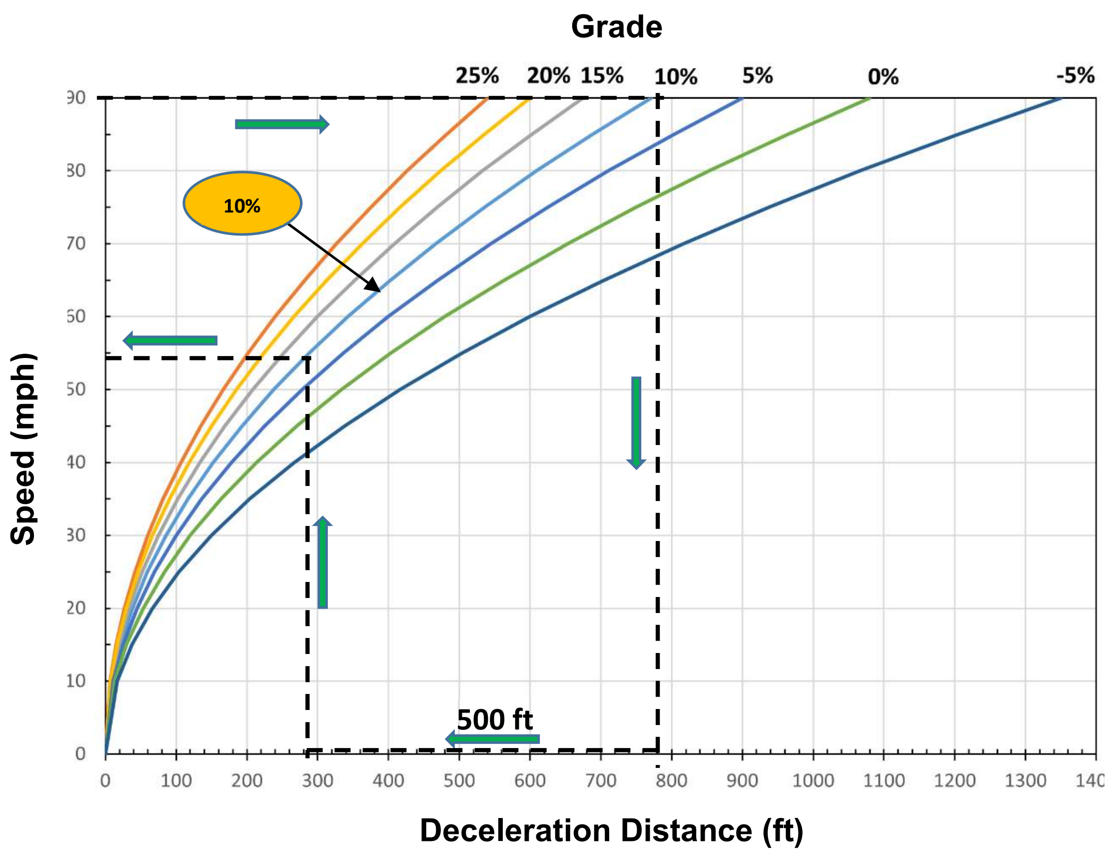
**Exhibit 23.4.2 Effect of Grade on Vehicle Speed in an Arrester Bed of Pea Gravel**



## Example 2: Determining Vehicle Speeds at Any Point Along an Arrester Bed

Due to site constraints, the available length for an escape ramp arrester bed is 500 feet at a 10% grade. A design speed of 90 mph is assumed. The designer must determine how much the vehicle speed will be reduced by a 500-foot arrester bed.

- Start with a 90 mph design speed on the left axis as shown on the graphic below (based on Exhibit 23.4.2).
- A horizontal line is drawn to the intersection point of the 10% curve and 90 mph.
- A vertical line is drawn downward to intersect the x-axis at 772 feet.
- A horizontal line is drawn 500 feet (i.e., the available length of the bed) to the left.
- A vertical line is drawn from the 272’ on the x-axis up to the 10% curve line.
- Lastly, a horizontal line is drawn from the intersection of the 272’ and 10% curve line to intersect the y-axis to 53 mph. It indicates that the arrester bed has reduced the speed of the vehicle to 53 mph.




An alternate method for solving this example would be to rearrange Equation 23.1 and solve for $V_{f.}$ (final velocity).

### 23.4.2 – Ramp End Treatments

In situations where site constraints prohibit the use of a full-length arrester bed, the designer should consider using an end treatment in combination with a shorter arrester bed. There are two types of end treatments:  barrels and transverse gravel mounds. Barrels are generally preferred over mounds.

The designer should consider the following:

- If appropriate grade and length are available to stop an out-of-control vehicle, an arrester bed without additional positive attenuation may be used.
- Where the only practical location for an escape ramp does not provide sufficient length and grade to stop an out-of-control vehicle, the ramp should be supplemented with a positive attenuation device.

Even where providing a full-length ramp with full-deceleration capability for the design speed, supplemental positive attenuation devices may still be a useful consideration at the end of a ramp and arrester bed. These “last chance” devices, such as a mound or a row of barrels, should be considered when the consequences of leaving the end of the ramp are serious.

Any ramp end treatment utilizing “last chance” devices should be designed with care so that its advantages outweigh its disadvantages. The risk to others resulting from an out-of-control truck overrunning the end of an escape ramp may be more important than the potential harm to the truck’s driver or cargo. Conversely, the abrupt deceleration of an out-of-control truck may cause shifting of the load, shearing of the fifth wheel, or jackknifing, all with potentially harmful consequences to the driver and cargo.

#### 23.4.2.a – Barrels

Barrel impact attenuators should be located near the end of arrester beds. This enables an errant vehicle to lose much of its initial speed on the arrester bed before hitting the barrels.

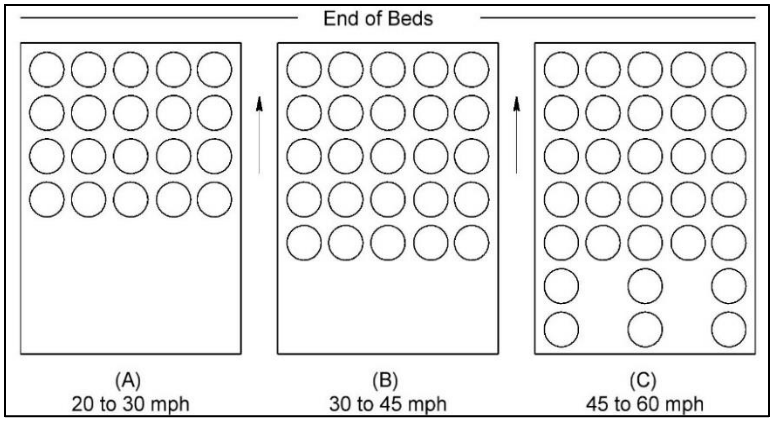
When a vehicle collides with a barrel impact attenuator, it decelerates as its kinetic energy is transferred to the barrels.  The impact displaces and deforms the barrels. In this case, the entry speed is the speed of the vehicle when it hits the barrels. The vehicle’s rate of deceleration depends on the number and weight of the barrels impacted, the greater the number and weight of barrels, the greater the deceleration. The rolling resistance of the arrester bed material under the barrels continues to decelerate the vehicle as well.

Deceleration is measured in “g’s” (32.2 ft/s$^2$), with the rate of deceleration expressed in units of standard earth gravity. A vehicle colliding with a row of three full barrels decelerates much faster than a vehicle colliding with a single half-full barrel—the more barrels impacted, the more resistance there is to the vehicle’s forward motion. Therefore, the more rapid the deceleration, the more g’s are acting on the vehicle and its occupants. To limit the potential for injuries, the recommended maximum rate of deceleration is 12 g’s, however a rate of 9 g’s is desirable.

### 23.4.2.a.1 – Barrel Configurations

**Exhibit 23.4.3** illustrates three different barrel configurations used to decelerate a vehicle. Barrels are placed at the end of an escape ramp arrester bed. Each barrel is approximately three feet in diameter. Barrels are spaced one foot apart to create a continuous array (configuration of barrels in rows and columns) across the width of the arrester bed.

**Exhibit 23.4.3 – Barrel Impact Attenuator Configurations on a 20-Foot-Wide Bed at Different Entry Speeds**




(Not to scale)

Regardless of the arrester bed width, the design should include enough barrels to create a continuous array across the entire width of the arrester bed. An array consists of all the barrels provided on an arrester bed, with the barrels arranged in rows and columns as shown above.

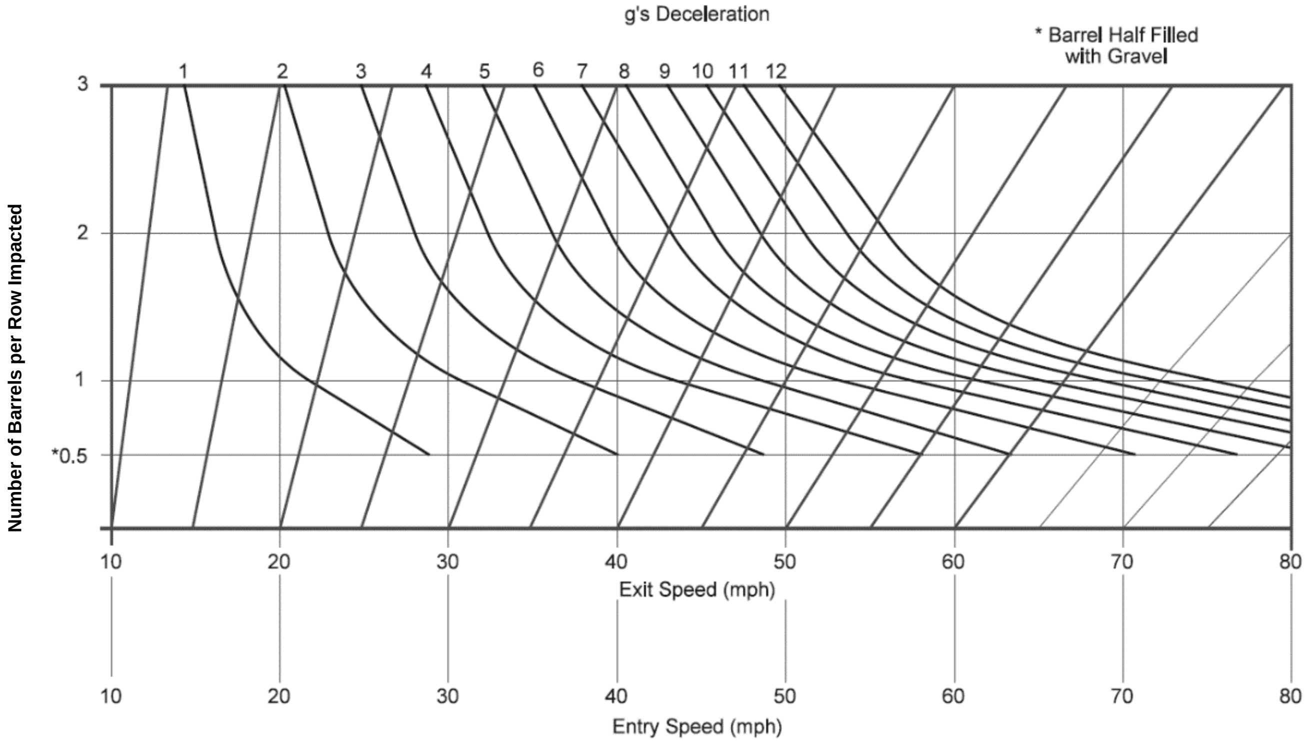
The range of entry (impact) speeds noted in Exhibit 23.4.3 are typical; the designer needs to perform the calculations to determine the design entry and exit speeds.

In a typical head-on collision, a runaway truck is expected to have a width of 8 to 8.5 feet, to hit the barrels head-on, and to punch a hole two to three barrels wide in the barrel array. Therefore, an approximate impact width of three barrels is the standard width for calculating the deceleration of a runaway truck. However, as shown in Exhibit 23.4.3(C), for entry speeds greater than 45 mph, starting the barrel configuration with barrels more widely spaced for the first two rows is needed to decelerate vehicles more gradually and thereby avoid excessively high g-forces.

The barrels behind the first row of barrels will absorb the energy of a runaway truck and bring it to a stop. The total number of rows required to stop a truck depends on the truck's initial entry speed.

The number of rows needed increases as the vehicle initial entry speed (i.e., the speed at which the vehicle impacts the first row of barrels) increases. To determine the required number of barrel rows, the deceleration chart presented in **Exhibit 23.4.4** is used.

**Exhibit 23.4.4 – Deceleration Chart for an 80,000-Pound Vehicle Impacting 22.6 ft³ Barrels**




As deceleration forces (i.e., g forces) up to 12 g's are acceptable to a vehicle's occupants, the chart in Exhibit 23.4.4 includes deceleration force levels up to 12 g's in relation to entry speed and the number of rows of barrels. However, for the purpose of design, a deceleration of 9 g's or less is desirable.

The elements within Exhibit 23.4.4 include:

- **Speed Axis**. The horizontal line at the bottom of the graph is the speed axis. It includes a range of speeds from 10 mph to 80 mph and is used for both the entry and exit speeds of the vehicle that strikes a barrel array.
- **Entry Speed Lines**. A series of entry speed lines extend vertically across the graph. They represent the entry speed of a vehicle when it strikes a row of barrels. The exhibit includes speeds from 10 mph to 80 mph, in 10-mph increments.
- **Exit Speed Lines**. Exit speed lines extend diagonally across the graph. They represent speeds of 10 mph to 75 mph in 5-mph increments and are used to determine the exit speed of a vehicle after it strikes a row of barrels. An exit speed under 10 mph is considered close enough to a stop condition that no further analysis is needed.
- **Number of Barrels per Row Impacted Axis**. The vertical line along the left side of the graph is the number of barrels per row impacted axis. It is subdivided into four horizontal lines that extend across the graph. The horizontal lines represent a half-filled (0.5)

barrel, one barrel, two barrels, and three barrels per row across the width impacted. Although more than three barrels will be needed to span the entire arrester bed, due to the expected vehicle width, three is the maximum expected number of barrels per row impacted. See Exhibit 23.4.3 for alternative barrel configurations, types A, B, and C.

- **Deceleration Curves**. Each of the four horizontal lines subdividing the number of barrels per row axis intersects a series of deceleration curves, labeled 1 to 12. These intersections indicate the number of g's acting on a vehicle when it strikes a row of a specified number of barrels.

## Example 3 – Determining Barrel Layout to Stop a Truck

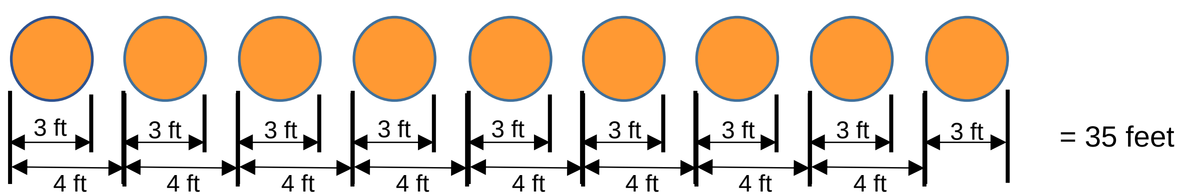
As a continuation of Example 2, the designer must determine a barrel configuration to absorb the energy resulting from the remaining 53 mph. The first step is to determine the general barrel layout needed to bring the vehicle to a stop.

The maximum length available for the bed is 500 feet at a 10% grade. Based on a 90 mph design speed, Example 2 demonstrated that the arrester bed reduced the vehicle speed to 53 mph. Therefore, a type-C barrel configuration (illustrated in Exhibit 23.4.3**)** is recommended.

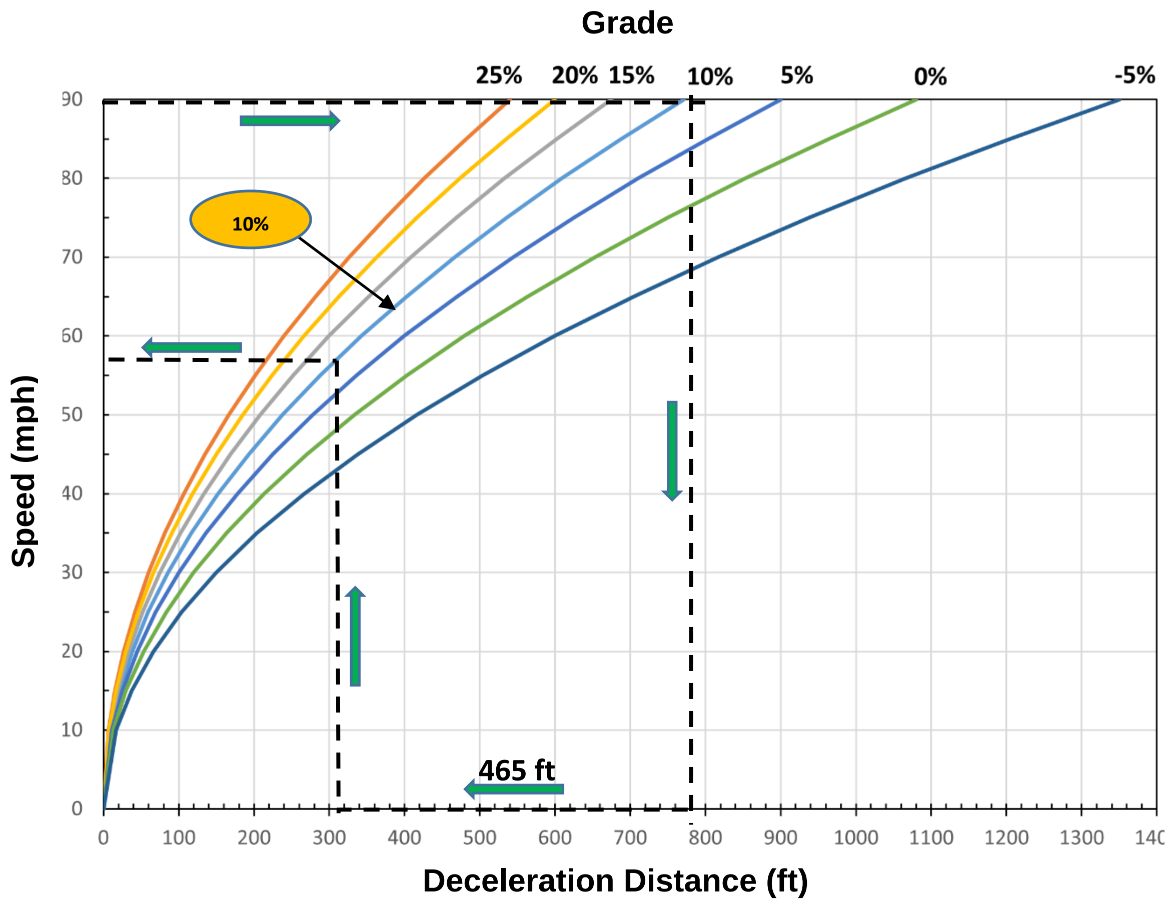
**Guidance**

The maximum safe deceleration is 12 g's. A deceleration of 9 g's or lower is desirable.

The designer should remember that the entry speed for each successive row must be identified to determine the amount of deceleration produced by each row.   This is an iterative process based on the barrel diameter (3 feet) and barrel spacing 1 foot apart. To begin the process, the designer assumes 9 rows of barrels within a ramp length of 35 feet, as shown below:




Subtracting this 35-foot length from the 500-foot arrester bed length (=465') and plotting the new length using Exhibit 23.4.2 (as shown in graphic below) results in a barrel array entry speed of 57 mph. Thus, the barrel array is designed to reduce the vehicle speed by 47 mph (57 – 10 mph) over its 35-foot length. The last 10 mph is considered close to a stop condition.

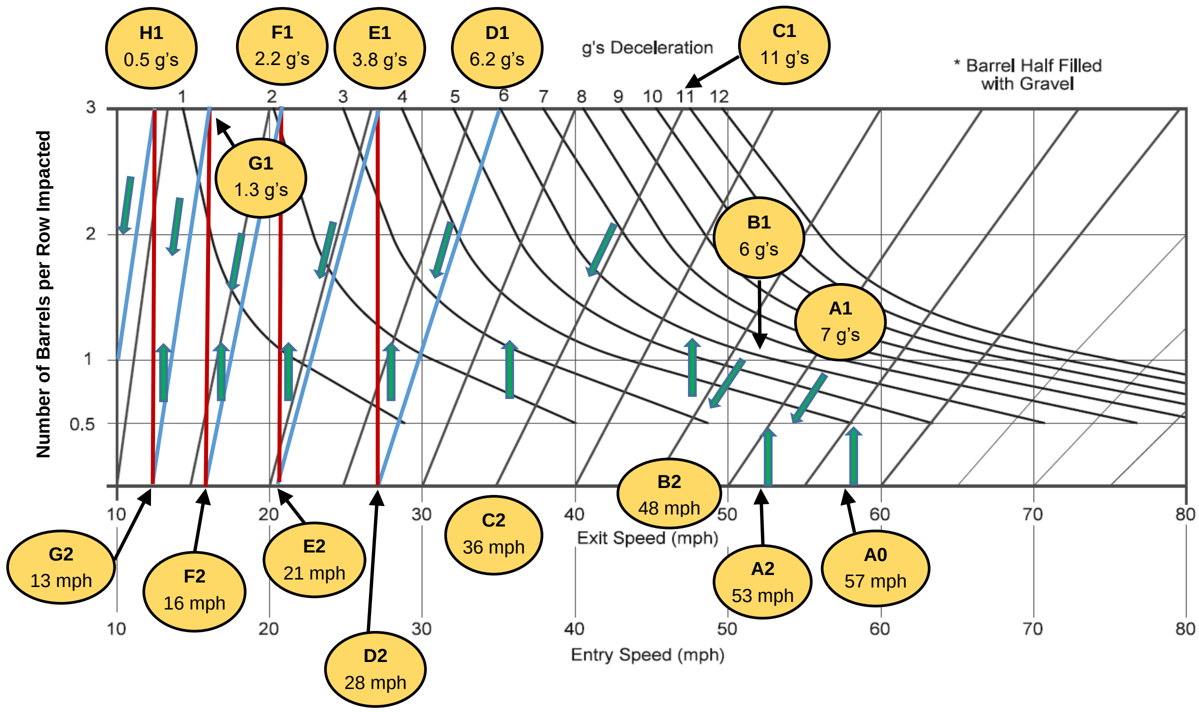



Using Exhibit 23.4.4, and completing the following steps, will enable the designer to determine the exit speed and deceleration of an 80,000-pound vehicle after it strikes each of the rows of barrels in a barrel array.

**A0** Start at **57 mph**.

**A1** Mark the vehicle's **57 mph** entry speed on the Speed Axis as Point (A0) and draw a vertical entry speed line up the graph to the one-barrel line, Point (A1). With one barrel, the vehicle will experience **7 g's**. To use to two-barrels initially in the first impact row, more than 12 g's would be experienced. Therefore, a one-barrel impact row should be used initially.

**A2** Find the exit speed line closest to Point (A1) and copy it parallel through Point (A1), to create the exit speed line shown. This blue line intersects the Speed Axis at Point (A2) indicating an exit speed of **53 mph**. This is the speed at which the vehicle exits the first row of barrels.




**B1** Repeat the above steps for the second row of barrels, but now starting at Point (A2) and an entry speed of **53 mph.** Draw a second vertical line up the graph to "1 Barrels Per Row Impacted Line". Note that this second line intersects the line at Point (B1), which indicates a vehicle deceleration of **6 g's**. To go to two-barrels the deceleration force would go above the 9 g desirable maximum deceleration. Therefore, although a two-barrel row could be used (=10.5 g's), a one-barrel impact row again would be desirable.

**B2** Find the exit speed line closest to Point (B1) and copy it parallel through Point (B1), to create the exit speed line shown. This blue line intersects the Speed Axis at Point (B2) or a speed of **48 mph**. This is the speed at which the vehicle exits the second row of barrels.

**C1** Repeat the above steps for the third row of barrels, but now starting at Point (B2) and an entry speed of **48 mph**, draw a third red vertical line across the graph to the green "3 barrels per row Line". Note that this third red line intersects the green line at Point (C1), which indicates a vehicle deceleration of **11 g's**. This is more than the desirable 9 g's, but less than the maximum 12 g's, therefore this is an acceptable configuration.

**C2** Find the exit speed line closest to Point (C1) and parallel it through Point (C1), to create the blue exit speed line shown. This line intersects the Speed Axis at Point (C2) indicating an exit speed of **36 mph**. This is the vehicle's exit speed from the third row of barrels.

**D1** through **H1**. This process is repeated until the vehicle is stopped. When the exit speed line drops below 10 mph, the speed is considered close enough to a stop condition that no further iterations of the above steps are necessary.

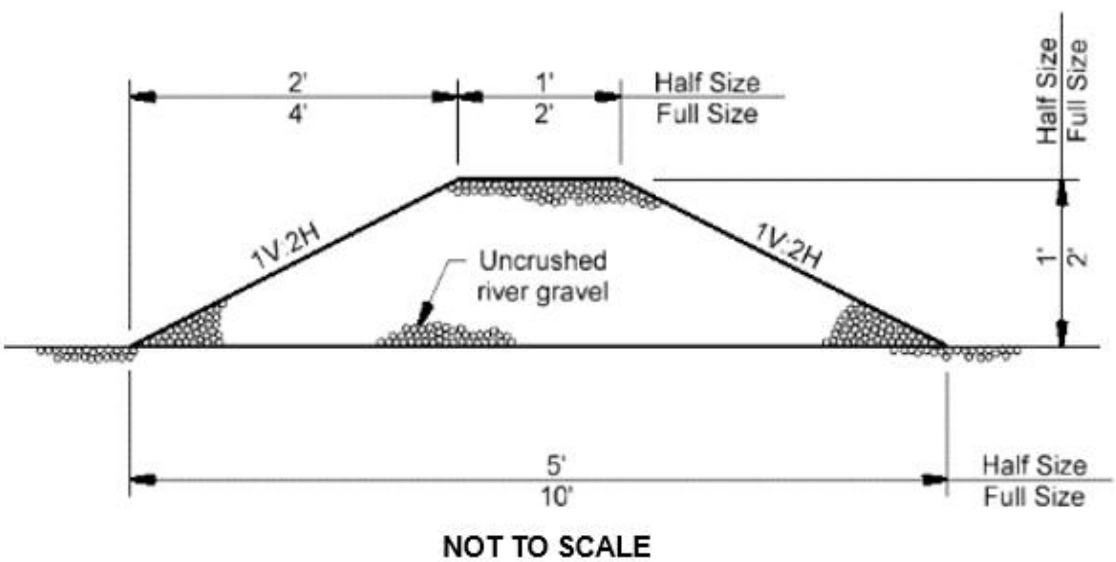
With the given parameters of a 500 ft arrester bed on a 10% grade with a design speed of 90 mph, the results from using Exhibit 23.4.4 show that the first two rows of barrels within the nine-row array will need to have one barrel per impacted row. The remaining rows after that will contain three barrels per impacted row and an 80,000-pound vehicle should come to a stop after the eighth row of barrels.

## 23.4.2.b.1 – Transverse Gravel Mounds

There are situations where the use of an arrester bed in combination with barrels cannot stop a vehicle within the g limits. In these instances, transverse gravel mounds placed at intervals along an escape ramp arrester bed and can be used to further reduce speed.

A transverse gravel mound is essentially a pile of gravel placed across the arrester bed. Deceleration occurs as the vehicle plows into the mound, pushing the gravel forward and transferring the vehicle's kinetic energy to the gravel. **Exhibit 23.4.5** illustrates the cross-section of a transverse gravel mound.

**Exhibit 23.4.5 – Cross-Section of Full-Size and Half-Size Transverse Gravel Mounds**



PennDOT has tested two mound shapes:

- Half-size mounds that are 1-foot high and 5-feet long.
- Full-size mounds that are 2-feet high and 10-feet long.

Mound length is measured parallel to the escape ramp along the direction of vehicle travel. The mound sides are sloped at a ratio of 1V:2H.

Mounds should contain the same type of aggregate (i.e., pea gravel) as used in the arrester bed.

**Exhibit 23.4.6** illustrates the deceleration for an 80,000-pound vehicle impacting a transverse gravel mound.

**Special Considerations Regarding Gravel Mounds:**

Mounds should be placed so that they are hit at slow speeds. Tests have shown that when a vehicle hits a gravel mound at high speeds, the mound can act as a launch pad, which reduces its effectiveness at slowing the vehicle and reduces the driver’s control of the vehicle.

The designer should place the first mound at least 100 feet from the beginning of the bed, where the bed depth is preferrable 42 inches. This distance and depth allow a truck to sink into the bed, thus reducing its speed. However, more distance may be needed based on the grade of the ramp.

**Exhibit 23.4.6 – Deceleration Chart for an 80,000-Pound Vehicle Impacting a Transverse Gravel Mound**

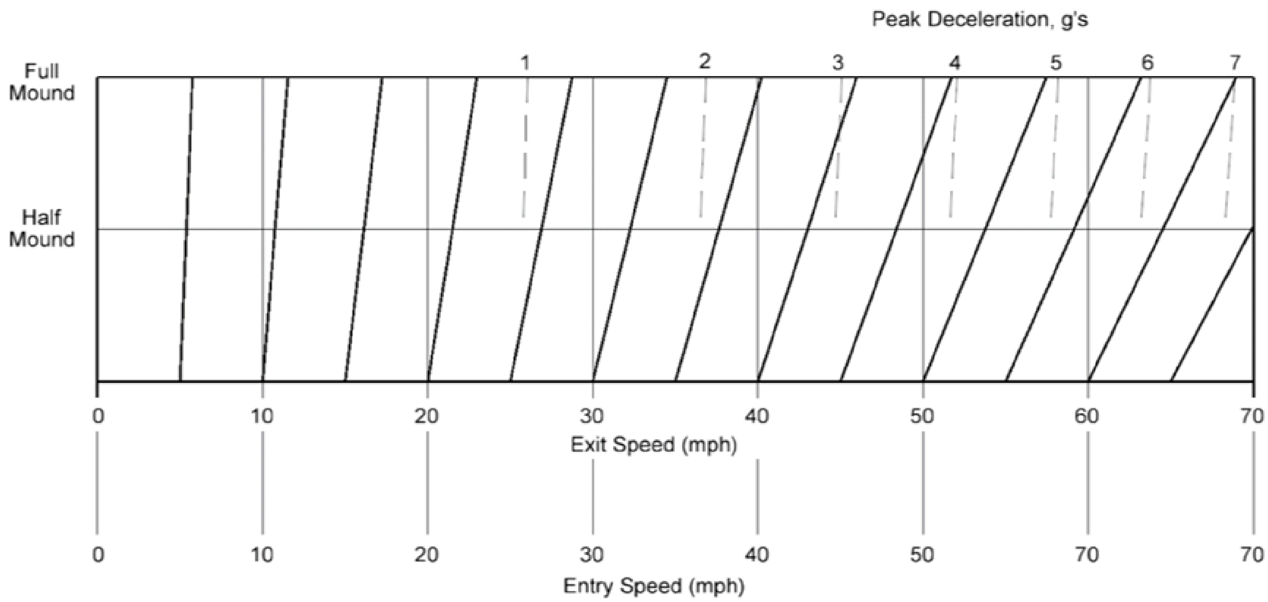


Exhibit 23.4.6 is similar to Exhibit 23.4.5 and contains the following elements:

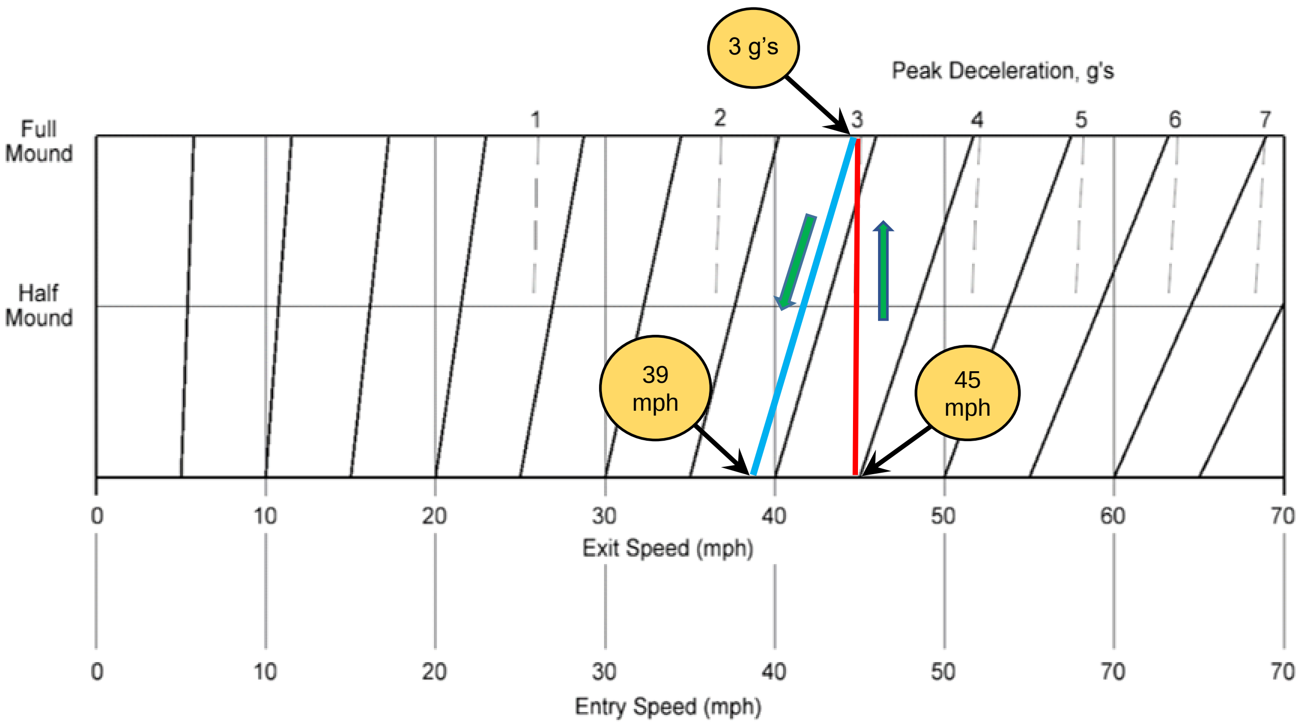
- **Speed Axis**. The horizontal line at the bottom of the graph is the speed axis. It indicates a range of speeds from 0 mph to 70 mph and is used for both the entry and exit speeds of a vehicle impacting a gravel mound.   Note however that although the axis extends up to 70 mph, the use of mounds should be limited to lower speeds because tests have shown that when a vehicle hits a gravel mound at high speeds, the mound can act as a launch pad, which reduces its effectiveness at slowing the vehicle and reduces the driver’s control of the vehicle.
- **Entry Speed Lines**. Extending vertically across the graph is a series of entry speed lines. They represent the entry speed of a vehicle upon impact with a mound, with speeds from 0 mph to 70 mph, in 10-mph increments.
- **Exit Speed Lines**. Extending diagonally across the graph is a series of exit speed lines. They represent speeds of 5 mph to 70 mph and are used to determine the exit speed of a vehicle after impacting a mound.
- **Deceleration Lines**. The exhibit has seven dashed, vertical lines that extend downward from the top of the graph. Ranging from 1 to 7 g’s, these lines indicate the vehicle’s deceleration upon impacting a mound. The greater the entry speed, the greater the deceleration.

Using Exhibit 23.4.6 for each mound, the designer:

1. Draws a vertical line beginning at the entry speed line to the half or full-mound line.
2. Draws a diagonal line parallel to the nearest exit velocity line to the base line to determine the exit speed.

## Example 4: Determining Deceleration and Exit Speed with Transverse Gravel Mounds

An 80,000-pound vehicle hits a full-size transverse gravel mound with an entry speed of 45 mph. Exhibit 23.4.6 is used to determine the vehicle's deceleration (in g's) and its exit speed.




The red vertical line represents the vehicle's 45-mph entry speed. The line extends to the top of the graph, indicating the peak deceleration upon striking a full-size mound. Its endpoint reaches the dashed line indicating 3 g's of deceleration.

To determine the exit speed, draw a line parallel to the closest exit speed line. This blue line intersects the exit speed axis at a speed of 39 mph, the speed at which the vehicle exits the mound. Using this exit speed, the designer can then repeat the process with more mounds or utilize other methods of deceleration until the exit speed is 10 mph or less. This process is described in more detail in Example 5.

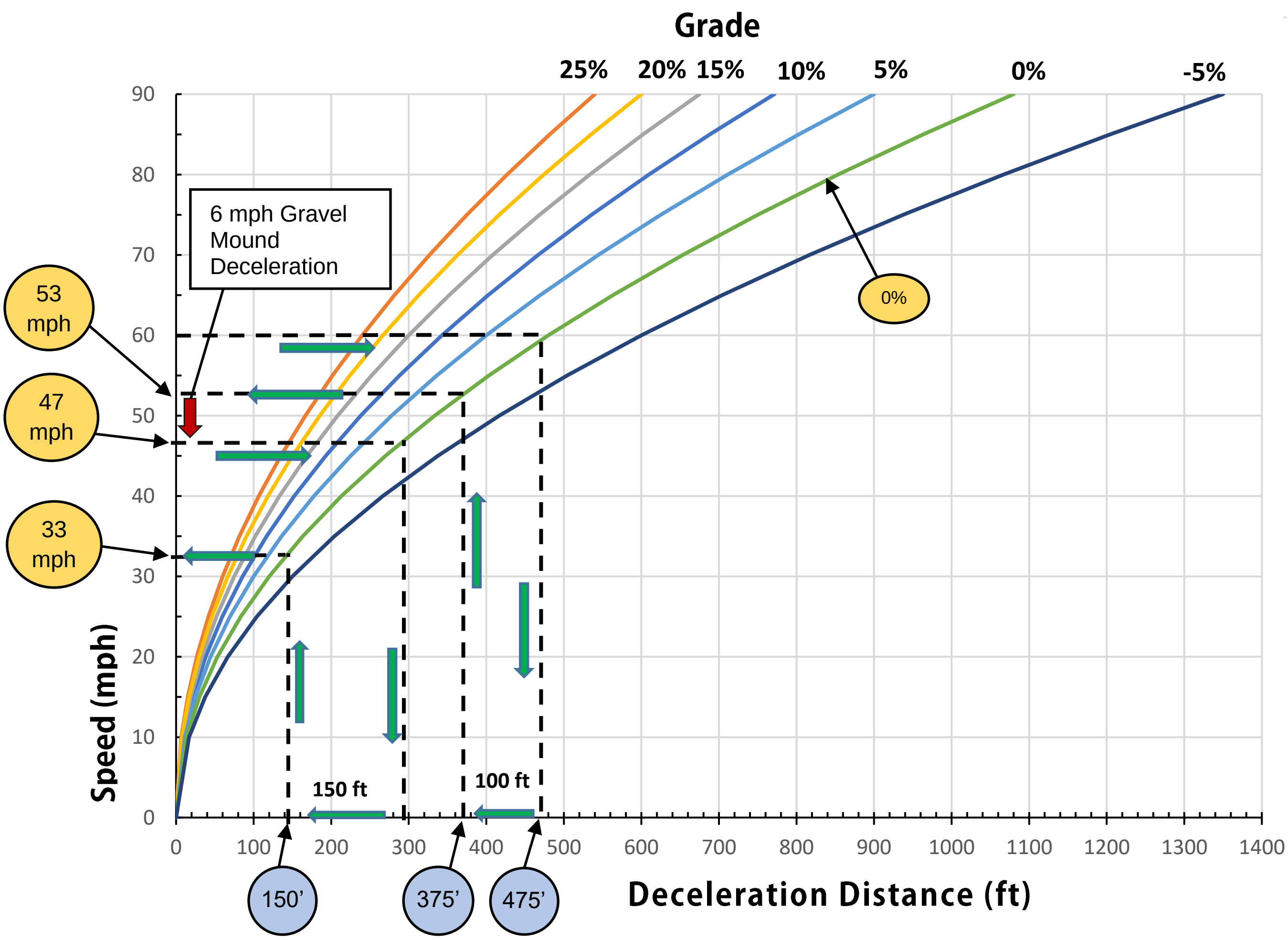
### 23.4.3 – Design with Combination Bed, Mounds, and Barrels

A bed design in combination with mounds, barrels, or both requires the use of the exhibits previously presented.

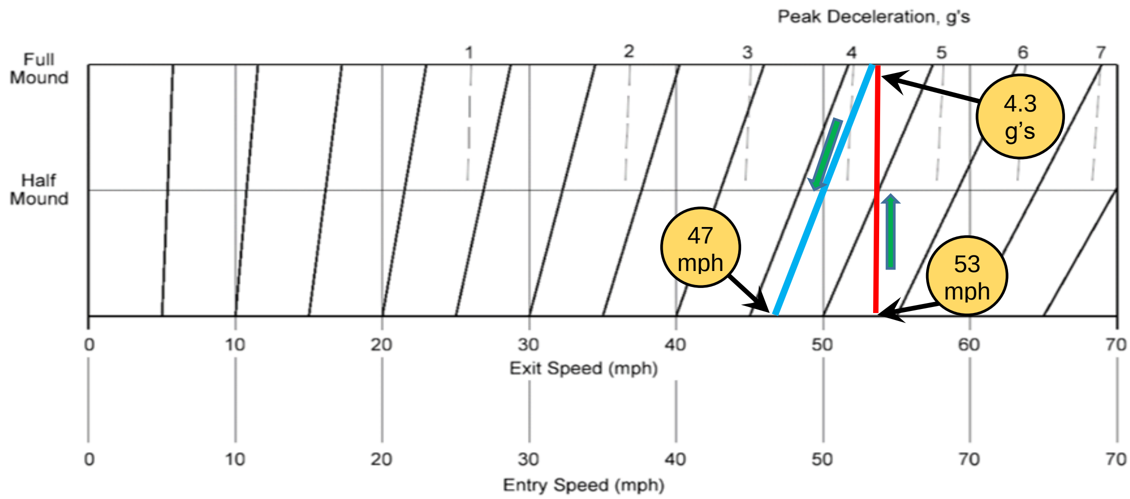
**Example 5: Determining the Length Required to Stop a Vehicle**

A bed is proposed to stop an 80,000-pound vehicle traveling at 60 mph on a 0% grade. The available length of the bed length is 300 feet.

Using Exhibit 23.4.2, as shown in the graphic below, the length required to stop an 80,000-pound truck is 475 feet, so additional impact attenuation is required. In this instance, a gravel mound is a consideration.

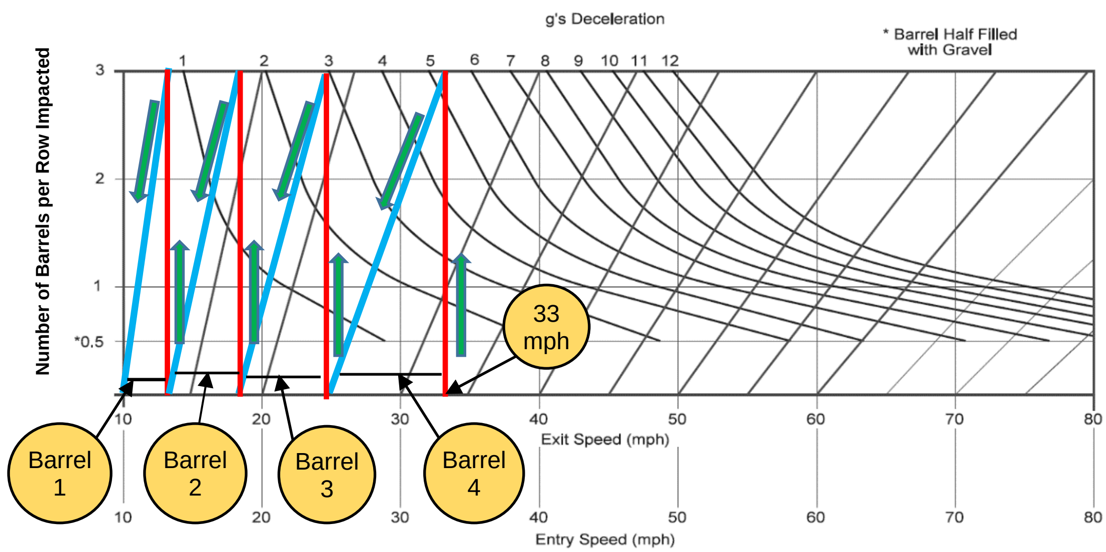


A gravel mound must be placed a minimum of 100 feet into the arrester bed. At this location, the vehicle impacts the mound at 53 mph. The exit speed after impacting a full mound is 47 mph (as shown in the graphic below, based on Exhibit 23.4.6), which occurs across the gravel mound width of 10 feet.




This leaves 190 ft of available length which does not provide enough length to dissipate the remaining speed. Therefore, it is assumed that a barrel array will be required at the end, for which 40 feet is a reasonable assumed length. This leaves an assumed length of 150 ft of arrester bed between the mounds and barrels. A line for this 150 feet of arrester bed is drawn on the graphic on previous page (based on Exhibit 23.4.2).

The designer must next determine the barrel configuration for the end of the ramp. For this example, a four-row barrel configuration is desired. Assuming the final exit speed to be 10 mph, based on Exhibit 23.4.4, as shown in graphic below, can be used to determine the resulting entry speed for a four-row barrel configuration.



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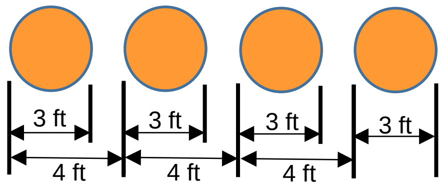
This barrel configuration uses 15 feet of arrester bed length.




To dissipate the remaining 10-mph exit speed, additional length of arrester bed is required. This additional length is calculated using Equation 23.1.

$$L = \frac{V^2}{30(R \pm G)} = \frac{10^2}{30(0.25 + 0)} = 13.33' \qquad \text{(rounded-up to 15 feet)}$$

The designer should check the actual lengths of arrester bed, mounds, and barrels to verify that it will fit within the available length. The resulting arrester bed length is 290 feet, which is less than the 300-foot available arrester bed length

$L_{Total}$ = 100 feet + 10 feet + 150 feet + 15 feet + 15 feet = 290 feet

If the resultant arrester bed length were to exceed the available length of 300 feet, the designer would need to repeat the above process using more mounds and/or barrels.

## 23.5 – Service Roads

As illustrated in **Exhibit 23.5.1**, a service road is constructed adjacent to the arrester bed. Its purpose is to enable tow trucks to extricate vehicles and provide access to the maintenance equipment used to restore and maintain the arrester bed clear of the adjacent road through-lanes.

Where possible, it is desirable for the service road to connect back to the through-roadway to permit vehicle return. The service road should have a minimum width of 10 feet. A 12 to 14-foot width is desirable. To maintain its stability and minimize maintenance, a paved surface is recommended.

The service road should have painted distance markers every 20 feet, starting at the beginning of the arrester bed, to allow for more effective monitoring of the arrester bed. Where practical, lighting should be provided to allow drivers to see the unobstructed escape ramp. Refer to Chapter 20, *Lighting*, for more information.

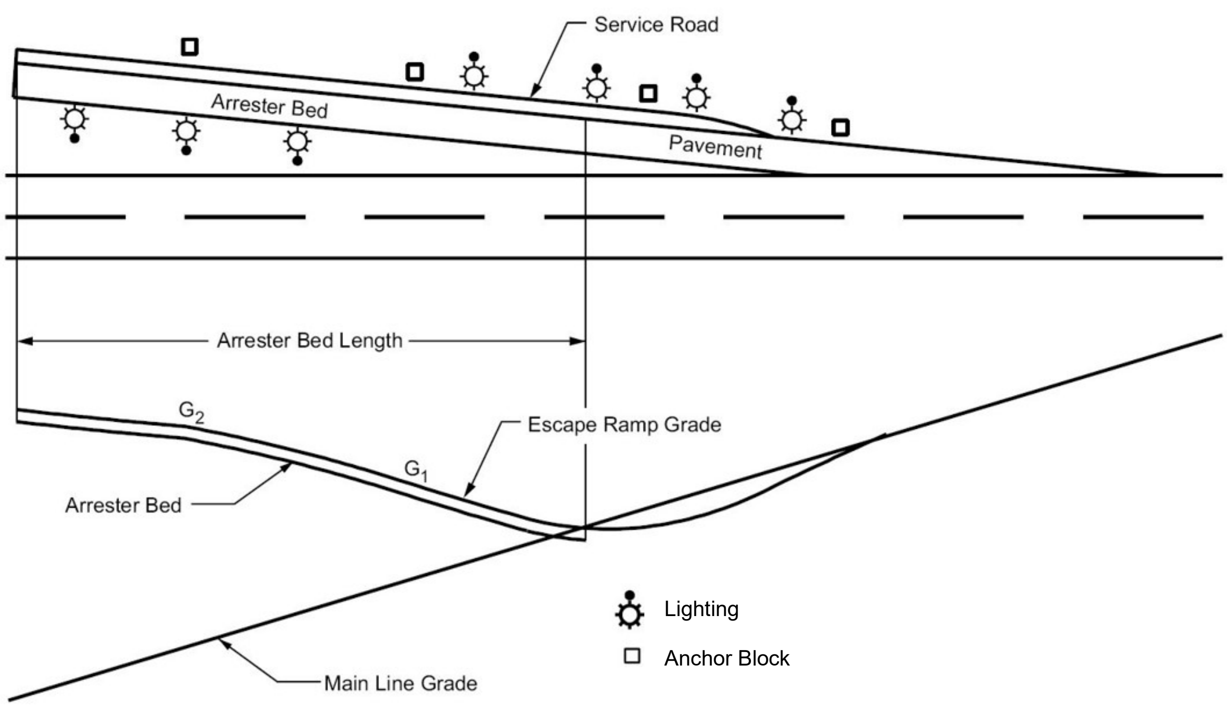
## 23.5.1 – Anchor Blocks

As shown in Exhibit 23.5.1, an escape ramp service road should be equipped with anchor blocks. The blocks help tow trucks extricate trapped vehicles from the arrester bed.

Anchor blocks should:

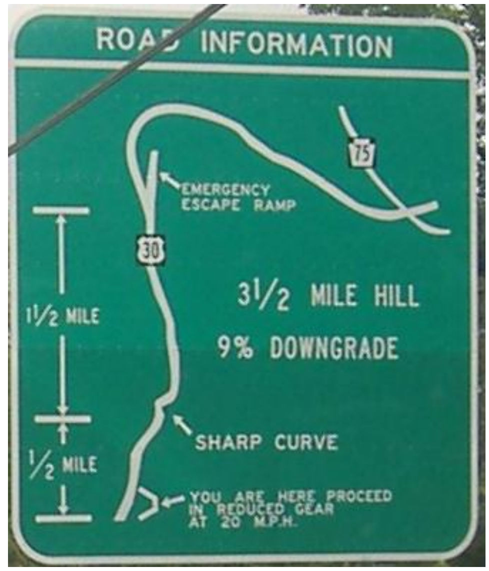
- Be offset to the side of the service road away from the gravel.
- Be evenly spaced at about 150-foot intervals (±25 feet).
- Be designated by a pavement marking on the adjacent service road for ease in locating.
- Be buried so the top of the anchor is flush with the ground.
- Include one anchor located about 100 feet in advance of the bed to assist the wrecker in returning a captured vehicle to a surfaced roadway.

**Exhibit 23.5.1 – Arrester Bed Layout with Anchor Blocks**




Anchor block markers should incorporate delineator posts to make them easier to locate at night or under snow. Refer to PennDOT Publication 13M, Design Manual Part 2, *Highway Design* (Change 7, December 2021) Figure 17.12, for concrete anchor block design details.

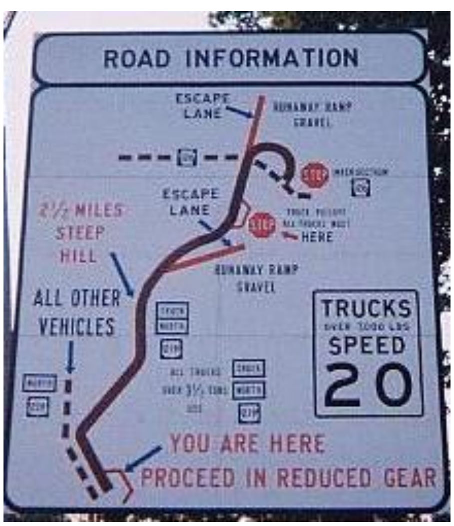
## 23.6 – Brake-Check Areas and Signing




Turnouts or pull-offs at the summit of a grade can be used as brake-check areas or mandatory-stop areas. These areas provide drivers the opportunity to inspect vehicle equipment and check that brakes are not overheated at the beginning of the descent. In addition, diagrammatic signing or self-service pamphlets can offer information about the grade ahead and the location of escape ramps.

The design of these areas does not need to be elaborate. A brake-check area can be a paved lane behind and separated from the shoulder or a widened shoulder where a vehicle can stop. Deceleration length approaching the area should be based on the speed limit approaching the down grade. The acceleration length should match the truck speed limit of the down grade. Appropriate tapers per the Green Book should be installed. Brake-check area length should be based on engineering judgement taking into consideration the maximum number of trucks anticipated at any one time, dwell time of each truck, and average truck length. Appropriate signing should be used to discourage casual stopping by the public.

The brake-check area should provide a diagrammatic sign to show the grade and alignment ahead, the locations of any sharp curves, and the location of the emergency escape ramp. The sign should also include a “You are here” label to orient the viewer.




The designer should use regulatory signs near the escape ramp to discourage other motorists from entering, stopping, or parking at or on the ramp. The design includes delineation of the ramp path to define ramp edges and provision of nighttime direction. Illumination of the approach and ramp is also desirable.

Providing appropriate warning signs, pavement markings, and delineators are important aspects of emergency escape ramp design. The MUTCD provides guidance on the types and placement of signs for emergency escape ramps.

# Chapter 24 – Rest Areas and Welcome Centers (To be Added Later)

This chapter will be published in the future. Until it is published, please refer to relevant topic in Publication 13M.