OS-299 (10-22) pennsylvania DEPARTMENT OF TRANSPORTATION www.penndot.pa.gov	TRANSMITTAL LETTER	PUBLICATION: Publication 13 DATE: 12/20/2024

SUBJECT:

Revisions to
Design Manual, Part 2
Contextual Roadway Design
April 2021 Edition, Change No. 6

INFORMATION AND SPECIAL INSTRUCTIONS:

Incorporate the attached revisions into the April 2021 Edition of Publication 13.

These new guidelines should be adopted on all new and existing designs as soon as practical without affecting any letting schedules, but must be used on projects Let after June 30, 2025.

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.

TABLE OF CONTENTS

-Updated for consistency with the revisions made as described below.

ABOUT DESIGN MANUAL 2

-The 8th bulleted reference listed on page A-1 was corrected to denote that the edition of the MUTCD is defined in Publication 212, not Publication 46.

PREFACE

-Corrected the reference to the Chapter 1 name in the last sentence on page P-2 to be "Context Based Design and Flexibility".

CHAPTER 2 DESIGN CONTROLS

*Section 2.1.1 (Relationship to the FHWA Functional Classification System)

-Expanded on Urban and Rural area type differences in relation to functional classification by adding the 2018 AASHTO Green Book, "Definitions of Urban and Rural Areas" to this section.

CHAPTER 3 NEW CONTRUCTION AND RECONSTRUCTION CHANGE IN ROAD TYPE

-Minor formatting of divider lines on the Matrix of Design Values tables (Pg. 3-70 and 3-74) so that "Cross Slopes (maximum)" columns would better align with typologies.

-Merged Preferred and Minimum turn lane width cells under Rural Town and Urban topographies to clarify that these Preferred and Minimum turn lane widths apply to both typographies.

CHAPTER 4 RECONSTRUCTION NOCIRT, 3R, AND PAVEMENT PRESERVATION PROJECTS

*Exhibit 4.2.2 table (Reconstruction NoCirt Design Criteria)

-Changed the "Urban Center" heading in the table to be "Urban Core".

*Exhibit 4.2.3 table (3R Design Criteria)

-Changed the "Urban Center" heading in the table to be "Urban Core".

CHAPTER 5 BRIDGES AND TUNNELS

*Section 5.2.3.b (Replacement Bridges (NHS and Non-NHS); Full Superstructure Replacements (NHS))

-Changed title of this Section (was Replacement Bridges (NHS and Non-NHS); Full Superstructure Replacements (NHS and Non-NHS)).

CHAPTER 6 INTERSECTIONS AND DRIVEWAYS

-Issued design guidance to replace the guidance found previously in Publication 13M, Design Manual Part 2, Highway Design, Chapter 3, *Intersections*, and Chapter 3 Appendix A*, Roundabout Key Considerations Checklist.*

CHAPTER 9 MAINTENANCE AND PROTECTION OF TRAFFIC

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

CHAPTER 17 PLAIN PEOPLE COMMUNITY CONSIDERATIONS

*Section 17.2 (Signage to Inform/Warn Motorists)

-Revised the first sentence of this section, *"The W11-14 warning sign, with a symbol of horse and closed buggy, shall be provided on roadways carrying Plain People buggies."* and replaced the word "shall" with "may" to be consistent with Publication 236.

CHAPTER 18 TRAFFIC CALMING

-New chapter not previously found in Publication 13M, Design Manual Part 2, Highway Design. This chapter replaces Publication 383, *Pennsylvania's Traffic Calming Handbook*. However, as Publication 383 is referenced in the PA Code, users accessing Publication 383 from PennDOT's *Forms, Publications, and Maps* webpage will be redirected to this chapter.

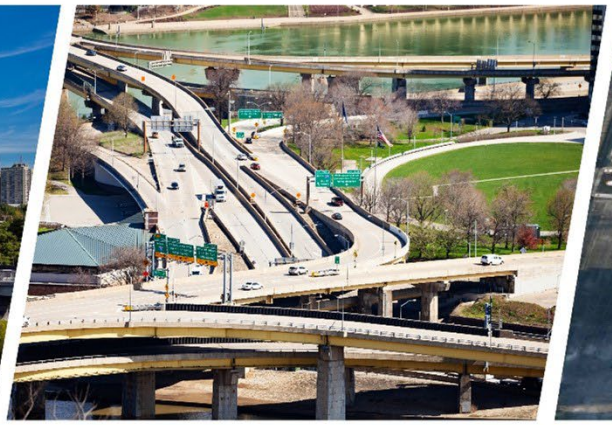
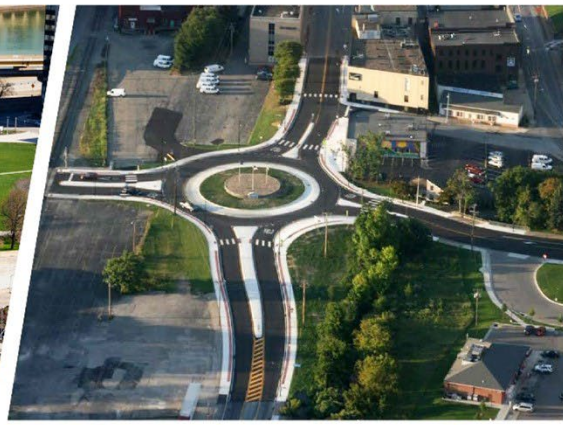
Any comments or questions regarding the above revisions should be directed to the Highway Design and Technology Division, Bureau of Design and Delivery.

CANCEL AND DESTROY THE FOLLOWING:	ADDITIONAL COPIES ARE AVAILABLE FROM:
Table of Contents - all pages About Design Manual 2 – page A-1 Preface – page P-2 Chapter 2 – page 2-3 Chapter 3 – pages 3-69, 3-70, and 3-74 Chapter 4 – pages 4-6, 4-10, and 4-11 Chapter 5 – 5-4 Chapter 6 placeholder - all pages Chapter 9 placeholder – all pages Chapter 17 – page 17-7 Chapter 18 placeholder – all pages	☒ PennDOT website - www.penndot.pa.gov *Click on Forms, Publications & Maps* APPROVED FOR ISSUANCE BY:  Gavin E. Gray, P.E. Chief Engineer Highway Administration

DESIGN MANUAL PART 2

CONTEXTUAL ROADWAY DESIGN

PUBLICATION 13




pennsylvania
DEPARTMENT OF TRANSPORTATION

Pub 13 (12-24)

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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, and the AASHTO publication, *A Policy on Design Standards-Interstate System* (for Interstate Federal-aid projects), takes precedence if more conservative than DM-2).

The Department develops Federal-aid highway projects in accordance with the standards and guides identified in 23 U.S.C. 109, 23 CFR 625 (as well as other FHWA policies identified in the Federal Register, the Federal-Aid Policy Guide and elsewhere) and/or Department standards or manuals approved by FHWA.

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, 7th Edition* commonly referred to as the "The Green Book", 2018.
- 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, *A 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 212).
- The Transportation Research Board, *Highway Capacity Manual* (HCM*),* (edition defined in Publication 46).

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

The inclusion of specified design criteria in this manual does not imply that existing roadways, which were designed and constructed using different criteria, are either substandard or must be reconstructed to meet the criteria contained herein. Many existing facilities which met the design criteria at the time of their construction are adequate to safely and efficiently accommodate current traffic demands.

The Department has prepared standard roadway drawings (Publication 72M, *Roadway Construction Standards*) to provide engineering personnel, designers and contractors with a catalog of specific design conditions for use as a guide in the development of the design of highways. The standard drawings shall be used in conjunction with the specifications, special provisions and construction plans to provide a more uniform design and construction practice for all projects.

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.

Initiative should be exercised to utilize the most appropriate design values within the given ranges based upon the project context and roadway typology wherever practicable and within reasonable economic limitations and sound engineering judgment.

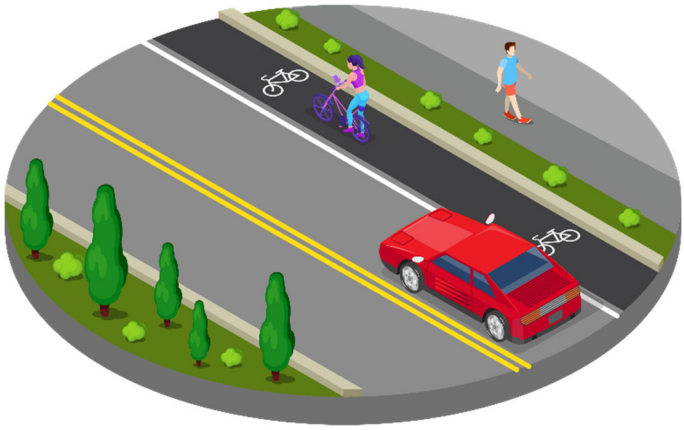
Framework for the Development of Projects

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

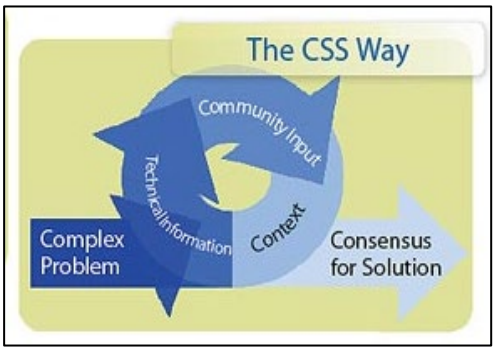
A complete streets approach challenges transportation professionals to routinely design and operate the entire right-of-way to enable safe access for all users, regardless of age, ability, or mode of transportation. This means that every transportation project should promote a street network better operationally 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 Based Design and Flexibility*.

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.



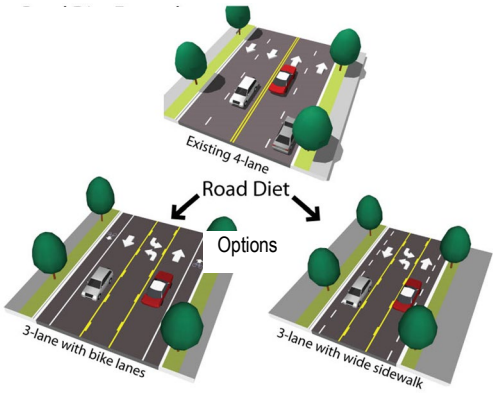
(Source: FHWA contextsensitivesolutions.org)

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 Controls*.

Design Flexibility

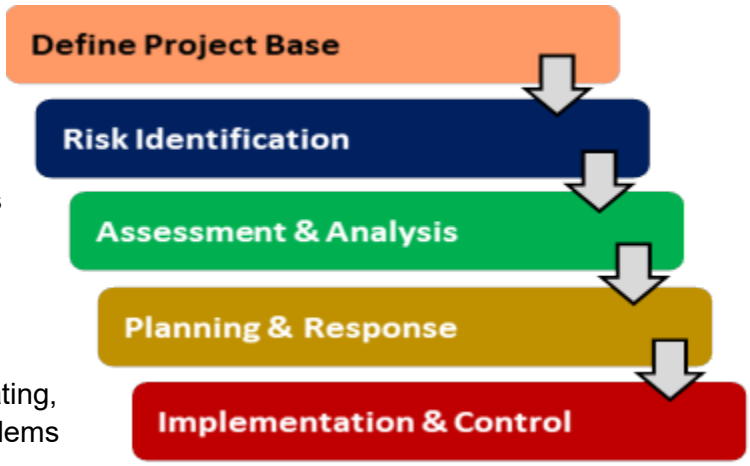
Flexibility in design is a context sensitive concept that encourages transportation professionals to expand their consideration in applying the AASHTO Green Book and other design criteria.



(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, *Design Controls*.

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 is provided in Publication 10X, Design Manual Part 1X, Appendix AH, *Risk Management for Project Development*.

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.

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.

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.

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 and Flexibility

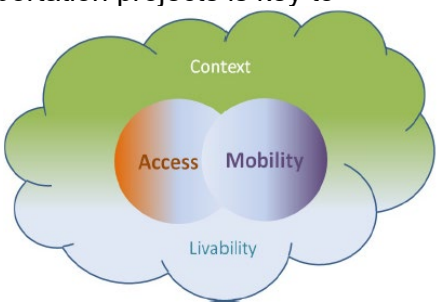
In this chapter there are references to future chapters that are currently not included in this Publication 13.

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

Chapter 1 – Context Based Design and Flexibility

1.0 – Introduction

Balancing access, mobility, livability, and the context of transportation projects is key to developing transportation facilities that meet the needs of PennDOT's customers, the travelling public.



Every project has a context, whether it is in a rural setting, small town, transition area, or urban grid. As each project is developed, the project team must have an understanding of the function of the roadway within its current and future framework and the needs of potential users. By considering the context, a project can be developed in harmony with the community and preserve resources that otherwise might be harmed or lost. The result is transportation investments that can be catalysts in creating lasting value in the community.

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. **Context Sensitive Design (CSD)** is closely related to CSS and asserts that the planning and design of a project should be responsive to the users, community, and the environment. Refer to Publication 10C, Design Manual Part 1C, *Transportation Engineering Procedures* (DM-1C) for more details on CSS.

This chapter provides guidance on how to identify project context and its relationship to roadway functional classification and potential users. It also addresses the importance of design flexibility in achieving transportation system goals. This includes:

- Enabling safe, convenient, and comfortable travel for all residents.
- Improving network connectivity for all modes, as well as addressing gaps.
- Providing access to key destinations.
- Aligning project designs with the goals articulated in state, regional, and local plans.

Context Sensitive Solutions

Proper context based design requires an understanding of the function of the roadway within its current and expected future context and the needs of the potential roadway users.

PennDOT's Core Principles emphasize incorporating context and flexibility in design, as detailed in Publication 10, Design Manual Part 1 (DM-1), *Transportation Program Development and Project Delivery Process*.

PennDOT's ten core principles are:

1. Money counts.
2. Choose projects with high value to price ratio.
3. Enhance the local network.
4. Look beyond level-of-service.
5. Safety always and maybe safety only.
6. Accommodate all modes.
7. Leverage and preserve existing investments.
8. Build towns and not sprawl.
9. Understand the context, plan and design within the context.
10. Develop local governments as strong land use partners.

1.0.1 – References and Resources

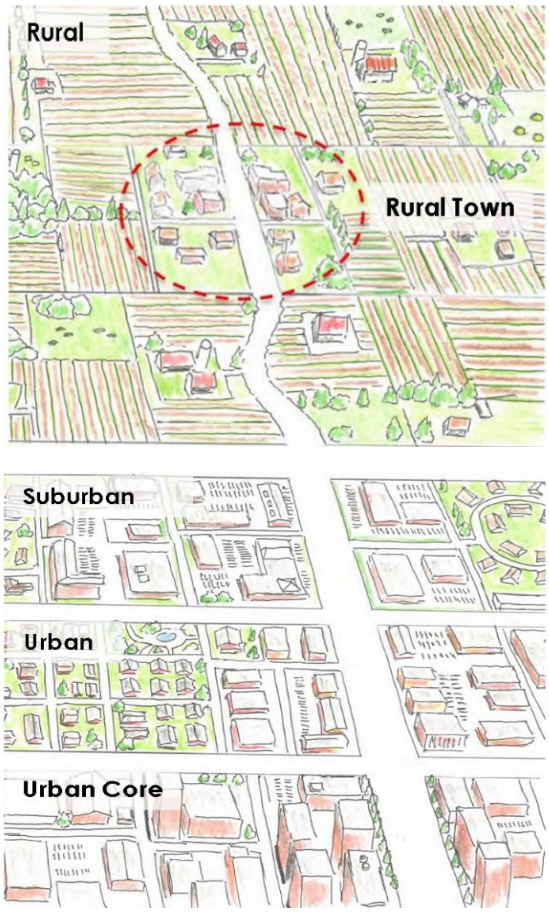
- PennDOT, Publication 10X, Design Manual Part 1X, Appendix F, *Guidance for Compiling Technical Service Data,* 2018.
- National Cooperative Highway Research Program (NCHRP), Research Report 855: *An Expanded Functional Classification System for Highways and Streets*, 2018.
- Transit Cooperative Research Program (TCRP), Report 19: *Guidelines for the Location and Design of Bus Stops,* 1996.

1.1 – Context

There are five primary context categories that represent unique land use environments and require wholly different geometric design practices (in terms of desired operating speeds, mobility and access demands, and user groups). As illustrated in **Exhibit 1.1.1**, these five primary context categories and their key characteristics are:

- **Rural.** Areas with the lowest density (e.g., widely dispersed or isolated residential and commercial structures or no residential, commercial, nor industrial uses); a predominance of agricultural, natural resource preservation, and outdoor recreation uses; and usually large setbacks or constraints due to topography.
- **Rural Town.** Areas with low to medium density (e.g., single-family houses and other single purpose structures); commercial uses predominantly along main streets (ranging from lower to higher densities); and on-street parking and sidewalks with predominantly small setbacks.
- **Suburban.** Areas with low to medium density (where single-family structures predominate, along with some multi-family and multistory commercial structures); mixed residential neighborhood and commercial clusters (including town centers, commercial corridors, big box commercial, and light industrial); and varied setbacks with some sidewalks and mostly off-street parking.

Exhibit 1.1.1 – Contexts



- **Urban.** Areas with high density (e.g., multistory, low-rise structures with designated off-street parking); mixed residential and commercial uses, with some industrial and prominent destinations; and potential for some on-street parking and sidewalks with close setbacks.
- **Urban Core.** Areas with highest density (e.g., multistory and high-rise structures); mixed commercial, residential, and institutional uses within and among predominantly high-rise structures; and no or small setbacks with sidewalks and pedestrian plazas. Parking garages / lots are also key to commuting and shopping travel.

1.1.1 – Context Overview



Rural areas range from those with no development (e.g., natural environment) to some light development, with sparse residential and other structures mostly associated with farms. The land is used primarily for outdoor parks and recreation, agriculture, farms, forested land, and/or resource extraction. Occasionally, a non-incorporated hamlet or village will include a few residential and commercial structures.

In a rural setting, there are very few pedestrians and bicyclists. Transit service is often absent, but availability can vary widely depending on the jurisdiction. On-demand service typically provides special assistance. However, there may be more of this activity near a rural town or village. Examples of commercial uses include a general store, restaurant, and filling station, usually located at crossroads.

Setbacks for structures in rural areas are usually large but can shrink in the immediate vicinity of a rural town or village.

There are unique considerations for rural areas that serve a Plain Sect population, particularly for non-motorized means of travel (including horses and buggies, bicycles, scooters, and pedestrians).

In the first set of photographs below, the photo to the left depicts a rural agricultural area under farm use. The photo to the right shows a rural natural environment with natural forested area.





The panel of photographs below depicts a variety of rural context settings. Only one residential structure is seen in the top right of the left panel. The right panel shows small-scale resource extraction with agricultural use. The center panel shows a cow farm.







RURAL TOWN

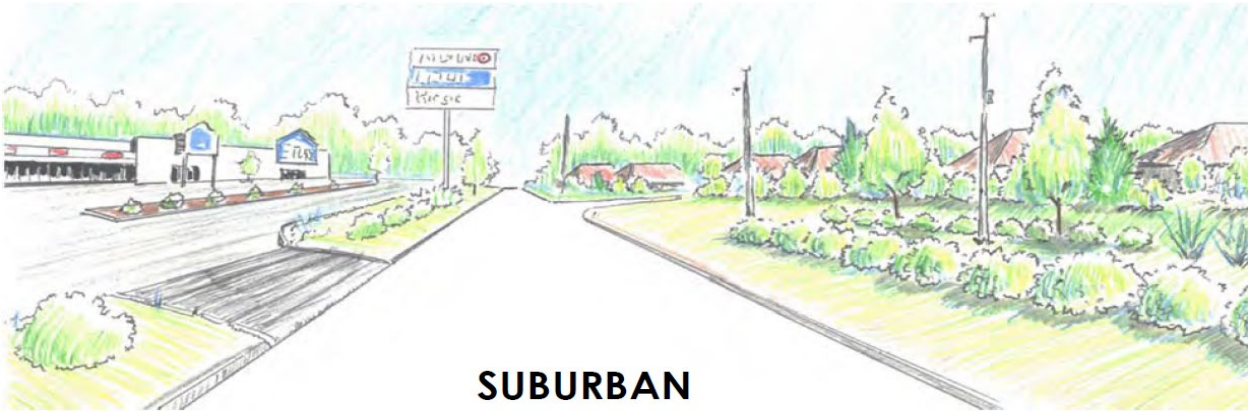
Rural towns are characterized by low to medium density, low rise (one or two story) structures but with concentrated development of diverse uses, including residential and commercial. Rural towns are usually incorporated and may have limited government services.

Rural towns usually have a roadway section that has a “Main Street” character (or even a town square) with on-street parking, sidewalks, and, in some cases, bicycle lanes. Public transit is uncommon or limited. Diversity of use can include a variety of commercial establishments that serve the surrounding rural area. Some relatively compact residential uses (and possibly schools) are common. The setbacks for structures are relatively small.

The photograph on the below left shows commercial establishments along a rural town’s main street, with sidewalks and on-street parking. The photograph on the right shows single-family homes on an adjacent street.







Suburban locations are of medium density and include a diverse range of commercial and residential structures. Commercial buildings with off-street parking. Sidewalks are usually present and bicycle lanes may exist.

Development includes suburban town centers or commercial corridors, with a range of uses, including shopping / strip malls, big box stores, health services, industrial, convenience stores, gas stations, grocery stores, restaurants, schools, and libraries. Typically, suburban areas rely heavily on passenger vehicles but may incorporate some public transit.

Residential areas may consist of single and multi-family structures. Setbacks are varied. Suburban areas are usually connected and closely integrated with an urban area. In addition, suburban areas may have well planned and arranged multi-use infrastructure that encourages walking and biking. Planned multi-use clusters may also integrate residential and commercial areas, schools, and parks.

The photos below show suburban area residential and commercial medium density structures. Both areas accommodate off-street parking.







Urban locations are high density, consisting principally of multistory and low- to medium-rise commercial and residential structures. Areas usually exist for light and sometimes heavy industrial use. Many structures accommodate mixed uses, including commercial, residential, and parking. Setbacks will usually include sidewalks with little or no open area. Urban locations are usually on the fringe of an Urban Core.

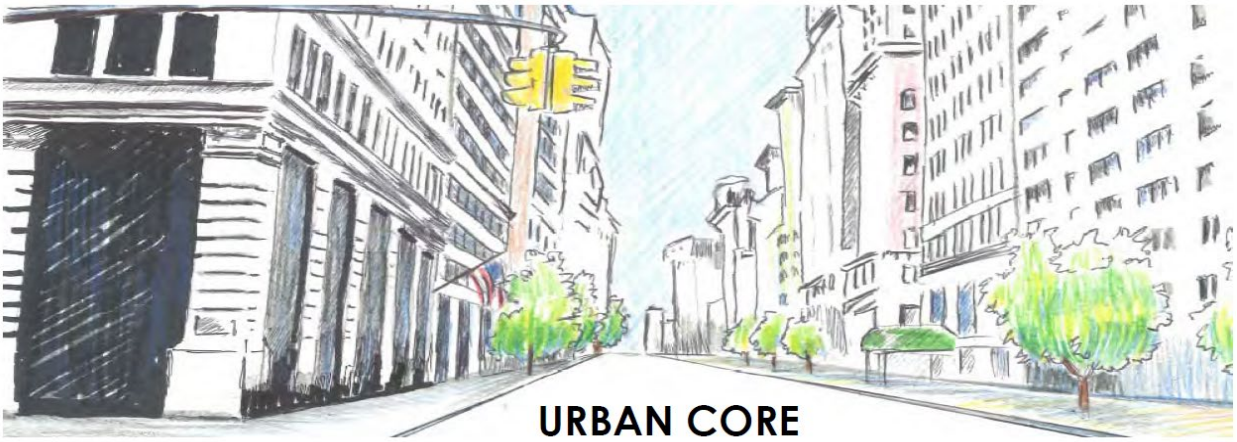
Urban areas usually include prominent destinations with specialized structures for entertainment, athletic, and social events, as well as conference centers.

Streets often have on-street parking. Wide sidewalks and plazas may accommodate more intense pedestrian traffic. Bicycle lanes and transit corridors are frequently present. Off-street parking may include multilevel structures that may be integrated with commercial or residential structures.

The urban mixed-use photographs below show low-rise commercial structures with minimum sidewalks and low-rise residential and mixed commercial structures.







Urban cores consist of the highest level of density, with mixed residential and commercial uses accommodated in high-rise structures. While there may be some on-street parking, it is usually very limited and time restricted. Most parking occurs in multilevel structures attached or integrated with other structures.

The area is typically accessible to automobiles, commercial delivery vehicles, and public transit. Sidewalks and pedestrian plazas are typically present, along with pedestrian bridges connecting commercial and parking structures. Bicycle facilities and transit corridors are common. Commercial uses predominate, including financial, legal, and government services.



Structures may have multiple uses and setbacks are not as generous as in the surrounding urban area.

The photograph to the right shows a pedestrian plaza in the foreground and a hotel and convention center in the background.

The photograph on the left shows highest density urban core with high-rise structures and surface transit (underground transit may also exist). Sidewalks are present with minimum setbacks and little or no on-street parking. The photograph on the right shows mixed uses with a pedestrian plaza.





1.2 – Roadway Functional Classifications and Potential Users

Facility users, including passenger vehicles, pedestrians, bicyclists, transit vehicles, and trucks have different needs within each roadway context. Designers should identify these various needs early in planning and design. Consideration of these needs is also key when balancing the design elements and tradeoffs necessary to develop contextually appropriate multimodal solutions.

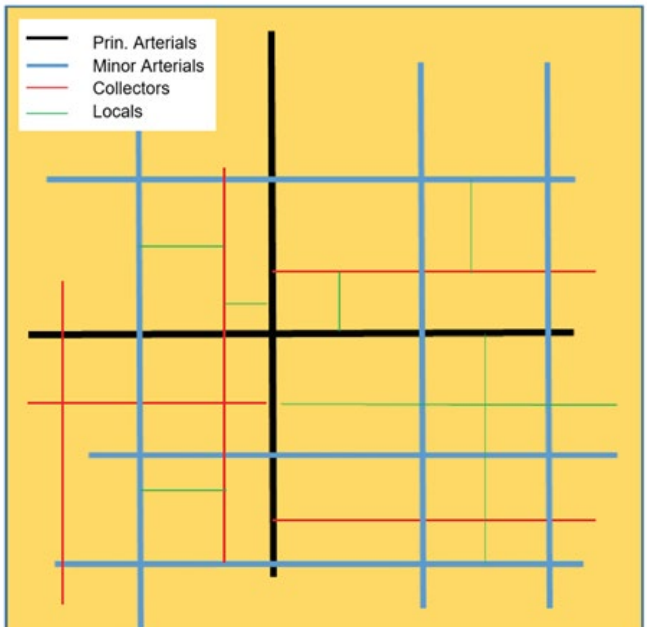


1.2.1 – Roadway Functional Classifications

Roadway functional classifications, as illustrated in **Exhibit 1.2.1**, are defined by their network function and the connectivity they provide among various centers of activity. Network function refers to the regional and local importance of a roadway as it pertains to vehicle movement. Connectivity identifies the types of activity centers and locales connected with the particular roadway. Functional classifications include:

- **Interstates, Freeways and Expressways.** Corridors of national importance connecting large centers of activity over long distances. These facilities have limited access.
- **Principal Arterials.** Corridors of regional importance connecting large centers of activity.
- **Minor Arterials.** Corridors of regional or community importance connecting centers of activity.
- **Collectors.** Roadways of lower community importance providing connections between arterials and local roads.
- **Locals.** Roadways with no regional importance, providing local circulation and access. Local roadway type refers to the function of the road, not the ownership. For example, a collector might be locally owned but that does not make it a local roadway.

Exhibit 1.2.1 – Roadway Functional Classifications



These Functional Classifications correspond to the FHWA Functional Classifications found in Chapter 2, Section 2.1.1.

1.2.2 – Bicycle Network Types



Similar to functional types for roadways, bicycle network classifications identify the priority and network importance of bikeways. The four standard bicycle network classifications are:

- **Statewide Route.** Provides tour bike routes through rural, suburban, and urban areas. The Bicycle PA routes are of this type.
- **Citywide Connector.** Provides citywide connections or connections to major activity centers stretching over several miles.
- **Neighborhood Connector.** Provides neighborhood or suburban area connection, establishing connections to higher order facilities or local activity centers.
- **Local Connector.** Provides local connections of shorter lengths, enabling internal connections to neighborhoods.

Additionally, bicycle facilities are generally categorized by the amount of separation from motorized traffic, which varies according to the bicycle route's classification and the roadway type and speed. These categories include:

- **High Separation.** Providing physical separation from traffic via a physical barrier or lateral buffer.
- **Medium Separation.** Providing a dedicated space adjacent to motorized traffic.
- **Low or no Separation.** Providing joint-use facilities for motorized and non-motorized traffic.

Chapter 14, *Bicycle Facilities*, provides more detail pertaining to bicycle facility design.

1.2.3 – Pedestrian Facility Types



Pedestrian facilities are designed, constructed, and provided for pedestrian travel and can be generally categorized according to the width of the facility. Pedestrian facilities categorized this way include:

- **No Facility.** In areas with very limited pedestrian activity, pedestrians can use wide shoulders or graded areas adjacent to the road.
- **Minimum Width.** Providing for the minimum required width based on Americans with Disabilities Act (ADA) requirements.
- **Wide Width.** Providing for more space than the required minimal width for a pedestrian facility. When the sidewalk is adjacent to parking, refer to Chapter 19, *Parking*, for the wide sidewalk width definition.
- **Enhanced Width.** Providing for additional space to accommodate congregating groups of pedestrians, street furniture, and pedestrian activities.

In addition to the facility width, it is important to consider separation of the pedestrian facility from the travelled way. The need for this separation is primarily dependent on the speed of the roadway rather than on the level of activity on the facility. Typically, medium and high speed (above 40 mph) roadway facilities will require separation from the pedestrian facility (e.g., in the form of a landscaped buffer, barriers, bicycle lanes, or parking areas). For low speed (i.e., 40 mph or lower) facilities, the sidewalk may be attached to the curb directly adjacent to the travel way, without a buffer area.

Chapter 13, *Pedestrian Facilities*, provides more detail on pedestrian facility design.

1.2.4 – Transit Networks, Users, and Facilities

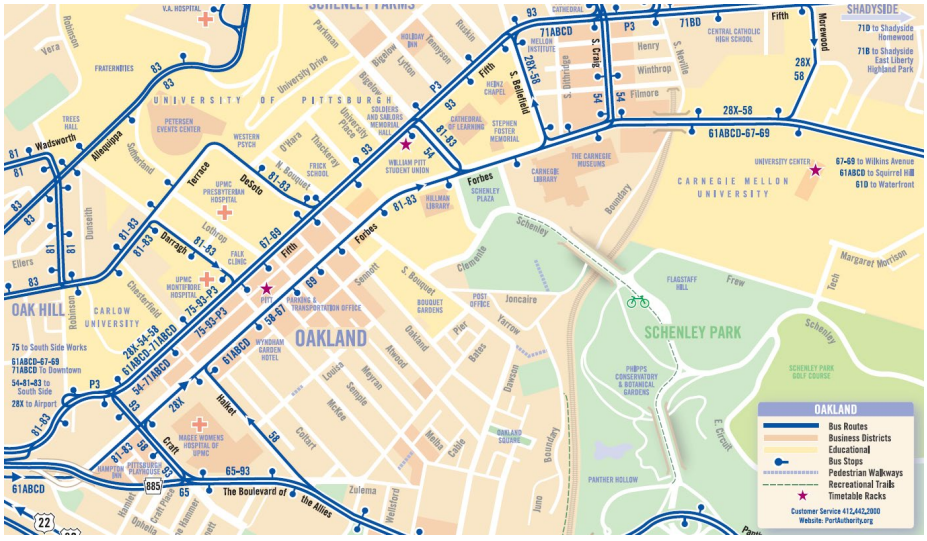


It is important to overlay the transit network with the roadway network to determine the context of the overall network. Many transit networks have defined, fixed routes. Coordinating with the local transit agencies can help identify current and future transit routing and transit issues along a corridor or area. **Exhibit 1.2.2** is an example of a transit network overlayed on the roadway network.

The importance of transit networks and facilities in urban and urban core context areas can become more pronounced than in other context areas. Issues may include incorporating bus stop amenities (e.g., shelters, seating, kiosks, bicycle storage racks, lighting, and landscaping), widened / paved shoulders or bus turnout area, and addressing street crossings.

Chapter 15, *Transit Facilities*, provides more detail pertaining to transit facility design.

Exhibit 1.2.2 – Oakland, PA Bus Route Example



1.2.5 – Freight Network Accommodation

Designated freight routes or truck routes may be identified as noted in Chapter 16, Freight. Freight networks are characterized by frequency and size of expected freight traffic. Considerations include vehicle classification counts and review of the land use in an area (e.g., industrial areas, intermodal facilities, and commercial areas).



On heavy freight routes, the roadway, adjacent facilities, and intersections should be designed to accommodate freight traffic and safe and efficient movement. This may include accommodating or designing for turning radii or loading activities. Freight vehicles have blind spots, creating challenges and conflicts for automobiles, pedestrians, and bicyclists, that must be considered.

Moderate or occasional use facilities may marginally accommodate larger freight vehicles while designed to provide lower speeds and shorter crossing distances for other users, including pedestrians.

Lower classification roadways may accommodate occasional through-freight vehicles, while certain roadway and land use contexts may preclude larger freight traffic.

Chapter 16, *Freight*, provides more detail pertaining to freight facilities and identifying freight networks

1.3 – Flexibility

Flexibility is crucial in developing solutions that balance the needs of all roadway users and the goals of the greater community. It facilitates a connected network of both motorized and non-motorized transportation infrastructure that enhances access to jobs, schools, and other destinations in a cost-effective manner.

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

Flexible thinking is about making informed choices. Simply applying the highest or lowest value within a range of design values might not lead to the optimum design. To best meet a project's objectives, context must also be considered.

AASHTO Green Book

"A roadway has wide-ranging effects in addition to providing traffic service to users. It is essential that the highways be considered as an element of the total environment. The term 'environment,' as used here refers to the totality of humankind's surroundings: social, physical, natural, and synthetic."

AASHTO Green Book 2018.

The scope of work of a project determines which geometric design criteria is applied to a highway or bridge project. It is generally preferable for a project to have one set of design

criteria. However, there may be cases where different portions of a project have distinctly different scopes of work. For example, a five-mile pavement overlay project may include a bridge replacement. In this case, it may be appropriate to apply Pavement Preservation criteria to the roadway portion of the project and Bridge Replacement criteria to the bridge portion of the project.

Flexibility encourages transportation professionals to provide a complete street. It considers the roadway context, implications for the safety and comfort of pedestrians and bicyclists, and implications for regional mobility. **Exhibit 1.3.1** provides examples of some flexible design considerations.

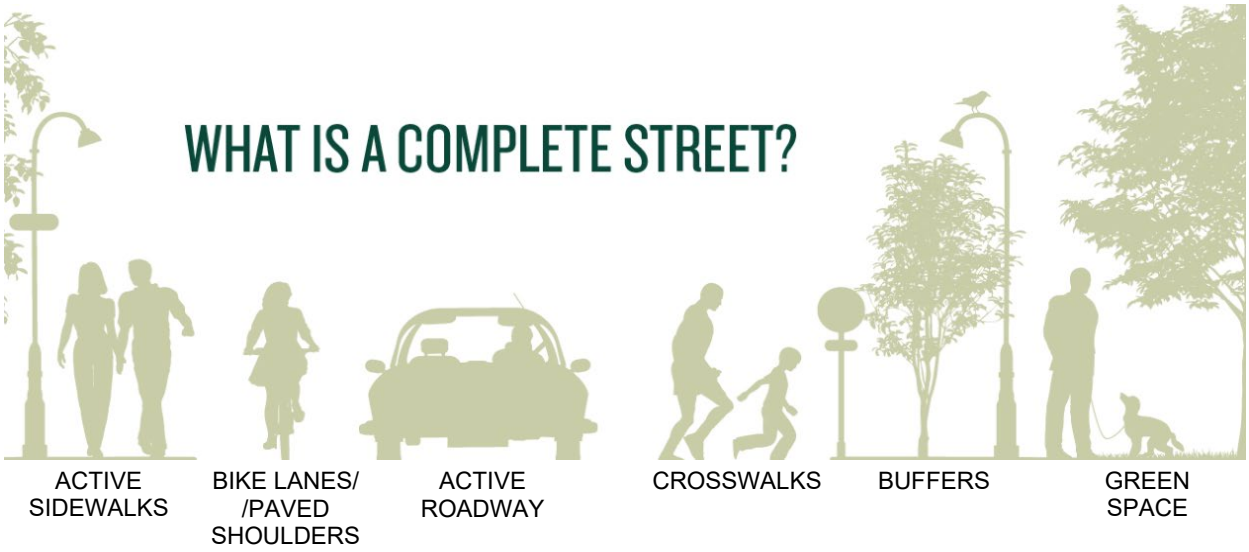
Exhibit 1.3.1 – Examples of Design Flexibility

Element	Design Flexibility Considerations
Lane Width	• Lane narrowing to accommodate center turning lanes, bike lanes, or sidewalks
Road Diets	• Four-lane to three-lane to accommodate bike lanes or parking • Level of service flexibility (safety considerations over congestion)
Intersection Geometry	• Careful consideration of a design vehicle to determine turning radius • Mountable truck aprons to reduce radius • Use of medians for pedestrian islands in crossing multilane roads and channelized turns
Transitions to Town Centers	• Transition zones including lane narrowing, shoulder removal, curb sections, landscaping, and sidewalk buffers • Gateway treatments such as roundabouts, chicanes, reduced lane width, shoulder removal, providing curb line, and landscaping
Pedestrian Crossing Treatments	• Consideration of mid-block crossings where sight distance is acceptable and pedestrian demand exists • Use of pedestrian islands for longer crossings (four lanes or more)
Paved Shoulders	• In lieu of bike lanes

1.4 – Complete Streets

The design of complete streets, as shown in **Exhibit 1.3.2**, encourages and facilitates active transportation and accommodates people of all ages and abilities, including vulnerable road users, such as pedestrians and bicyclists.

Exhibit 1.3.2 – Complete Street Components



Complete streets:

- Are context sensitive, so there is no one-size-fits-all approach to design. Flexibility enables tailoring projects to the specific needs of each community, allowing for the selection of facilities and amenities best suited to their surrounding land uses and street character.
- Are implemented incrementally as a vital tool for filling gaps and making important connections toward a transportation network that addresses all travel modes.
- Benefit economic growth and stability through safe and accessible connections between homes, offices, schools, parks, public transit, essential services, and retail destinations.
- Benefit children by creating safe routes to school. Enabling children to walk and ride bikes to school increases physical activity, provides independence, and helps to foster a sense of pride for the community.
- Are good for the environment. Facilitating the use of non-motorized modes of transportation can help decrease the number of trips made by car, resulting in reduced air and noise pollution.
- Can improve health and wellness by replacing short car trips with non-motorized forms of transportation. This, in turn, can create an environment where pedestrians and bicyclists of all ages and abilities feel safe and comfortable.

- Encourage safe driving habits. Treatments such as road diets can help to reduce excessive speeds and vehicle interactions and providing an appropriate number of through lanes based on actual vehicle capacity.

1.5 – Incorporating Context and Flexibility into Projects

The correlation of context, roadway functional classification, and users comprises the decision correlation matrix presented in **Exhibit 1.4.1**. This matrix assists in the development of a multimodal, context-based design with some degree of flexibility.

Each matrix cell defines the various users (drivers, bicyclists, and pedestrians) and identifies characteristics the designer must balance. The matrix can also be used to define Transit, Freight and Plain People Accommodations.

Exhibit 1.4.1 – Decision Correlation Matrix

Context / Roadway	Rural	Rural Town	Suburban	Urban	Urban Core
Principal Arterial	DRIVER BICYCLIST PEDESTRIAN				
Minor Arterial					
Collector					
Local					

The classification of the functional types for the driver and bicyclist are considered across the entire network. Their combination provides the coverage required to address and balance the needs within the roadway context.

It should be noted that a corridor might transition into different contexts over its length. This transition will be reflected in the design considerations and cross sections.

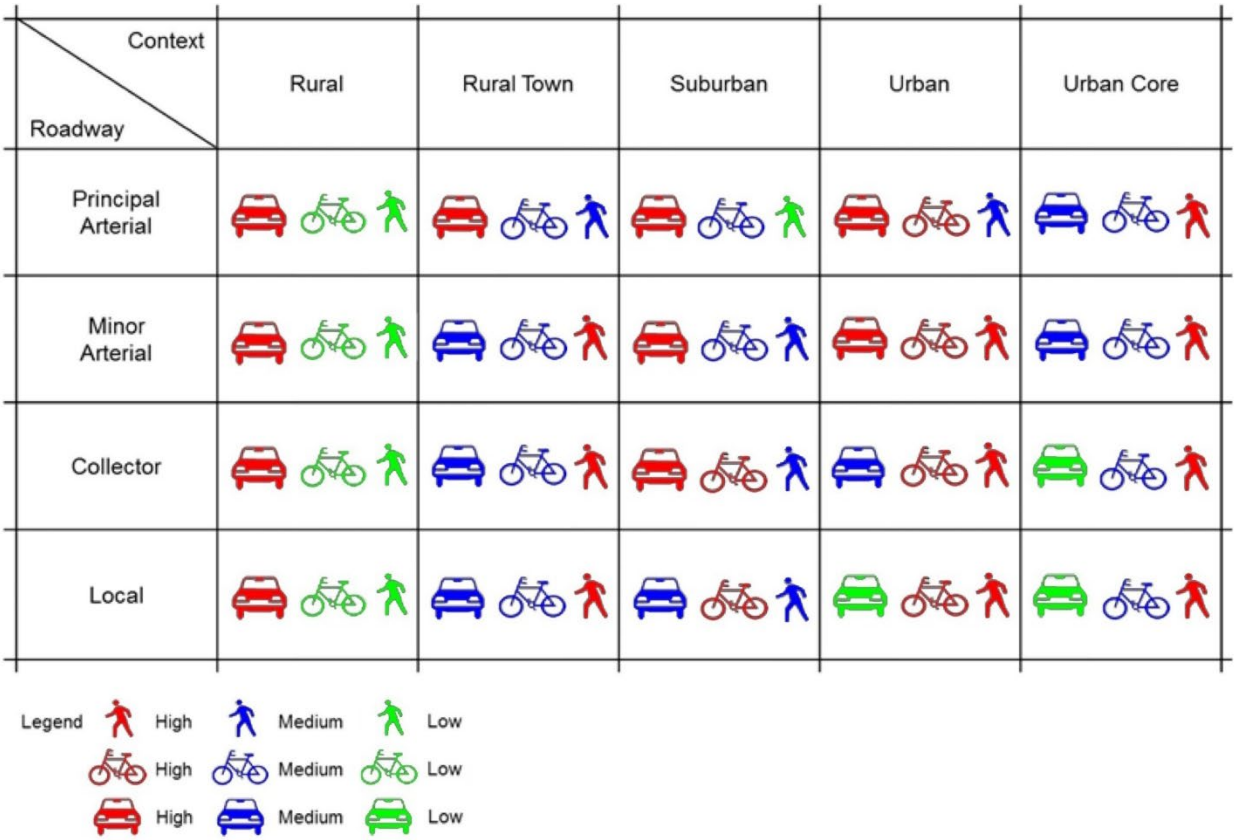
1.5.1 – Decision Correlation Matrix Application

When approaching project design, the design team should use the decision correlation matrix to understand the role the roadway plays within its location environment and within the transportation network. The matrix identifies the user groups that should be accommodated so that their competing needs and spatial demands may be considered. As noted above, the matrix also identifies the importance of the corridor within the individual network of each road user to assist in balancing and prioritizing these needs.

While balancing various user needs, the designer will not always be able to provide the best facilities for all of the users at all times and at the same location on all roadways.

Further, there will be instances where mobility needs require adjustments and/or the consideration of alternative routes, as well as revised system overlays. For example, on high-speed arterials, the mobility of bicycles and pedestrians might be accommodated on a parallel roadway with lower speeds. Likewise, a corridor with high bicycle demand and mobility may require facilities that would lower speeds and possibly reduce the number of vehicle lanes if there is limited right-of-way. **Exhibit 1.4.2** provides a matrix that identifies potential user levels.

Exhibit 1.4.2 – Typical User Priority



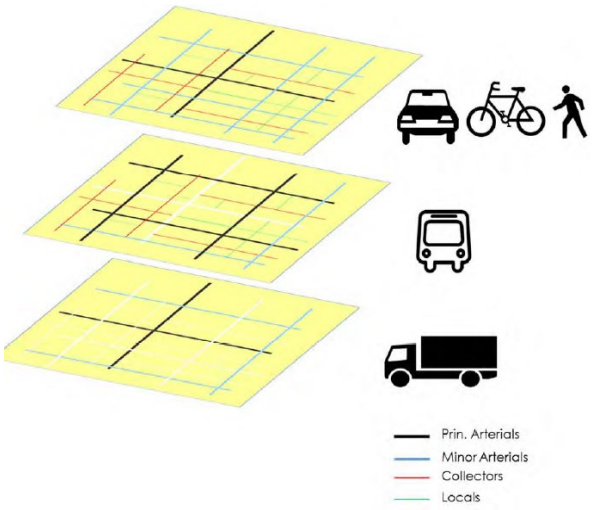
1.5.2 – Overlay Matrices

In addition to the context, roadway type, and user groups presented in the decision correlation matrix, it is critical that the design team address the needs of specific networks (such as transit and freight), the networks in which they operate, and potential conflicts among users. This is accomplished through the application of overlays (i.e., superimposing each network over each other). When considering how to balance the needs of roadway users and overlays, information regarding the frequency, use, and importance of the individual routes within the overlay network is essential.

1.5.2.a – Applying Network Overlays

Designers can assemble a modal network to determine good network layouts for each user. Once complete, these networks may be overlaid to develop a representation of the entire transportation network, corridor, or project and its individual users as illustrated in **Exhibit 1.4.3**.

Exhibit 1.4.3 – Network Overlays



Incompatibilities between user groups will likely arise throughout the project development process. When these conflicts occur, applying an alternate network strategy can identify parallel routes that are compatible with the transportation needs of other users. Therefore, it is imperative that the designer evaluate the needs of all users and understand their priorities within the route and each of their networks.

If a modal network is needed, a project team (in conjunction with project stakeholders and public input) may identify the priorities for the project. Primary considerations include identifying the generators for each mode and providing a connection between major points of trip attraction or generation. For instance, a roadway in the urban core with heavy pedestrian-focused retail should place a high priority on pedestrian movement as it serves as the point of attraction. Roadways connecting the activity center with either residential or transit centers may also need to prioritize pedestrian movements. Connecting roadways, however, may become less of a priority if an alternative better accommodates the mix of users, such as establishing a pedestrian-only

Example

While it may be desirable to accommodate bicyclists on an arterial, heavy vehicle volumes may present a challenge on how to accommodate demand. In this case, parallel roads may be used to divert the bicycle traffic and establish the required separation to accommodate them.

corridor closed to automobile traffic. At a minimum, the design should accommodate intended users on the road or move users to a parallel route.

1.6 – Terrain

The topography of the land traversed has an influence on the vertical and horizontal alignments of roadways and streets. To characterize variations, topography is separated into three classifications according to terrain which include: (1) level terrain, (2) rolling terrain and (3) mountainous terrain.

In level terrain, highway sight distances, as governed by both horizontal and vertical restrictions, are generally long or can be made to be so without construction difficulty or major expense.

In rolling terrain, natural slopes consistently rise above and fall below the road or street grade, and occasional steep slopes offer some restriction to normal horizontal and vertical roadway alignment.

In mountainous terrain, longitudinal and transverse changes in the elevation of the ground with respect to the road or street are abrupt and benching and side hill excavations are frequently needed to obtain acceptable horizontal and vertical roadway alignment.

Terrain classifications pertain to the general character of a specific route corridor. Routes in valleys, passes, or mountainous areas that have all the characteristics of roads or streets traversing level or rolling terrain should be classified as level or rolling. In general, rolling terrain generates steeper grades, then level terrain, causing trucks to reduce speeds below those of passenger cars; mountainous terrain has even greater effects, causing some trucks to operate at crawl speeds.

1.7 – Tort Liability Concerns with Design Flexibility

Designers have a general misconception that applying design flexibility could lead to tort liability. As noted in the FHWA's *Flexibility in Highway Design,* Chapter 2, *Tort Liability as it Relates to the Green Book*:

> "As a result of concerns about litigation, designers may be tempted to be very conservative in their approaches to highway design and avoid innovative and creative approaches to design problems. While it is important for design engineers to do their jobs as thoroughly and carefully as possible, avoiding unique solutions is not the answer. This may undermine design practice and limit growth in the engineering profession. Designers need to remember that their skills, experience, and judgment are still valuable tools that should be applied to solving design problems and that, with reliance on complete and sound documentation, tort liability concerns need not be an impediment to achieving good road design."

Design manuals also encourage flexibility and engineering judgement. For example, the AASHTO Green Book emphasizes the need for flexibility, stating:

> "The intent of this policy is to provide guidance to the designer by referencing a recommended range of values for critical dimensions. Good highway design involves balancing safety, mobility, and preservation of scenic, aesthetic, historic, cultural, and environmental resources. This policy is therefore not intended to be a detailed design manual that could supersede the need for the application of sound principles by the knowledgeable design professional. Sufficient flexibility is permitted to encourage independent designs tailored to particular situations."

The best defense for a design engineer is persuasive evidence that the guidelines were not applicable to the project's circumstances or that the guidelines could not be reasonably met. When one or more of the controlling criteria design elements require a design exception, the best protection against future liability is a well-developed design exception request document. As stated in FHWA's *Flexibility in Highway Design,* Chapter 2, *Tort Liability as it Relates to the Green Book*:

> "If the justification documented by a designer completely describes the physical and environmental factors that make the exception or any design necessary, it is likely that this will be legally persuasive that the correct procedures were followed and ultimately the appropriate decision was made."

Design documentation and exceptions are discussed in Chapter 2, *Design Controls*. Details pertaining to documentation and the process of design exceptions are outlined in Publication 10X, Design Manual Part 1X (DM-1X), Appendix P, *Design Exceptions.*

Chapter 2 – Design Controls

In this chapter there are references to future chapters 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 2 – Design Controls

2.0 – Introduction

Design controls are physical and operational characteristics that guide the selection of design elements for designing transportation corridors. Some design controls, such as terrain, are fixed; however, most design controls can be influenced in some way through the design process. The designer accomplishes this by establishing a basis for selecting criteria, geometric design elements, and dimensions.

This chapter provides guidance on the selection of design controls to accommodate the physical, operational, and multimodal characteristics.

Design controls include:

- Roadway context and typology
- Design speed
- Design vehicle
- Traffic characteristics
- Modal considerations

2.0.1 – Resources and References

- National Cooperative Highway Research Program (NCHRP), Report 616: *Multimodal Level of Service Analysis for Urban Streets,* 2008.

2.1 – Roadway Context and Typology

Context and typology make up the organizing framework for the selection of appropriate values for design controls. As described in Chapter 1, *Context Based Design and Flexibility,* context is a land area comprising combinations of different land uses, architecture, building density, topography, and natural features. The context used to develop transportation projects should be compatible with a land use plan that reflects a community vision, or the existing land use if a community vision has not been developed.

Context and typology can directly affect:

- Number of lanes
- Lane/facility types
- Lane width
- Shoulder width
- Grades
- Design speeds

To determine context, whether considering a community vision or existing condition, the designer should consider three primary factors:

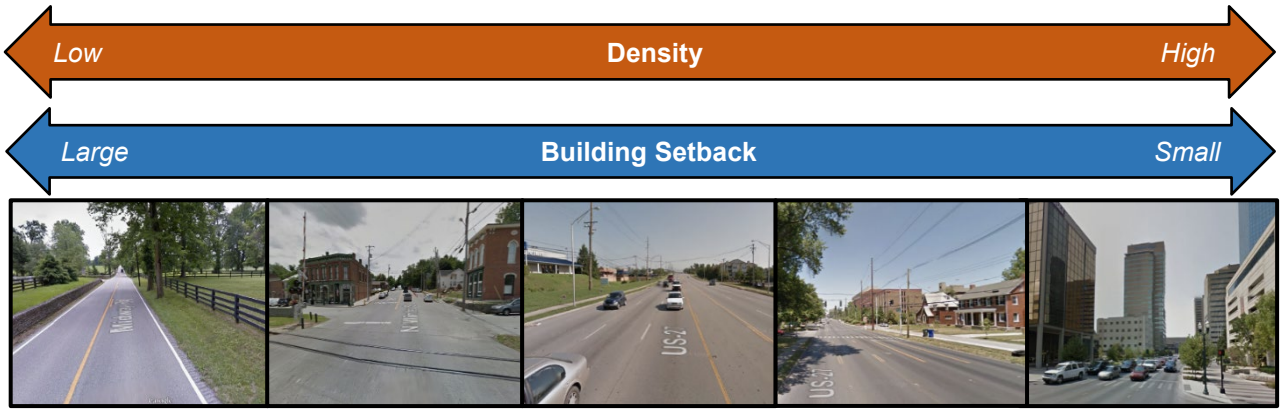
- Density (existence of structures and structure types)

- Land uses (primarily residential, commercial, industrial, forested and/or agricultural)
- Building setbacks (distance of structures to adjacent roadways)

These factors are identified by observing the landscape adjacent to an existing or planned roadway. Additionally, **Exhibit 2.1.1** provides context characteristics to assist in identifying appropriate project area context. Note that it is possible for a project to include more than one context based on its location. Transitions between typologies are also important.

Exhibit 2.1.1 – Context Characteristics

Rural	Rural Town	Suburban	Urban	Urban Core
• Lowest density • Uses include agriculture and natural resources with some residential or commercial • Usually large setbacks	• Higher density relative to Rural • Primarily commercial and residential uses along a main street • On-street parking and sidewalks with small setbacks	• Medium density • Mixed residential neighborhood and commercial clusters • Varied setbacks with some sidewalks	• High density • Mixed residential and commercial uses with high traffic volume destinations • Some on-street parking and sidewalks with mixed setbacks	• Highest density • Mixed uses within and among predominantly high-rise structures • Small setbacks with sidewalks and pedestrian plazas



Understanding the land use context provides guidance on who will use the road and how. This leads to typology identification, which encompasses how different transportation modes interact in different settings, to influence the roadway's geometric design and features required within the right-of-way. Depending on the topology, the roadway could include bicycle facilities, pedestrian facilities, multiple travel lanes, center left turn lanes, and other features.

Design teams use roadway typology to capture the role of the roadway within the community. Typology focuses on the characteristics of access, mobility, and speed. For example, if a segment of a functionally classified arterial roadway has a relatively low speed, is important to

community access, and has a lower average trip length, it should probably not be designed like a regional arterial. Further, under this approach, roadway designs are segmented to match changes in topology.

Chapter 1, *Context Based Design and Flexibility,* provides more detail pertaining to context.

2.1.1 – Relationship to the FHWA Functional Classification System

The functional classification system developed by the FHWA and applied to all roadways in the United States remains a key element of system planning. This system helps to ensure that a safe and efficient transportation network, providing the desired level of regional connectivity and land access, is developed and maintained.

FHWA functional classifications include:

- Urban and rural interstates
- Principal and minor arterials
- Major and minor collectors
- Local roads

This FHWA classification often serves as a useful starting point but should not be relied upon as a design control. The designer should select the roadway typology that reflects the actual role that the roadway plays in the transportation system. For example, a roadway may serve a high number of regional trips but may pass through a portion of town with frequent driveways, close intersection spacing, and high levels of pedestrian activity. In this case, the roadway has components of both an arterial and a local road. The designer will need to decide the appropriate design control for this roadway considering both classifications.

The designer should work closely with the community to determine the roadway characteristics and appropriate design considerations to serve both the regional purpose of the roadway and its role in the local setting. Knowledgeable local stakeholders that could aid in this determination could include municipal staff, municipal engineer, county and/or regional planning agency.

As stated in the Green Book, Section 1.4.3.1, *Definitions Of Urban And Rural Areas*.

> "… *it is important to recognize that a roadway's formal classification as urban or rural may differ from actual site circumstances or prevailing conditions. For this reason, it is important for the designer, working with the community and project reviewers, to determine an appropriate area type or types for a project early in the planning process. The area type classification should be based on actual roadway conditions, not boundaries shown on maps. Thus, the area type classification (urban or rural) used in design may differ from that used in the roadway's formal functional classification."*

2.2 – Design Speed Selection

AASHTO defines design speed as follows:

> *Design speed is a selected speed used to determine the various geometric features of the roadway. The selected design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway.*

Using this definition, it follows that many design elements are dictated by the design speed. The design elements should reinforce the appropriate operating speed as discussed in Section 2.2.1.

Design speed can directly affect these design elements:

- Horizontal curves
- Vertical grade
- Stopping sight distance
- Superelevation
- Widening on curves

2.2.1 – Operating Speed and its Relation to Design Speed

Operating speed is the measured speed at which drivers are observed operating their vehicles in a typical free-flow environment. Operating speeds are usually reported using percentile speeds; the 85th percentile speed is often used to characterize the operating speed on a roadway. The *Manual of Traffic Control Devices* (MUTCD) states that when a speed limit within a speed zone is posted, it should be within 5 mph of the 85th-percentile speed of free-flowing traffic.

The operating speed should be consistent with the level of multimodal activity generated by adjacent land uses, to provide both mobility for motor vehicles and a comfortable environment for pedestrians, bicyclists, and public transit users. In most cases, the operating speed should equal the posted speed limit. The designer should select design elements, consistent with the design speed, that encourage the operating speed to equal the design speed. Significant differences between posted speeds and the operational speed dictated by the design will lead to driver confusion and, potentially, unsafe operation.

The roadway's features, such as curves and topography, width, access to adjacent properties, presence of pedestrians and bicyclists, parking, traffic control devices, and lighting, affect the operating speed. During peak periods, when traffic congestion or intersection operations are controlling movement along a corridor, observed operating speeds may be substantially lower than the operating speed measured during off-peak conditions (when the roadway's design and context are controlling speed). The designer should try to obtain the existing operating speed for a roadway and consider its value when determining the design speed for a project.

2.2.2 – Considerations when Selecting Design Speed

When developing a transportation project, the designer should select design speeds that are consistent with the road function as perceived by the driver. Designing transportation facilities to achieve greater congruity between driver perceptions of appropriate operating speeds and visual cues provided by the road (e.g., narrowing lanes) lends itself to conformity with context and typology.

Considerations for selecting the appropriate design speed include operating speed as discussed in Section 2.2.1, functional classification, context and typology, regulatory speed limit posting, and Pennsylvania statutory speed limits.

2.2.2.a – Functional Classification

For every established functional classification of a roadway, there is a suggested range of design speeds. **Exhibit 2.2.1** illustrates the range of design speeds for general functional classifications. Note that 50 mph is the required minimum interstate design speed.

Exhibit 2.2.1 – Design Speed Ranges by Functional Classifications

Functional Classification	25 mph	30 mph	35 mph	40 mph	45 mph	50 mph	55 mph	60 mph	65 mph	70 mph	75 mph
Interstate/ Freeway/ Expressway						X	X	X	X	X	X
Arterial	X	X	X	X	X	X	X	X			
Collector	X	X	X	X	X	X	X				
Local Road	X	X	X	X	X	X	X				

Higher functionally classified roadways warrant higher design speeds. This is due to the relationship between mobility and functional classification. However, designers should consider functional classification only as a starting point in determining design speed. Once the design speed range is established, the designer should consider the context, terrain, posted speed limit and anticipated operating speed to select the appropriate design speed.

2.2.2.b – Context and Typology

Context and typology influence design speed selection, and land use context should play a large role in determining the desired operating speed. For example, pedestrian travel and the presence of public uses and retail close to a street all suggest the need to use the lower range of the desired operating speed and, thus, an appropriately related design speed.

The selected design speed should be consistent with speeds that drivers are likely to expect on a given highway facility. Roadway geometry and cross-sectional elements, in combination with the land use context, establish a driving environment where drivers choose speeds that feel reasonable and comfortable. Where a reason for limiting speed is obvious, drivers are more apt to accept lower speed operation than where there is no apparent reason.

An arterial or higher functional classification often have higher design speed than a lesser classified facility in similar topography.

A low design speed should not be selected where the drivers are likely to travel at higher operating speeds. Drivers do not adjust their speeds to the typology of the highway but to their perception of the physical limitations of the highway and its traffic.

Design Factors that Influence Speed

Establishing a design speed that is artificially low relative to the context of the corridor will only result in operating speeds that are higher than desired for the design elements and difficult to enforce. The roadway design should start with the selection of an appropriate design speed, which is then applied to geometric design elements.

However, the following design factors can contribute to speed reduction and may be considered in rural town through urban core projects:

- Using narrower travel lanes
- Using physical measures to narrow the roadway
- Using on-street parking to create side friction
- Eliminating superelevation
- Eliminating shoulders (except for bicycle lanes)
- Using smaller curb radii
- Eliminating channelized right-turn lanes
- Using paving materials with texture

For urban street design, design speeds may fall between 25 mph and 35 mph on many streets. The designer may consider many of the elements of urban street design to support lower design speeds and naturally encourage slower speeds. Refer to Chapter 18, *Traffic Calming,* for more information.

In selecting design speed, with full recognition of the context of the project, potential tradeoffs should be considered with respect to the role of vehicle speed and:

- Crash severity. An increase in operating speed may result in higher crash severity (e.g., higher percentages of injury and fatality crashes and more serious property damage).

- Sight distance. An increase in design speed requires larger geometric design values for minimum intersection sight distance, minimum sight distance on horizontal and vertical curves, horizontal curvature (radii), and vertical curvature (length of crest and sag vertical curves).
- Lane widths. Wider lane widths are typically associated with higher speed roadways such as freeways, arterials in suburban areas, and two-lane rural arterial and collector highways. In urban areas and along rural routes that pass-through town settings, narrower lane widths may be appropriate, as space is limited and lower speeds desired.
- Design of separated facilities. When locating bicycle facilities on higher speed or higher volume facilities, the separation afforded by separated bike lanes may provide increased comfort and safety.
- Community residents' willingness to bicycle and walk on the facility. Roadways with relatively high volume and high-speed motor vehicle traffic may discourage many bicyclists and pedestrians from using the facility (e.g., walking or biking on the shoulder adjacent to motor vehicle traffic in the travel lanes). In contrast, lower speed motor vehicle traffic may encourage more bicycle and pedestrian traffic.

A link to illustrated examples of Roadway Typologies can be accessed by contacting PennDOT's Highway Design and Technology Division (HDTD).

2.2.2.c – Regulatory Speed Limit Posting

Design speed shall not be less than the posted regulatory speed. Note that advisory speeds are not regulatory speeds.

On expressways, freeways, and interstate facilities, it is recommended that the design speed is at least 5 mph greater than the posted speed limit. On all other facilities, the selected design speed must be equal to the posted regulatory speed limit, but it may be greater if the context and expected operating speeds justifies a higher design speed. In general, it is appropriate to establish the design speed equal to the existing posted speed limit if transportation corridors' context is not in conflict, the vision of the corridor is consistent with the posting, and the existing posted speed is within an acceptable range of the operating speed.

The design of the geometric features of the roadway should be consistent with the established design speed. The post construction posted speed limit should reflect the established design speed.

The following situations may use a design speed lower than the regulatory posted speed:

- Roundabout intersections including their approaches
- Stop or yield controlled intersections including their approaches
- Diverging diamond interchange crossover roadways

The MUTCD recommends setting the posted speed limits near the 85th percentile speed. This is the speed at which 85% of all vehicles are observed to travel under free-flowing conditions past a monitored point. A speed study must be done in order to determine what the 85th percentile speed is. Engineering judgement should be used to determine if the speed limit should be adjusted from the 85th percentile.

2.2.2.d – Pennsylvania Statutory Speed Limits

Title 75, Vehicle Code § 3362 establishes maximum lawful speeds limits.

- 35 mph in urban districts
- 65 mph or 70 mph on freeways (as posted).
- 25 mph on non-numbered roads in residence districts classified as local roadways. Note that not all locally owned roads bear this classification. Numbered traffic routes refer to interstate routes, US routes, and Pennsylvania routes.
- 55 mph in other locations

If a roadway does not have a posted regulatory speed limit, a 55-mph speed limit applies, except for the following:

- 35 mph in urban districts.
- 25 mph on non-numbered roads in residence districts which have the "local" roadway classification. Note that locally owned roads may not all have a "local" functional classification. Numbered traffic routes refer to Interstate routes, US routes and PA routes.

Title 75, Section 102 defines the following terms:

- **Residence district** – The territory contiguous to and including a highway not comprising a business district when the property on the highway for a distance of 300 feet or more is mainly improved with residences or residences and buildings in use for business.
- **Urban district** – The territory contiguous to and including any street which is built up with structures devoted to business, industry, or dwelling houses situated at intervals of less than 100 feet for a distance of a quarter of a mile or more.

For further clarification on “residence district” and “urban district,” refer to Publication 46, *Traffic Engineering Manual* and the Pennsylvania Vehicle Code.

2.3 – Design Vehicle and Control Vehicle Selection

The term “design vehicle” traditionally refers to the largest vehicle that uses a street with considerable frequency. It is used to establish specific geometric and performance features. Since a design vehicle influences the proposed geometry and design elements, selecting the appropriate design vehicle is critical to effectively developing a multimodal transportation corridor.

A design vehicle can directly affect these design elements:

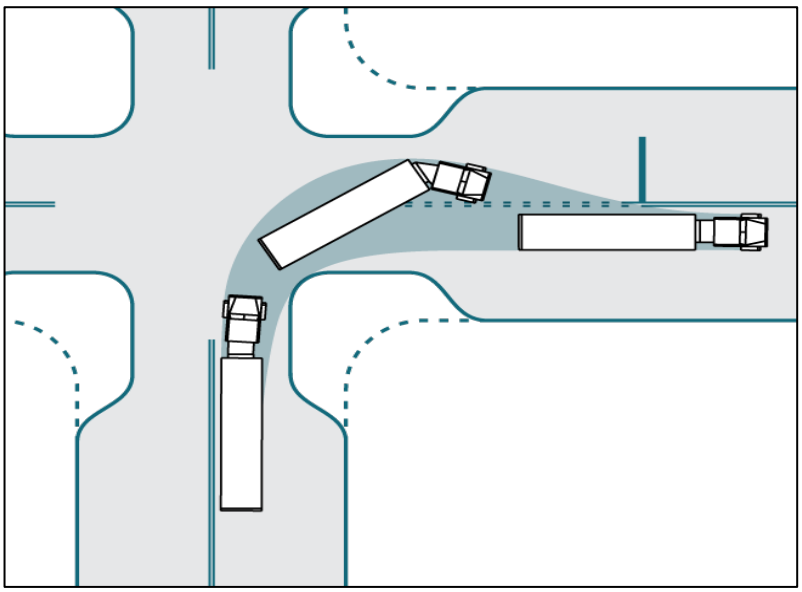
- Curb radii
- Lane width
- Intersection layout
- Pedestrian facilities
- Widening on curves
- Pavement design

Selecting the appropriate design vehicle involves evaluating traffic engineering, safety, land use, livability, and sustainability impacts, including evaluation of the tradeoffs of using one design vehicle over another.

When examining a particular corridor or intersection approach, consider the following two types of vehicles:

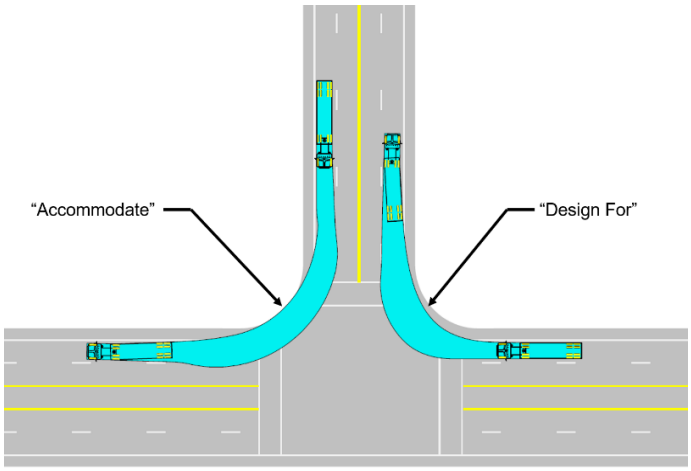
- **Design vehicle** – A vehicle that must be regularly accommodated without encroachment into the opposing traffic lanes or into the street side.
- **Control vehicle** – A vehicle that uses a facility infrequently but must be accommodated. When using a control vehicle, encroachment into the opposing traffic lanes, multiple-point turns, or minor encroachment into the street side is acceptable as illustrated in **Exhibit 2.3.1**. These two types of vehicles are typically considered in rural towns and urban cores, where walkability becomes a greater design consideration. In these areas, it is not desirable to choose the largest vehicle that occasionally uses the facility.

Exhibit 2.3.1 – Control Vehicle



(Source: Urban Street Design Guide, National Association of City Transportation Officials)

Exhibit 2.3.2 – "Design for" Versus "Accommodate"



The designer should understand the difference between "design for" versus "accommodate" when designing a project. Both "design for" and "accommodate" have their place to enable safe mobility for all people traveling. Accommodating for a vehicle allows encroachment into other lanes (potentially including opposing travel lanes) or other elements to complete the required maneuver. Designing for a vehicle does not require encroachment onto any of those elements. Typically, an intersection turn movement is considered "accommodated for" if the design vehicle is allowed to encroach on shoulders, roundabout aprons, and the lane adjacent to the typical receiving lane for the turn movement (far right lane for a single right turn lane), provided that encroachment is not into opposing traffic. This distinction is depicted in **Exhibit 2.3.2.**

Typically, the Design Vehicle is "designed for" while both the Design Vehicle and the Control Vehicle are "accommodated".

2.3.1 – Considerations for Selecting a Design and Control Vehicle

In selecting the appropriate design vehicle, the designer should consider:

- The largest vehicle that is likely to use that facility with considerable frequency.
- The vehicle appropriate to a particular intersection approach (as individual intersection approaches can have different design vehicles).
- The appropriate control vehicle for the facility and intersection approaches.

Exhibit 2.3.4 provides circumstances for selecting a design vehicle.

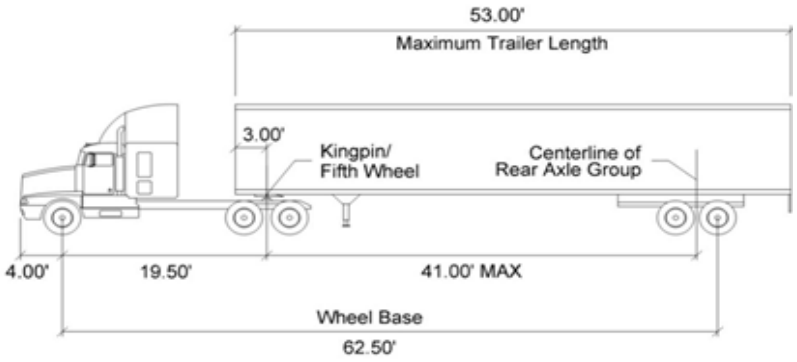
Fire trucks, garbage trucks, school buses, and snowplows frequently use lower classification roadways and should at least be accommodated.

Exhibit 2.3.4 – Circumstances for Selecting a Design Vehicle

Design Vehicle	Circumstance for Selecting a Design Vehicle
Passenger car (P)	Use when the main traffic generator is a parking lot or series of parking lots. In cases of a single lane entry/exit, ensure that snowplows are accommodated.
Two-axle single-unit truck (SU-30)	Use for roadways or intersections for non-State Routes of residential streets and park roads where larger trucks are not expected.
Three-axle single-unit truck (SU-40)	Use for non-State Route roadways or intersections classified as Local or Collector where larger trucks are not expected.
Intermediate semitrailer (WB-40)	Use for non-State Route roadways and intersections where larger trucks are not expected.
City transit bus (CITY BUS)	Use for State Route intersections with city streets that are designated bus routes and that have relatively few large trucks using them. Use for park-and-rides to accommodate a bus.
Interstate semitrailers (WB-62 with 53T)	Use for turning movements at State Route intersections where a WB-67 or City Bus are not appropriate.
Interstate semitrailers (WB-67)	Must be used for Interstates, associated interchanges, and ramp terminals. Preferred for Freeways and Expressways, associated interchanges, and ramp terminals. Also preferred for crossroads and adjacent roadways within one mile of ramp terminals. Use for non-state routes that carry significant truck volumes or provide local access for trucks as determined by the designer.

Exhibit 2.3.5 shows the dimensions of the WB-62 with 53T. It is essentially a WB-62 with a 53-ft trailer instead of a 48-ft trailer while maintaining the same wheelbase of 62.50-ft.

Exhibit 2.3.5 Dimensions of a WB-62 with a 53 Foot Trailer (WB-62 with 53T)



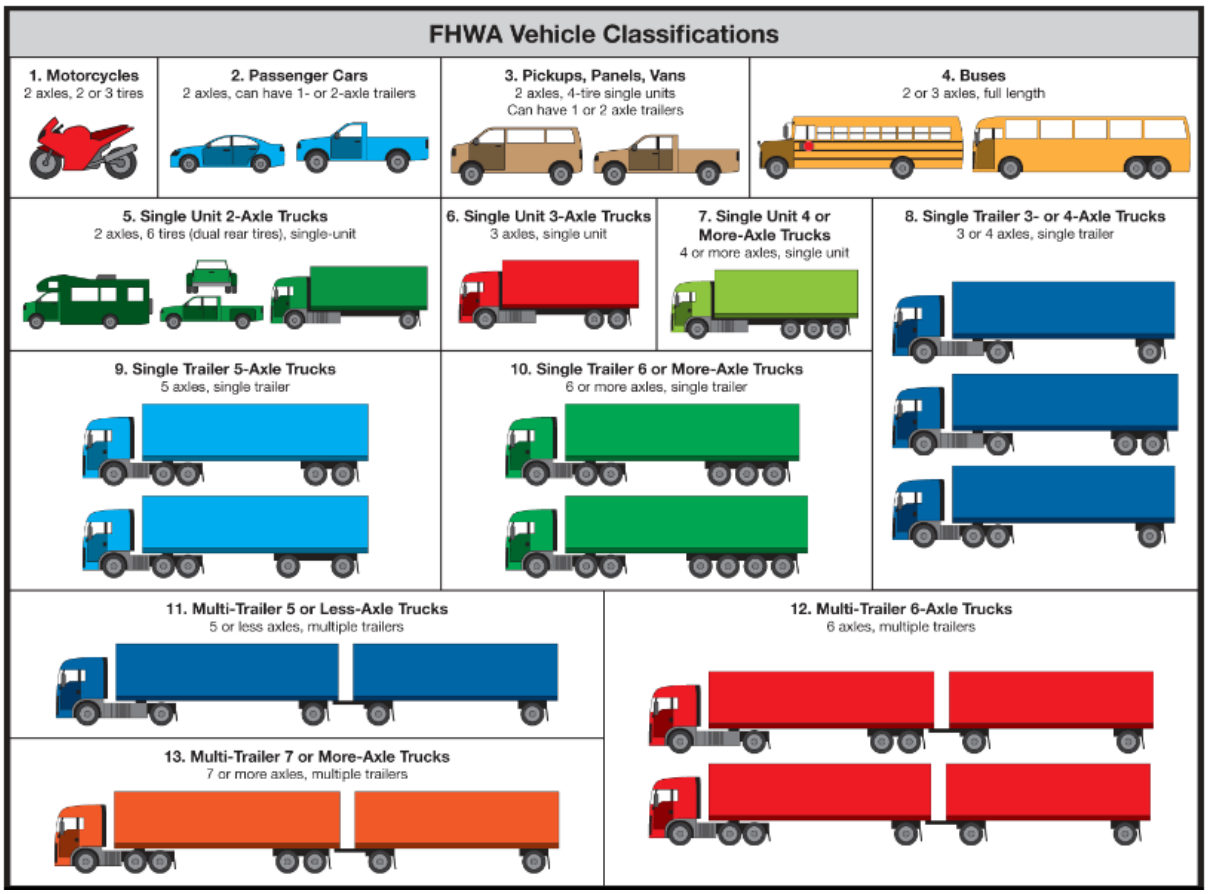
The Green Book, Chapter 2, provides information for AASHTO's motorized vehicles and considerations for selecting a design vehicle.

2.3.2 – Vehicle Classifications

The vehicle classifications categorize vehicles by whether the vehicle carries passengers or commodities. Non-passenger vehicles are further categorized by the number of axles and the number of units, including both power and trailer units. The addition of a trailer to vehicle classes 1 to 5 does not change the classification of the vehicle. Typically, FHWA defines heavy vehicles as any vehicle with more than four tires (classifications 4 through 13).

Pennsylvania uses the FHWA recommended 13 vehicle classifications, presented in **Exhibit 2.3.6**.

Exhibit 2.3.6 – FHWA 13 Vehicle Classifications



(Source: FHWA)

Exhibit 2.3.7 – Green Book References for Vehicle Characteristics

Green Book Reference	Description
Table 2-1b	Design Vehicle Dimensions
Figures 2-1 through 2-9 Figures 2-12 through 2-23	Minimum Turning Paths for Design Vehicles
Table 2-2b	Minimum Turning Radii of Design Vehicles

Refer to Section 2.5.5 for more information on trucks and freight.

2.3.3 – Non-Motorized Traffic

There may be contexts where the appropriate design vehicle is the non-motorized traveler. For example, bicycle facilities, such as shared use paths and bike lanes, are typically designed and built to accommodate bicycles, a non-motorized design vehicle as described in Chapter 14, *Bicycle Facilities*. Additionally, pedestrian traffic is non-motorized, with facilities needed to accommodate pedestrians as deemed appropriate. Horse-drawn vehicles may also need consideration in certain parts of Pennsylvania see Chapter 17, *Plain People Community Considerations*.

2.4 – Traffic Characteristics

Understanding how, when, and why people are using a specific roadway corridor is critical in developing a project. If any of these components are misrepresented, the design parameters can be drastically different, resulting in a project that does not meet customer needs.

Traffic volumes (all modes) and composition represent the user demands for a roadway. Users include motor vehicles, pedestrians, bicyclists, and transit users, each with demands that must be addressed. Additionally, a roadway's demands and activities will change over a 24-hour period, during weekdays and weekends, seasonally, and yearly. While design parameters usually concentrate on the peak periods of traffic, it is also important to understand the impact of all periods on users.

Traffic characteristics can directly affect these design elements:

- Number of lanes
- Lane/facility types
- Shoulder width

This section discusses traffic design controls including:

- Traffic composition
- Design year traffic volumes
- Operational characteristics

2.4.1 – Traffic Composition

In designing a facility, proper sizing of roadway elements, such as number of lanes, width of lanes, curb radii, length of turn lanes, and traffic signal timing, requires an accurate estimation of the total traffic volume and vehicle mix that will use the facility. Additionally, the traffic composition is required for operational analyses, bridge fatigue design, and pavement design.

To determine the vehicle mix of a facility, vehicle classification data should be collected in the field. A more thorough breakdown of vehicle types may be desired, as opposed to bundling all heavy vehicles together. Where data collection is not feasible or needed, Roadway Management System (RMS) data may permit an estimation of expected heavy vehicle traffic

that may use a facility. Heavy vehicle traffic is based off of the Federal Highway Administration (FHWA) classes 4-12, see Section 2.3.2. The heavy vehicle traffic volume is also called the truck volume and is defined as vehicles that fall into FHWA classes four through twelve.

An evaluation of existing and proposed land use should be completed in determining the proposed traffic volumes, as large open parcels with access to regional roadways often make attractive locations for the development of distribution centers or major shopping centers.

2.4.2 – Design Year Traffic Volumes

A design project typically incorporates several different traffic volumes, including existing traffic volumes, opening year traffic volumes, average daily traffic volumes, and design year and hourly volumes. These values are usually based on field studies. The values are then projected to opening and design year information through extrapolation of historical traffic data or the use of travel demand forecasting, depending on the project's complexity or risk parameters.

2.4.2.a – Determining the Design Year

The design of new highways or improvements to existing highways should consider both current and future traffic volumes (i.e., design volume). A period of 20 years beyond completion of construction (i.e., opening year) should serve as the basis for design of New Construction and Reconstruction projects. For more information on these types of projects see Chapter 3, *New Construction and Reconstruction Change in Road Type* and the reconstruction section of Chapter 4, *Reconstruction No Change in Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects*.

For 3R, and pavement preservation projects, estimating traffic volumes for a 20-year design period is usually not appropriate because of the shorter design life of these improvements. For 3R projects, a minimum 8-year design life is required. No minimum design year is recommended for Pavement Preservation. See Chapter 4, for more information on 3R and Pavement Preservation projects. Note that the project design year may not be the same as the pavement design year provided in Publication 242, *Pavement Policy Manual*.

For determining the design year of bridge projects, refer to Chapter 5, *Bridges and Tunnels*.

2.4.2.b – Projecting Traffic to the Design Year

Current traffic forecasting methods range from time series methods (in which future traffic volumes are estimated by extrapolating from historical data) to complex network models that predict demand over a multimodal transportation system (by modeling trip choices of individuals or groups of travelers).

For portions of Pennsylvania without a model (and if the project itself does not warrant development of its own model), forecasts are normally based on historical traffic volume trends.

Growth rates may also be developed using gasoline consumption reports and census data, and by working with counties or municipalities and their comprehensive plans. Normally, linear growth is assumed.

When historical Average Annual Daily Traffic (AADT) data is used, linear regression is calculated using the most recent ten years of data, when available. Special care should be taken to negate counts that might be obviously "out-of-sync" with other years. The designer can also use information presented in the most recent Pennsylvania Traffic Data Report for factors to develop projections if local data is not available.

Travel demand modeling involves forecasting future transportation conditions, based on anticipated supply and demand for transportation services. The technique can assist in evaluating changes in land use, demographics, public transportation services, and roadway capacity. Typical applications at the regional level include evaluating candidate projects for the Long Range Plan, the Transportation Improvement Program (TIP) and air quality conformity analyses. Sub-area or small-area analyses can be applied with enhanced detail to evaluate a wide range of transportation projects (including new streets, road extensions, road diets, changes in public transportation, and impact analyses of new land use development). Some of Pennsylvania's Metropolitan Planning Organizations (MPOs) and Rural Planning Organizations (RPOs) have travel demand forecasting models that can be enhanced to create a sub-area network appropriate for specific projects.

2.4.2.c – Calculating Design Traffic Volumes

The following provides guidance for the collection of traffic data, use of Annual Average Daily Traffic, Average Daily Traffic, and the calculation of basic traffic design values such as Design Hourly Volumes and Directional Design Hourly Volumes.

2.4.2.c.i – Average Daily Traffic and Annual Average Daily Traffic

Average Daily Traffic (ADT) is the volume that results from dividing a traffic count obtained during a given period by the number of days in that period. For example, given a traffic count of 52,800 vehicles taken over a continuous period of 30 days, the ADT equals 1,760 vehicles (52,800 divided by 30).

Another commonly used measure of traffic volume is the Annual Average Daily Traffic (AADT), which is determined by dividing a count of the total yearly traffic volume by 365. Current year traffic volume estimate values for AADT are produced annually by PennDOT's RMS. The ADT and the AADT are not the same, and it is important to be aware of the period when calculating the ADT.

ADT should not be used for geometric design due to natural weekly, monthly, and seasonal variations in traffic. The Pennsylvania Traffic Data Report provides procedures to adjust for these variations to estimate the AADT, which can then be used to develop design traffic volumes.

2.4.2.c.ii – Design Hourly Volume

The peaking characteristics associated with the design hour play a significant role in design elements determined by traffic volumes. Since traffic volumes vary considerably during different hours of the day, and traffic volumes during any particular hour may vary from day-to-day throughout the year, it is important to understand how this fluctuation will affect design.

This fluctuation is stabilized through the calculation of the Design Hourly Volume (DHV), which is the number of vehicles that travel through a segment of roadway during the design hour. DHV is the volume unit used for making roadway structural and capacity design decisions.

Since using the highest hourly volume in an entire year's worth of volume data might result in over design, the DHV is usually considered the 30th highest hourly volume from a year's worth of data projected out to the design year. The formula for calculating the design hour volume is:

$$DHV_{Design\ Year} = AADT_{Design\ Year} \times K$$

The K-factor represents the proportion of traffic occurring during the 30th highest hour of the year. Values for K typically range from 8 to 12 percent for urban facilities and 10 to 18 percent for rural facilities. If an actual K-factor is not available, an estimated K-factor is calculated from the ADT by dividing the p.m. peak hour volume by the total 24-hour volume. Similar factors can be developed for analysis of other peak periods.

The highway facility should be able to accommodate the DHV (adjusted for the peak-hour factor) at a selected level of service. The DHV can affect many design elements, including the number of through-travel lanes and intersection geometrics. The designer should also analyze the proposed design using a.m., p.m., and other peak hour DHVs separately, as each peak period could have an impact on the geometric design of the transportation facility (due to different travel characteristics during different times of the day).

It is important to balance the desire to provide an adequate level of service (see Section 2.4.3.b) for the peak hour traffic volume with a design in which the highway capacity would only be affected for a few hours of the year.

2.4.2.c.iii – Directional Design Hour Volume

Directional Design Hour Volume (DDHV) is the one-way volume in the predominant direction of travel in the design hour, expressed as a percentage of the two-way DHV. The directional distribution factor (D) ranges from 50 to 80 percent.

Directional distribution can change during the day. For example, traffic volume heading into a central business district is usually higher than outbound traffic in the morning, but the reverse is true during the afternoon peak hour.

$$DDHV_{\ DESIGN\ YEAR} = AADT_{\ DESIGN\ YEAR} * K * D$$

2.4.2.c.iv – Truck Volume, Truck Percentage and Truck DDHV

The truck volume as determined in Section 2.4.1 is divided by total traffic volume to determine the truck percentage. Typically truck percentage is calculated on an annual basis using AADT.

The DDHV, as determined in Section 2.4.2.c.iii, is multiplied by the truck percentage to determine the Truck DDHV.

Refer to Section 2.5.5 and Chapter 16, *Freight,* for more information on trucks and freight.

2.4.3 – Operational Characteristics

There are many ways to measure the operation and performance of a transportation facility or service, and many points of view to consider in deciding which measurements to make. Automobile drivers, pedestrians, bicyclists, bus passengers, decision makers, and the community at large all have perspectives on how a roadway or service should perform and what constitutes "good" performance.

The Transportation Research Board's *Highway Capacity Manual*, Chapter 5*, Quality and Level-of-Service Concepts* (HCM), describes performance from the traveler's point of view. The discussion that follows provides an overview of quality of service, level of service, and service measures that can be used on a project, depending on the nature of the needs addressed.

2.4.3.a – Quality of Service

Quality of service describes how a transportation facility or service operates from a traveler's perspective**.** Factors that influence traveler-perceived quality of service include:

- Travel time, speed, and delay
- Number of stops incurred
- Travel time reliability
- Maneuverability (e.g., ease of lane changing, percent time spent following other vehicles)
- Comfort (e.g., bicycle and pedestrian interaction with and separation from traffic, transit vehicle crowding, ride comfort)
- Convenience (e.g., directness of route, frequency of transit service)
- Safety (actual or perceived)
- User cost
- Availability of facilities and services
- Facility aesthetics
- Information availability (e.g., highway wayfinding signage, transit route and schedule information)

HCM also identifies a variety of performance measures that assess the quality of service of a transportation facility of service.

2.4.3.b – Level of Service

Level of service (LOS) is a quantitative measure of operating conditions within a traffic stream and its perception by motorists and passengers. HCM defines six levels of service, ranging from A (best operating conditions) to F (worst operating conditions), for each service measure. Typical measures of effectiveness include speed, travel time, density, and delay.

2.4.3.c – Service Measures

Service measures are performance measures used to define Quality of Service and LOS for transportation systems. Ideally, service measures should:

- Reflect travelers' perceptions (i.e., things travelers can perceive during their journey).
- Be useful to operating agencies (i.e., agency actions should be able to influence future LOS).
- Be directly measurable in the field (i.e., an analyst seeking to determine LOS for a two-lane highway used for recreational access can go into the field and directly measure average travel speed).
- Be estimable given known or forecast conditions (i.e., ability to estimate the average travel speed for a two-lane highway, given inputs for roadway and traffic conditions).

The *Highway Capacity Manual* provides guidance about service measures with issues crosscutting all modes and for modes within specific system configurations.

2.4.3.d – Using Quality of Service, LOS, and Service Measure Metrics to Develop a Project

Performance indicators, such as quality of service, LOS, and service measures, provide the mechanism by which transportation facility designers can measure critical success factors.

Traditionally, PennDOT uses LOS C for rural areas and LOS D for urban areas as its measure for acceptable roadway operations. These measures should continue to be a guide for facilities. However, densely populated urban areas with existing poor LOS may find that a delay metric is more useful. Design LOS or delay metrics should be determined in consultation with the District Traffic Engineer, central office and FHWA, if federal oversight applies.

Desirable LOS

PennDOT uses LOS C for rural areas and LOS D for urban areas as its measure for acceptable roadway operations. These measures should be used as a guide.

For transportation facilities where context is the driving force for design, multimodal considerations have changed the LOS evaluation to consider

person capacity for a corridor rather than just vehicle capacity. This results in the need to consider multiple metrics in determining acceptable operations rather than a single LOS.

2.4.3.e – Capacity

The HCM defines capacity as the maximum sustainable hourly flow rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic and control conditions. HCM is a basic reference for determining capacity for various types of highways, as well as capacities pertaining to pedestrians, bicycles, transit, and transit passengers.

Vehicle capacity is the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control conditions. This assumes that there is no influence from downstream traffic operation, such as queues backing into the analysis point.

Person capacity is the maximum number of persons that can pass a given point during a specified period under prevailing conditions. Person capacity is commonly used to evaluate public transit services, and general pedestrian facilities.

Persons per hour, passenger cars per hour, and vehicles per hour are measures that define capacity, depending on the type of system element and type of analysis. The concept of person flow is important in making strategic decisions about transportation modes in heavily traveled corridors and in defining the role of transit and high occupancy-vehicle priority treatments. Person capacity and person flow weigh each type of vehicle in the traffic stream by the number of occupants carried.

NCHRP Report 616, *Multimodal Level of Service Analysis for Urban Streets*, provides a method for assessing how well an urban street serves the needs of all its users. This Multimodal Level of Service (MMLOS) aids in evaluating “complete streets” and context-sensitive solutions from the perspective of all users. The designer can use the MMLOS method to evaluate the tradeoffs of various street designs in terms of their effects on the perceptions of auto drivers, transit passengers, bicyclists, and pedestrians about the quality of service provided by the street.

2.4.3.f – Performance Metrics

Not all state routes are the same. Not all communities are the same. Not all modes are the same. Therefore, the performance metrics used for motor vehicle traffic are not necessarily applicable to pedestrian, bike, or transit modes. For these reasons, it is important to consider communities’, and partnering agencies’ views regarding which performance metrics are relevant to them and the context.

Ideally, the selection of metrics results from planning and is refined later during the design phase. Planning documents (such as corridor sketch plans) may include input from partners and stakeholders about which performance metrics may be useful in understanding the project needs. However, not all programmed projects will have identified performance metrics in the

design phase. Therefore, performance metrics should be discussed and identified during project scoping and in conjunction with risk assessment.

Exhibit 2.4.1 provides a potential starting point from which to identify metrics as they relate to mobility, safety, and economic vitality. This list is not all-inclusive and may be used in conjunction with the Measures of Effectiveness for Alternatives Analysis, which is provided in Publication 10C, Design Manual Part 1C (DM-1C), *Transportation Engineering Procedures*, Chapter 3, Section 3.4.E. Other metric topics that should be considered (as appropriate) include infrastructure condition, congestion reduction, system reliability, freight movement, environmental sustainability, and reduced project delivery delays.

Exhibit 2.4.1 – Example Performance Metrics for Projects

Performance Category	Mode	Metric	Unit of Measurement	Comments/Applicability
Mobility	Auto, Freight, and Transit	LOS	A, B, C, D, E, F	Consider when evaluating the motor vehicle modes and when a corridor is or will experience congestion
		Delay	Seconds/Vehicle	Consider at intersections, roundabouts, and street networks
		Travel Time	Integer value (minutes or minutes/mile)	Consider this for locations without congestion
		Travel Time Reliability	Integer value (minutes or minutes/mile)	Consider when evaluating a routinely congested corridor
		Volume to Capacity Ratio	Ratio or percentage	Consider when only evaluating motor vehicle modes
	Transit	Transit Seats Occupied	Ratio or percentage	Consider when transit is identified as a modal priority, and/or the baseline need is directly associated with transit
		P&R Spaces Occupied	Ratio or percentage	Consider when transit is identified as a modal priority
	Bicycle	Miles of Continuous Roadway Bike Facilities and Shared Facilities	Integer value (miles)	Consider when the bicycle mode is identified as a modal priority
		Number/Size of Gaps Bike Facility Network	Integer value (feet, miles, block length)	Consider when the bicycle mode is identified as a modal priority
	Pedestrian	Miles of Continuous Pedestrian Facilities and Shared Use Facilities	Integer value (miles)	Consider when the pedestrian mode is identified as a modal priority
		Number/Size of Gaps in Pedestrian Facility Network	Integer value (feet, miles, block length)	Consider when the pedestrian mode is identified as a modal priority
Safety	All	Number of Fatal and Serious Injury Crashes	Integer value	Always apply
		Number of [Mode] Crashes	Integer value	"Mode" means pedestrian, bike, or transit and excludes motorized vehicle only crashes; consider with modally integrated designs
Economic Vitality	Pedestrian and Bicycle	Street-Side Zone Width	Integer value per block length	Context dependent (site design and retail functions associated - typically urban core, traditional main streets
		Number of [Type] Street-Side Amenities	Integer value per block length	Context dependent (site design and retail functions associated) - typically urban core, traditional main streets
	Bicycle and Auto	Number (or Spacing) of Parking Amenities	Integer value per block length	Context dependent (site design and retail functions associated - typically urban core, traditional main streets
	Auto	Land Use Access Connection Density	Integer value per block length	Context dependent - typically suburban strip mall
	Freight	Number of Truck-Related Slow Downs	Integer value	Non-congestion related

Performance management or metrics promote informed decision making by relating community goals to the measurable effects of transportation investments. Key steps in identifying project metrics include deciding what measure to use to capture the current state of the study area system, setting targets to improve those measures, and using the measures to evaluate and compare the effects. Metrics are also used for alternative analysis. See DM-1C, Chapter 3.

Project metrics allow PennDOT to align decisions with established community goals. In most cases, transportation itself is not a goal, but rather a means to achieve other community goals. For example, mobility, referring to the easy movement of people and goods, does not alone achieve important goals. Instead, mobility is an important feature of the transportation system that can foster economic activity by connecting workers to jobs.

Many project metrics relate directly and indirectly to community goals. For example, accessibility is important for economic goals because it helps connect buyers to sellers and supports a community's livability. When developing project metrics, consider how to accommodate and measure the project so that it will:

- Support the economic vitality of the area, especially by enabling global competitiveness, productivity, and efficiency.
- Increase the safety of the transportation system for motorized and non-motorized users.
- Increase the accessibility and mobility of people and freight.
- Protect and enhance the environment, promote energy conservation, improve the quality of life.
- Promote consistency between transportation improvements and planned growth and economic development patterns.
- Enhance the integration and connectivity of the transportation system, across and between modes, for people and freight.
- Promote efficient system management and operation.
- Emphasize the preservation of the existing transportation system for efficiency.
- Improve the resiliency and reliability of the transportation system.
- Reduce or mitigate stormwater impacts of surface transportation.
- Enhance travel and tourism.

Once project metrics are identified, whether quantitative or qualitative, local facility users and the project team should agree to them. During project development, these metrics should be used to identify specific project improvements that balance the project development with the community vision.

2.5 – Modal Considerations

Automobile traffic, pedestrian, and bicyclist requirements, as well as transit and freight accommodations, affect the utilization of a corridor's right of way. For example, corridors with high levels of transit stops or pedestrian and bicycle usage require appropriate street side and bicycle lane facilities. As such, freight movement, transit, pedestrian, and bicycle requirements function as design controls that influence decisions for the utilization and prioritization of all elements within the right-of-way.

2.5.1 – Automobiles

Automobiles include passenger-carrying motor vehicles other than buses. Specifically included within the broad category of automobiles are passenger cars, motorcycles, sports utility vehicles, and light trucks (such as pickup trucks). For many roadways, automobiles are the primary mode of travel and transport the largest proportion of road users. In recent years the focus of road design has shifted consistently to consider the needs of all transportation modes including, pedestrians, bicycles, transit, and freight.

2.5.2 – Pedestrian Traffic

The pedestrian mode comprises travelers along a roadway or pedestrian facility making a journey (or at least part of their journey) on foot. Pedestrians walk at different speeds, depending on their age, their ability, and environmental characteristics (e.g., grades and climate). Sidewalks and pathways are often used by more than just foot-based traffic (e.g., inline skaters, bicyclists, persons using wheelchairs).

Designers should consider the following:

- Peak pedestrian volumes tend to (but not always) follow peak motor vehicle volumes. Land use activity areas generating or attracting pedestrian traffic (e.g., transit stops, schools, parks, shopping centers, recreational areas, employment centers, places of worship) can create pedestrian traffic at different times of the day and week.





- Walking speeds decrease as the pedestrian density of the walkway increases. As with roadway capacities, there is an optimum speed and density under which the walkway will carry the largest volumes. The width used for walkway calculations should be reduced where parking meters, hydrants, newsstands, litter barrels, utility poles, benches or similar obstructions preclude the use of the full walkway.
- Walking speeds can change based on pedestrian demographics. For example, areas with a larger elderly population (such as near a senior living complex) will have a lower-than-average walking speed. This might also be a consideration when timing signalized intersections with pedestrian access.



(Source: Peter Lagerwey)

- In areas without sidewalks, the presence of worn paths along the roadway are a clear indication of pedestrian use. Additionally, the presence of pedestrian generators, such as transit stops, schools, parks, shopping centers, recreational areas, employment centers, and places of worship, indicates pedestrian activity.
- Quantifying the amount of pedestrian traffic currently using a facility and that will use an enhanced facility can be more difficult than predicting motor vehicle traffic. For example, pedestrian volumes on a given day are much more sensitive to the weather. In addition, hourly pedestrian volumes at most locations tend to be relatively low, compared to the volumes observed at typical motorized vehicle count sites. Lower volumes also contribute to higher day-to-day variability. In developing pedestrian volume projections, consider the existing pedestrian volume, the context and facility connections, trip generators, and destinations in the area.
- Other factors in the project area that could affect the type of pedestrian users such as visual and physically disabled pedestrians, schools for the disabled, senior centers, and physical rehabilitation centers.
- Designing for large vehicles increases pedestrian crossing distances and increases the turning speed of smaller sized vehicles resulting in outcomes that reduce pedestrian comfort and may be incompatible with the community vision and with the goals and objectives for the throughfare.

Chapter 13, *Pedestrian Facilities,* provides more detail on pedestrian facility design.

2.5.3 – Bicycle Traffic

The bicycle mode comprises travelers on a roadway or pathway who use a vehicle propelled solely by human-powered pedals or with electric assistance (i.e., electric bike).



Bicyclists are a highly diverse population with varying needs and interests. These transportation system users include:

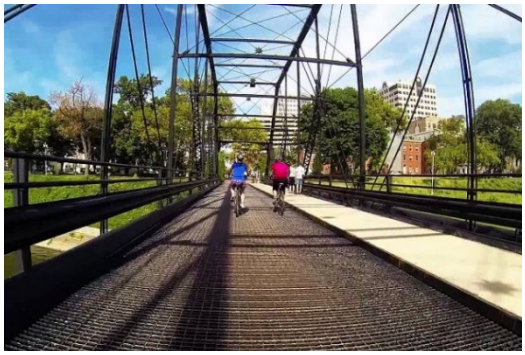
- Advanced, highly experienced bicyclists who ride frequently, often have special training, are confident in all traffic conditions, and can negotiate with less operating space.
- Basic riders who are more casual in their riding practices and are less comfortable riding in traffic.
- Young children who have not developed adequate judgment or received special training.



As with pedestrian volumes, bicycle volumes tend to follow peak motor vehicle volumes (but not always). Land use areas generating or attracting bicycle traffic can create bicycle traffic at different times of the day and week.

Title 75 of the *Pennsylvania Consolidated Statutes* considers bicycles as vehicles. As such, bicycles are governed by a general set of rules common to all vehicles, as well as a specific set of rules designed for bicycles. *Because bicycles are considered vehicles, they are allowed on all public roadways except for certain prohibited facilities.*

On-street bicycle facilities include:



- Roadways on which bicycles share a travel lane with motorized vehicles.
- Dedicated on-street bicycle lanes.
- Paved roadway shoulders available for use by bicyclists.

For each facility type, bicycle flow is generally one-way.

Off-street bicycle facilities consist of pathways dedicated to the exclusive use of bicyclists and multi-use trails shared with pedestrians and other types of users.

Chapter 14, *Bicycle Facilities,* provides more detail pertaining to bicycle facility design.

2.5.4 – Transit

The transit mode is about moving people rather than vehicles. Transit operations at their most efficient, involve relatively few vehicles, each carrying a large number of passengers. In evaluating priority measures for transit and automobile users, the number of people affected is often more relevant than the number of vehicles.



The major transit modes (in terms of passengers carried) are buses and light rail. The bus mode offers considerable operational flexibility, from local buses stopping every two to three blocks, to limited-stop service stopping every ½ to 1 mile, to express service that travels along a roadway without stopping. Light rail typically comprises multiple car trains along fixed routes located in a separate, commonly grade separated right-of-way, with interaction occurring at gate-controlled grade crossings.

For each of these modes, local transit agencies can provide schedules and service frequency. Schedules usually note major transit stops but may not indicate all transit stops.

Transit capacity differs from highway capacity in that it:

- Deals with the movement of both people and vehicles.
- Depends on the size of transit vehicles and how often they operate.
- Reflects the interaction of passenger traffic and vehicle flow.
- Depends on the operating policy of the transit agency, which specifies service frequencies and allowable passenger loadings.

Vehicle capacity for transit reflects the number of transit units (buses or trains) that pass a given location during a given time period. Vehicle (bus) capacity is commonly determined for three locations along an urban street: individual loading areas (berths) at bus stops, individual bus stops, and an urban street facility.

Person capacity reflects the number of people than can be carried past a given location during a given period under specified operating conditions, without unreasonable delay, hazard, or restriction, and with reasonable certainty. Three primary factors determine person capacity:

- Vehicle capacity, which determines the maximum number of buses that can be scheduled to use the bus facility over the course of an hour.
- Agency policy, which sets loading standards for buses and determines how frequently buses operate (which is usually less than the maximum possible frequency).
- Passenger demand characteristics reflected by a peak hour factor.

In most cases, the transit provider will provide the locations of existing service and stops, as well as plans for service expansions. The designer should consider this information in the development of projects to provide transit stop locations.

This manual focuses on the integration of public bus systems into transportation projects rather than on rail or other forms of transit. This is because buses are more common than other forms of mass transit in Pennsylvania and have the greatest daily impact on roadway operation.

Chapter 15, *Transit,* provides more detail pertaining to transit facility design.

2.5.5 – Trucks (Freight)

Trucks generally use higher classification roadways, but often must get to and from delivery origins/destinations along lower classification roadways. To determine if a route should be considered a Freight Route and may need specific truck design accommodations, refer to Chapter 16, *Freight*.

Data provided based on truck volumes (instead of truck percentage) provides a better design. Volume-based truck counts present a clearer picture of the number of times daily a larger vehicle will have to navigate the designed facility, subsequently better informing decision to ‘design or accommodate’.

At major intersections, the truck volume during the morning and evening peak hours, and during other critical hours of the day, should be determined separately. Variations in truck traffic between the different traffic movements may be substantial and may influence the geometric layout.

2.6 – Other Considerations

In addition to the design elements presented in previous Sections, there are other elements that affect or are affected by the geometric design of a roadway. Each of these additional elements is addressed briefly below only to the extent necessary to indicate its relationship to geometric design.

2.6.1 – Traffic Control Devices

Traffic control devices provide guidance and navigation information and also display additional information that augments some roadway or environmental feature that might otherwise be overlooked or difficult to receive. Traffic control devices include regulatory, warning, route guidance information, markings and delineation measures. Control devices are essential elements for all functional classification systems and their application shall be consistent and uniform especially at intersections where multiphase or actuated traffic signals may be needed. Geometric design should not be considered complete nor should it be implemented until it has been determined that needed traffic control devices will have the desired effect in controlling traffic.

Traffic control signals (including railroad crossing signals) represent devices that control vehicular and pedestrian traffic by assigning the right-of-way to various movements for certain pretimed or traffic-actuated intervals of time. Since they are one of the key elements in the function of many urban streets and rural intersections, the planned signal operation for each intersection of a facility should be integrated with the design so as to achieve optimum operational efficiency. The guidelines for the design and operation of traffic signals on all streets and highways shall conform to Publication 149, *Traffic Signal Design Handbook;* Publication 408, *Specifications*; Publication 111, *Traffic Control - Pavement Marking and Signing Standards,* TC-8600 and TC-8700 Series; and Publication 148, *Traffic Standards - Signals*, TC-7800 Series. For railroad crossing signals, refer to the MUTCD, Part 8.

Traffic signs, pavement markings, and traffic signals are directly related to the design of the highway or street and are features of traffic control and operation that should be considered in the geometric layout of such a facility. Traffic control devices should be designed concurrently with the geometrics since future operational efficiency can be significantly enhanced if signs, markings, and signals are treated as an integral part of design. The extent to which traffic control devices are used depends on the traffic volume, the type of facility, and the extent of traffic control appropriate for safe and efficient operation.

The geometric design of the facility should be supplemented by effective signing, markings, and signals as a means of informing, warning and controlling drivers during day and night operations and under a variety of environmental conditions. Signing, marking, and signal plans should be coordinated with horizontal and vertical alignment, sight distance obstructions, operational speeds and maneuvers and other applicable items before completion of design. The design, location and operation of all traffic signs and markings shall be governed by the regulations contained in 67 PA Code § 212.

2.6.2 – Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) involve the installation and use of electronic message signs, highway advisory radios, closed circuit television (CCTV) and other electronic devices by PennDOT to provide real-time emergency or congestion information to motorists. Design guidance is found in Publication 646, Intelligent Transportation Systems Design Guide and Publication 647M, *Civil and Structural Standards for Intelligent Transportation Systems.* Maintenance guidance is provided in Publication 697, *Intelligent Transportation Systems Maintenance Standards.*

2.6.3 – Railroad-Highway Grade Crossings

All railroad-highway grade crossings come under the jurisdiction of the Public Utility Commission (PUC) and cannot be constructed or altered without their prior approval. Appropriate grade crossing warning devices, as determined by the PUC, shall be installed at all railroad-highway grade crossings. Details of the available devices to be used are given in Publication 212, *Official Traffic Control Devices* and in the MUTCD, Part 8.

Sight distance is an important consideration at railroad-highway grade crossings. There shall be sufficient sight distance on the highway for the driver to recognize the crossing, perceive the warning device and stop if necessary.

Another important consideration is the required minimum railroad vertical and/or horizontal clearances between the track and an obstruction. Refer to Publication 371, *Grade Crossing Manual,* Appendix H, *Standards and References*, for these requirements.

Additional design guidance for railroad requirements may be found in Publication 371, *Grade Crossing Manual.*

2.6.4 – Curbs

The type and location of curbs affects driver behavior and, in turn, the safety and utility of a highway. Curbs serve any or all of the following purposes: (1) drainage control; (2) roadway edge delineation; (3) right-of-way reduction; (4) aesthetics; (5) delineation of pedestrian walkways; (6) reduction of maintenance operations; and (7) assistance in orderly roadside development. Curb configurations include both vertical and sloping curves. The design and construction of curbs shall be in accordance with Publication 72M, *Roadway Construction Standards*; Publication 408, *Specifications*; and Chapter 6, *Intersections and Driveways*, Chapter 13, *Pedestrian Facilities*, and Chapter 19, *Parking*. For further information refer to the 2018 AASHTO Green Book, Chapter 4, Section 4.7, "Curbs". Vertical curbs should not be used along freeways or other high-speed roadways because an out-of-control vehicle may overturn or become airborne as a result of an impact with such a curb. Since curbs are not adequate to prevent a vehicle from leaving the roadway, a suitable traffic barrier should be provided where redirection of vehicles is needed. Sloping curbs can be used at median edges, to outline

channelizing islands in intersection areas or at the outer edge of the shoulder. Sloping curbs are designed so vehicles can cross them readily when the need arises.

There are three curb heights shown in Publication 72M, *Roadway Construction Standards*. These types of curbs have the following primary uses:

1) **4 in Curb.** Use in conjunction with guide rail to bridge barrier transitions as shown in RC-50M. Also, may be used with guide rail and curb combinations as shown in RC-51M and as described in Chapter 12. For high-speed roadways, curbs should be avoided; however, if a curb is necessary, a 4 in curb should be used.
2) **6 in Curb.** Use when on-street parallel or perpendicular parking is present in order to minimize the chance of car doors or front/rear bumpers hitting the curb. Can also be used in constrained urban areas, e.g., where sidewalks are adjoining to buildings. Also, may be used with guide rail and curb combinations as shown on RC-51M and as described in Chapter 12.
3) **8 in Curb.** Use for all other uses.

In general, curbs are not desirable along high-speed roadways. A high-speed roadway is defined as having a design and/or posted speed limit of 50 mph or greater. However, if a curb is needed for drainage, constrained right-of-way or other reasons, a sloped (mountable) curb with a maximum height of 6 in, as shown in RC-65M, placed at the outside edge of the shoulder may be considered.

2.7 – Design Consistency and Driver Expectations

As context and flexibility are design considerations, it is important to be cognizant of how drivers react to changes in roadway geometrics. In this respect, design consistency is achieved when the geometric features of the roadway are consistent with the operational characteristics expected by the driver.

Design Consistency

Design consistency is achieved when the geometric features of the roadway are consistent with the operational characteristics expected by the driver.

Inconsistencies normally relate to:

- Changes in design speed.
- Changes in cross section.
- Incompatibility in geometric features and operational requirements expected by the driver.

Changes in design speed may occur on roadways constructed over an extended period of time, and are therefore subject to variable standards, classifications, or funding. This may also occur when the project extends through more than one topology.

There are two major types of design inconsistencies related to cross section: point inconsistencies and general incompatibility between cross section and alignment. Point

inconsistencies may include the narrowing of lane widths, a narrow bridge, a lane drop, or a change from multilane section to two lanes.

A cross sectional inconsistency is usually the result of upgrading a highway cross section without upgrading the alignment. For examples, pavements may be widened, and shoulders added to an older two-lane highway. The wider cross section on an old alignment might convey a conflicting message to the driver and lead to inappropriate expectancy based on the visual aspects of the cross section, because cross section features can be more apparent than the alignment.

Widening can improve the safety characteristics of a road, particularly on very narrow, low-volume roads. However, designers should be aware of potential inconsistencies that can be overcome with relatively low-cost treatments. In the case of widened roads on old alignments, treatments such as pavement markings, warning signs, and delineation devices can be very helpful to the driver.

Inconsistencies may also relate to incompatibility in geometric elements and operational requirements. Occasionally, elements of the design may have been selected to fit the geometric components conveniently and economically, rather than to satisfy operational requirements.

Design inconsistencies can result in driver uncertainty, an increase in response time, and an increase in the probability of inappropriate driver response.

Driver expectancy relates to the driver's readiness to respond to events, situations, or the presentation of information. Driver expectancy may be defined as the driver's inclination, based on previous experience, to respond in a set manner to a roadway or traffic situation.

Expectancy can affect the perception and use of information. In most circumstances, the expected and actual conditions are the same. However, when design inconsistencies occur, and a driver's expectancy is incorrect, it takes longer to respond properly, there may be no response, or the response may be inappropriate for actual conditions.

There are certain elements in the design that particularly affect design consistency, driver expectancy, and vehicular operation. These components include horizontal and vertical alignment, embankments and slopes, shoulders, crown and cross slope, superelevation, bridge widths, signing and delineation, guiderails, and utility poles or light support placement.

2.8 – Design Documentation and Exceptions

Over the years, the conventional design process has become structured and formalized, primarily balancing tradeoffs strictly between transportation requirements and other goals. As the design process evolves to be context based and flexible, the designer should consider issues beyond design criteria that are increasingly important in determining the ultimate success of a project. This signals a need to accurately and completely identify tradeoffs associated with design decisions and to strike a balance between competing factors in the decision-making process.

Be sure to document and retain documents supporting design decisions. Consider input from all team members and the community. Carefully considered and documented engineering decisions are more important than strict compliance with numerical values.

Projects comprise a series of tasks, each of which may involve a series of decisions. It is critical to document the decision process, what decisions were made, and what analyses, processes, and documents were produced to support the outcome. The documentation should be concise yet include pertinent discussion about items that led to a particular decision.

Refer to Publication 10C, Design Manual Part 1C, *Transportation Engineering Procedures*, (DM-1C), for documentation procedure for each phase of a project.

Transportation professionals may find that some geometric elements in their preferred alternative do not meet controlling criteria. In those instances, design exceptions may be needed. Publication 10X, Design Manual Part 1X (DM-1X), Appendix P, *Design Exceptions* provides details pertaining to what constitutes a design exception, how it is documented, and the approval process. It also has documentation requirements for projects not meeting geometric criteria.

Transportation professionals should expect design exceptions. Design exceptions show careful consideration of project design decisions.

The purpose of the project development process is to evaluate the anticipated performance of the transportation network improvement (in terms of accessibility, mobility, quality of service, reliability, and safety) and to ascertain whether variation from published design criteria has a positive or negligible impact on achieving the project's desired outcome.

Also, as stated in the Publication 10X, Design Manual Part 1X, Appendix P, *Design Exceptions*, many design elements are not included in the controlling criteria governing design exceptions. When these design elements do not meet criteria presented in Design Manual Part 2, they should be identified, justified and documented as early as possible during the design process which may be in the District Safety Review or Design Field View. See Appendix P for further details.

Appendix 2A: Utilities

Highway and street improvements, whether upgraded within the existing right-of-way or entirely on new right-of-way, must be designed to avoid or minimize impacts to utility facilities. This is in accordance with State and Federal regulations (PA One Call, 23 CFR and the Federal Program Guide on Utility Relocation and Accommodation on Federal-Aid Highway Projects) and must be done. Information regarding PA One Call procedures, designer and locator effectiveness guidelines, responsibilities of the various stakeholders, definition of terms, and the current Pennsylvania One Call legislation is available on the PA One Call Website at www.pa1call.org/PA811/Public/.

The existing utilities should be placed on the plans early in the development of a project to identify conflicts when designing the new or upgraded highway and street improvements. Designers must perform a minimum of two PA One Call notifications during project development:

1) **Final Notice.** Designers are required to notify the PA One Call system not less than 10 nor more than 90 days before the advertisement date of a project.
2) **Preliminary Notice.** Any notification to the PA One Call system performed by the designer more than 90 days in advance of the advertisement date (in preliminary or final design of the project) is considered preliminary. The designer must state in the requirements that such work is preliminary. The preliminary notice may be waived with appropriate justification by the HDTD Chief.

In many instances engineering and construction drawings are prepared far in advance of the bid date or the start of construction, or last-minute project owner/designer adjustments may result in changes to the proposed excavation area. Preliminary design notifications must be created. The date of the most recent design one call notification should never be more than 90 days prior to the project advertisement date or date of construction in the absence of a bid.

The use of Subsurface Utility Engineering (SUE) may be required to determine the exact horizontal and vertical location of all underground utilities (refer to Publication 16, Design Manual, Part 5, *Utility Relocation*, Chapter 6, Subsurface Utility Engineering). The SUE Utility Impact Form (see Publication 16, Design Manual, Part 5, *Utility Relocation*, Appendix A-501) is a tool that was developed to address the legal requirements and to comply with the State and Federal laws. The form provides an analysis based on project criteria to determine if SUE use is "practicable," when SUE should be considered on a project, and what SUE quality levels should be utilized. SUE should be considered for all projects regardless of a project's estimated cost. The SUE Impact form should be completed by the Project Manager in coordination with the District Utility Relocation Unit.

Special construction items should be shown on the utility submissions (see Publication 16, Design Manual, Part 5, *Utility Relocation*, Appendix A-502).

It is important that the Project Manager coordinate plan revisions with the District Utility Administrator to determine the effect they may have on the relocation of utilities. In many cases minor revisions to the highway plan can have major impacts to the relocation of utilities.

Although utilities generally have little effect on the geometric design of the highway or street, full consideration should be given to measures, reflecting sound engineering principles and economic factors, needed to preserve and protect the integrity and visual quality of the highway or street, its maintenance efficiency and the safety of traffic. The various policies and procedures to accomplish utility adjustments made necessary by highway construction projects are contained in Publication 16, Design Manual, Part 5, *Utility Relocation*.

Underground utilities are to be located and marked out by the facility owner prior to any excavation (for example: boring, drilling, blasting, etc.) or demolition work on every project (during design and/or construction).

The contractor/consultant is required to notify the Department and to submit an Alleged Violation Report (AVR) to the PA Public Utility Commission through the PA One Call System, www.pa1call.org, within ten (10) business days after a utility line is struck, damaged or previous damage is discovered (such as any break, leak, dent, gouge, groove or other damage to such lines or to any coating or cathodic protection) in the course of the excavation, subsurface exploration or demolition work as required by Pennsylvania's Underground Utility Line Protection Law Act 50 (P.L.852, No. 287 amended Oct. 30, 2017).

The Department, as the property owner is also required to submit an Alleged Violation Report (AVR) to the PA Public Utility Commission through the PA One Call System, www.pa1call.org, within ten (10) business days after a utility line is struck, damaged or previous damage is discovered on a Department construction project.

Chapter 3 – New Construction and Reconstruction Change In Road Type

In this chapter there are references to future chapters 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 3 – New Construction and Reconstruction Change In Road Type

3.0 – Introduction

The roadway design process is needs-based and varies with the purpose and needs of each project.

Once the scope of the project is known, there are separate requirements for each of the following general project types:

1) **New Construction** – roads on new alignment
2) **Reconstruction Change in Road Type (CIRT)** – roads on existing alignment with a change in basic road type or cross section
3) **Reconstruction No Change in Road Type (NoCIRT)** – existing roads; with no change in basic road type. Refer to Chapter 4 and the Green Book, Section 1.7.3, *Construction Projects on Existing Roads*.

Exhibit 3.0.1 – General Roadway Project Types and the Associated Chapters

New Construction	Reconstruction Change in Road Type (CIRT)	Reconstruction No Change in Road Type (NoCIRT)
No Existing Road	On an Existing Road	
Chapter 3		**Chapter 4**

Some major projects, e.g., a new interchange, may involve a combination of new construction, reconstruction with change in road type, and construction on existing roads, and portions of the project may, therefore, require use of different design criteria.

Important Context Questions:

- Where should a proposed alignment be located to best serve the needs of all road users while complementing adjacent land uses?
- What cross sectional elements are needed to best meet the needs of all road users?
- What design alternatives demonstrate specific awareness of the following?
    - Context
    - Expected project outcomes based on performance and measures of effectiveness
    - Project needs

- Financial feasibility
- Benefit-cost ratio

3.0.1 – New Construction Projects

Of the three general roadway project types listed above in **Exhibit 3.0.1**, this is the only one that does not involve an existing roadway alignment and is therefore the project type least likely to be constrained by existing features. Unlike projects on existing roads, New Construction projects are on new alignment, unaffected by existing roadway past performance issues and generally less affected by constraints such as traffic control or existing utilities, rights-of-way, or easements, etc. Consequently, on New Construction projects designers typically have less need to deviate from the dimensional design criteria presented in this chapter and therefore should make every effort to adhere to it as closely as possible; resorting to a more flexible, performance-based approach only where necessary to adapt the design to fit the roadway context and to meet multimodal needs.

As a practical consideration, a project with most of its length on new alignment (i.e., not on existing alignment) should generally be treated as a new construction project. For more information about New Construction project design see the Green Book, Section 1.7.1, *New Construction Projects*.

3.0.2 – Reconstruction and Road Type

Traditionally, the term, “reconstruction” has meant the full depth replacement of pavement down to the subgrade, but there are now two “reconstruction” type projects, and a “reconstruction” type project is no longer limited to just full depth replacement of the pavement. “Reconstruction” type projects now include both Change in Road Type (CIRT) projects and No Change in Road Type (NoCIRT) projects.

“Road Type” refers to the predominate typical section of the roadway corridor, such a “two-lane”, “four-lane undivided”, or “four-lane divided’. Minor dimension changes, such as minor shoulder widening, which do not change the use and operations, do not change the road type. Note that Road Type is not a Functional Classification or Typology. These concepts are based on the Green Book Section 1.7, *Design Process to Address Specific Project Types*, and are shown in Exhibit 3.0.1. This chapter includes geometric criteria and guidance for Reconstruction (CIRT) and New Construction projects.

3.0.2.a – Reconstruction CIRT Projects

Of the three project types listed in Exhibit 3.0.1, this project type tends to be the most difficult to design because it involves an existing road that typically has past performance issues; it generally has the most design constraints and involves a change in road type or cross section.

Reconstruction CIRT projects superimpose a new road type onto an existing alignment. This may require adapting the new road type to fit within the existing community context. While designers are to use the design criteria in this chapter for both New Construction and Reconstruction CIRT projects, Reconstruction CIRT projects may need to utilize a more flexible, performance -based design approach, depending on the existing context.

Examples of typical Reconstruction CIRT projects include:

- Widening to add one or more through lanes
- Widening to add auxiliary lanes such as connecting freeway ramps between two interchanges
- Widening to add a two-way left turn lane where none previously exists
- Widening to add new through lanes, parking lanes, or bike lanes, with or without full depth (to subgrade) pavement removal and replacement
- Projects that modify horizontal and/or vertical alignments beyond minor shifts
- The addition of a median greater than or equal to one lane width or changing the median to/from traversable from/to non-traversable
- Reconstruction of interchanges and associated acceleration/deceleration lanes and ramps with added capacity or major realignments
- Major interchange reconfiguration such as converting a standard diamond interchange to a DDI or SPDI

Note that other geometric changes, such as changing the pavement cross slope or minor changes to horizontal or vertical alignment, do not constitute a change in road type by themselves. Major changes in alignment without a change in road type require the use of New Construction design criteria. For a table of project examples, see Appendix 3B.1, *Applicable Design Criteria for Roadway Projects*, of this chapter.

3.0.3 – Resources and References

The following resources provide additional information:

- AASHTO, *A Guide to Achieving Flexibility in Highway Design*, 2018.
- AASHTO, *Geometric Design of Low-Volume Roads*, 2019.
- Ohio DOT, *Location and Design Manual*, 2013.

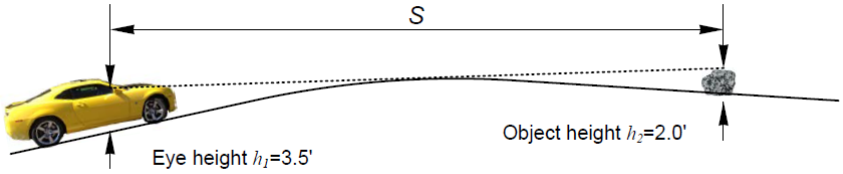
References to AASHTO Publications

In many cases information contained in the Green Book is included by reference to avoid unnecessary duplication. While the Green Book presents a range of accepted design practices, this design manual defines methods and criteria that are accepted by PennDOT. Although this design manual is closely aligned with the Green Book, the designer should be

aware of those situations where PennDOT's criteria is more conservative than criteria in the Green Book, such as passing sight distance and vertical clearance.

Initiative should be exercised to utilize the most appropriate design values within the given ranges based upon the project context and roadway typology wherever practicable and within reasonable economic limitations and sound engineering judgment. When design criteria presented in this manual differs from criteria presented in other sources, this manual shall take precedence. However, for Federal-aid projects on the National Highway System (NHS), this manual only takes precedence when criteria in this manual exceed the criteria in the Green Book and the AASHTO publication, *A Policy on Design Standards - Interstate System* (for Interstate Federal-aid projects). The design criteria and text presented herein provide guidance to the designer by referencing a range of values for critical dimensions.

3.1 – Sight Distance



Sight distance enables drivers to assess roadway and traffic conditions ahead and take appropriate actions. Additionally, it represents the continuous length ahead along a roadway throughout which an object of specified height is continuously visible to the driver. The following four types of sight distance are to be considered:

- Stopping sight distance and headlight sight distance
- Decision sight distance.
- Passing sight distance for two-lane highways.
- Intersection sight distance

3.1.1 – Stopping Sight Distance

Stopping Sight Distance (SSD) represents the length needed for a vehicle traveling at a given speed to stop before reaching an object in its path. The Green Book, Section 3.2, *Sight Distance*, provides equations for calculating the SSD for various design speeds and grades.

The recommended SSDs are based on P vehicle (passenger car) operation. Although trucks need longer stopping distances than P vehicles, separate SSDs for both vehicles are not generally used in highway design because truck drivers can see substantially farther beyond vertical sight obstructions because of the greater eye height provided by trucks. This factor tends to balance the additional braking lengths for trucks with those for P vehicles.

The stopping distances needed on upgrades are shorter than those needed on level roadways, and those needed on downgrades are longer than those needed on level roadways. The extent

of the corrections for grade, which are based on wet pavement conditions, is indicated in the Green Book, Section 3.2, *Sight Distance*. On roadways traversed by traffic in both directions, the sight distance available on downgrades is larger than that available on upgrades. This automatically provides the appropriate corrections for grade.

3.1.2 – Decision Sight Distance

Stopping Sight Distance (SSD) is often inadequate in situations where drivers must make complex or instantaneous decisions, where information is difficult to perceive, or where unexpected or unusual maneuvers are required, the Green Book recommends providing drivers sight distances that are longer than the basic SSD. Decision Sight Distance (DSD) is the sight distance recommended in these situations. The following are examples of critical locations were providing DSD is recommended:

1) Interchanges and intersections.
2) Changes in cross section such as interchanges and lane-drops.
3) Areas of concentrated demand where there is apt to be "visual noise".
4) Railroad-highway grade crossings.

DSD varies with location (rural, suburban, or urban), and the type of avoidance maneuver (stop, or speed/path/direction change). For more information about DSD, refer to the Green Book, Section 3.2.3, *Decision Sight Distance*.

3.1.3 – Passing Sight Distance for Design of Two-Lane Highways

Passing Sight Distance (PSD) is considered only on two-lane roads. PSD is an area where PennDOT design criteria is more conservative than Green Book design criteria. Therefore, the designer shall use the PSD criteria provided herein, rather than the PSD criteria in the Green Book.

PSD on two-lane highways is the minimum sight distance that shall be available to enable the driver of one vehicle to pass another vehicle safely and comfortably, without interfering with the speed of an oncoming vehicle traveling at the design speed should it come into view after the overtaking maneuver is started. The sight distance available for passing at any location is the longest distance a driver, whose eyes are 3.5 ft above the road surface, can see the top of a 3.5-foot-high object on the road surface.

The available passing sight distance is to abide by the PA Vehicle Code, Title 75, Chapter 33, § 3305, titled "Limitations on overtaking on the left". It states:

> “No vehicle shall be driven to the left side of the center or marked center line of the roadway in overtaking and passing another vehicle proceeding in the same direction unless the left side is clearly visible and is free of oncoming traffic for a sufficient distance ahead to permit the overtaking and passing to be completely made without interfering with the operation of any vehicle approaching from the opposite direction or any vehicle overtaken. In every event

the overtaking vehicle must return to an authorized lane of travel as soon as practicable and, in the event the passing movement involves the use of a lane authorized for vehicles approaching from the opposite direction, before coming within 200 ft of any approaching vehicle."

The minimum PSD required for design should be determined on the basis of the distance needed to complete normal passing maneuvers and is determined for a single vehicle passing another single vehicle, and should be based on the following assumptions:

1) The overtaken vehicle travels at uniform speed.
2) The passing vehicle has reduced speed and trails the overtaken vehicle as it enters a passing section.
3) When the passing section is reached, the passing driver needs a short period of time to perceive the clear passing section and to start the passing maneuver.
4) Passing is accomplished under what may be termed a delayed start and a hurried return in the face of opposing traffic. The passing vehicle accelerates during the maneuver and its average speed while in the left lane is 10 mph higher than that of the overtaken vehicle.
5) When the passing vehicle returns to its lane, there is a suitable clearance length (200-ft. min.) between it and an oncoming vehicle in the other lane.

As shown in **Exhibit 3.1.1**, the minimum passing sight distance for two-lane highways represents the sum of the following four distances:

1) Distance traversed during perception and reaction time and during the initial acceleration to the point of encroachment on the left lane (initial maneuver, d_1).
2) Distance traveled while the passing vehicle occupies the left lane (occupation of left lane, d_2).
3) Distance between the passing vehicle at the end of its maneuver and the opposing vehicle (clearance length, d_3).
4) Distance traversed by an opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane (opposing vehicle, d_4 or 2/3 of d_2 above).

These distances and the relative positions of the vehicles are shown in Exhibit 3.1.1.

Exhibit 3.1.1 – Elements of Passing Sight Distance for Two-Lane Highways

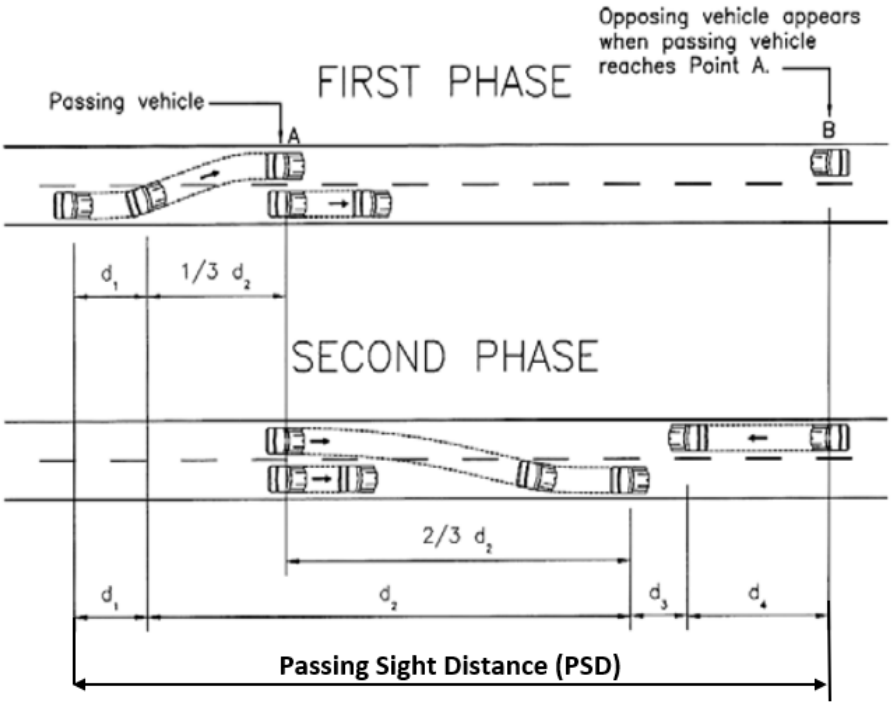


Exhibit 3.1.2 presents the minimum passing sight distance values for design in Pennsylvania. These values are based on the Pennsylvania Vehicle Code and do not match those in the current Green Book.

The rate of vertical curvature, K (= L/A), is the ratio of vertical curve length, L (in ft) to the algebraic difference in grade, A (in percent). K is the vertical curve length needed to make a 1% grade change based on the passing sight distance needed for the selected design speed. The K values in Exhibit 3.1.2 are used to determine the minimum vertical curve length needed for the passing sight required by the Pennsylvania Vehicle Code.

Exhibit 3.1.2 – Minimum Passing Sight Distances for Design of Two-Lane Highways

Design Speed (mph)	Passing Sight Distance (ft)	Rate of Vertical Curvature, K* design
20	710	180
25	900	289
30	1090	424
35	1280	585
40	1470	772
45	1625	943
50	1835	1203
55	1985	1407
60	2135	1628
65	2285	1865
70	2480	2197
* Rate of vertical curvature, K = L/A		

The passing sight distances listed in Exhibit 3.1.2 are directly applicable for passing on horizontal tangent roadway sections with a very flat vertical alignment. They are of limited practical value except on long curves since it is difficult to maintain passing sight distance on other than very flat curves.

Steep upgrades affect vehicle performance and consequently require longer Passing Sight Distances (PSD's) greater than the derived design values in Exhibit 3.1.2. Although no specific adjustments for design are available, the desirability of exceeding the values shown should be recognized.

The frequency and length of passing sections depend on many factors, including topography, design speed, traffic data (truck percentages), intersection spacing, and construction cost, and must be determined based on an evaluation of site-specific conditions. At all passing sections, the sight distance provided should be as long as practical and should equal or exceed the PSD values listed above. On two-lane rural highways, passing sections should be provided at frequent intervals and for substantial portions of the length of the highway.

3.1.4 – Sight Distance for Multilane Highways

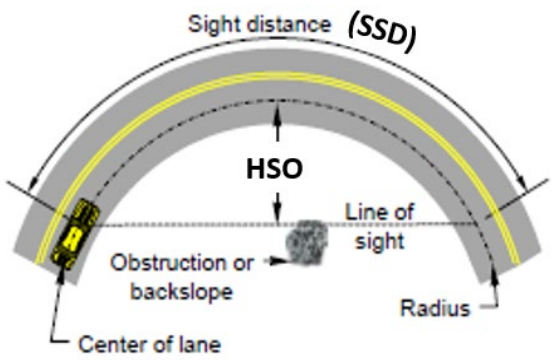
Multilane roadways should be designed to provide adequate stopping sight distance continuously with greater than design sight distances preferred. It is not necessary to provide passing sight distance on roadways that have two or more traffic lanes in each direction of travel.

3.1.5 – Criteria for Measuring Sight Distance

The criteria for measuring sight distance depends on the height of the driver's eye above the road surface, the specified object height above the road surface - and the height and lateral position of a sight obstruction within the line of sight. The Green Book, Section 3.2.6, *Criteria for Measuring Sight Distance*, provides separate criteria for measuring stopping, decision, passing, and intersection sight distances.

3.1.6 – Sight Distance on Horizontal Curves

When designing a horizontal curve, a designer must evaluate the inside of the curve for roadside features such as backslopes, walls, barriers, vegetation, etc., that could obstruct a driver's line of sight across the curve. As shown in **Exhibit 3.1.3**, the Horizontal Sightline Offset (HSO) is the perpendicular distance between inner lane centerline and the line of sight. For a curve to be driven safely at its design speed, a driver must at a minimum,



have an unobstructed line of sight across the curve that provides Stopping Sight Distance (SSD) along the centerline of the travel lane that is required by the curve design speed. In practice, providing the required SSD along the line of sight provides meeting or slightly exceeding the SSD required for the design speed.

The HSO distance required for a particular curve design speed is based on the height criteria for stopping sight distance: a 3.5-foot driver's eye height and a 2-foot object height, and the following two variables: (1) the radius of the inner lane centerline and (2) the SSD required for the curve design speed. The Green Book, Equation 3-36, is used to calculate the required HSO distance.

Curve designs should be checked to ensure no potential sightline obstructions are located within the calculated HSO distance. This often involves working backwards to determine the actual SSD distance given a proposed HSO distance and proposed inner lane centerline radius. In such situations the following equation, which is derived from the Green Book, Equation 3-37, is often very useful.

$$SSD = \left(\frac{R}{28.65}\right)\left(\arccos\frac{R - HSO}{R}\right) \qquad \text{Equation 3.1}$$

where: SSD = Stopping Sight Distance
R = Radius at centerline of inner lane
HSO = Horizontal Sightline Offset

Note that the equation discussed above is only exact when both the vehicle and the sight obstruction are located within the limits of the curve. When either the vehicle or the sight obstruction is outside the curve, the values obtained are only approximate and should be checked graphically. Both horizontal and vertical sight distances should be measured graphically, and the shorter distances recorded. In the case of a two-lane highway, both PSD and SSD should be measured and recorded. For more information about sight distance on horizontal curves, refer to the Green Book, Section 3.3.12, *Sight Distance on Horizontal Curves*.

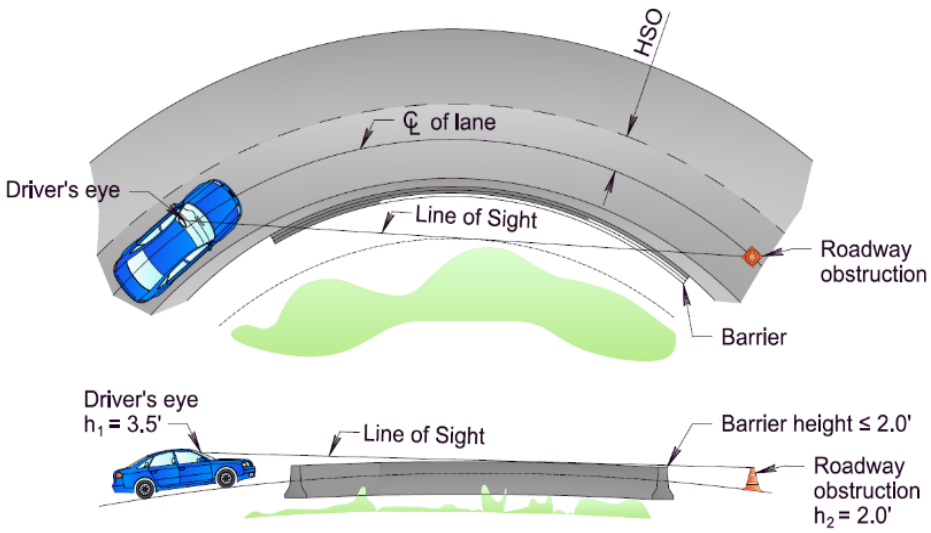
3.1.7 – Overlapping Horizontal and Vertical Curves

Vertical curves on a horizontal curve can cause roadside objects to be sightline obstructions. Crest vertical curves make roadside objects more likely to become sightline obstructions. Sag vertical curves make roadside objects less likely to be sightline obstructions.

Exhibit 3.1.4 can be used to determine the sight distance for crest vertical curves on horizontal curves with:

- Sightline obstructions inside the HSO distance.
- Sightline obstruction height (h_0) of 2.0 ft or less.

Exhibit 3.1.4 – Stopping Sight Distance on a Horizontal Curve with Roadside Obstruction



The following equation may be used to determine the sight distance for roadside sightline obstructions inside the Horizontal Sightline Offset (HSO) distance (see Exhibit 3.1.4) with a height of 2.0 ft or less above the centerline of the lane on the inside of the curve on overlapping horizontal and crest vertical curves.

$$S = \sqrt{\frac{100L\left[\sqrt{2(h_1 - h_0)} + \sqrt{2(h_2 - h_0)}\right]^2}{A}} \quad \text{Equation 3.2}$$

Where: L = Length of vertical curve (ft)
S = Stopping Sight distance (ft) across the curve
A = Algebraic difference in grade (%)
h_1 = Driver's eye height (3.5 ft)
h_2 = Object height (2.0 ft)
h_0 = Height of roadside sightline obstruction above the centerline of the curve lane ($\leq$ 2.0 ft)

For other locations, the sight distance can be checked graphically.

Note: The above equation cannot be used for sightline obstruction heights (h_0) more than 2.0 ft above the centerline of the lane on the inside of the curve. The available sight distance must be checked graphically for these sightline obstructions.

3.1.8 – Intersection Sight Distance

The driver of a vehicle approaching an intersection should have an unobstructed view of the entire intersection, including any traffic control devices, and sufficient sight distance along the intersecting highway to permit the driver to anticipate and avoid potential collisions.

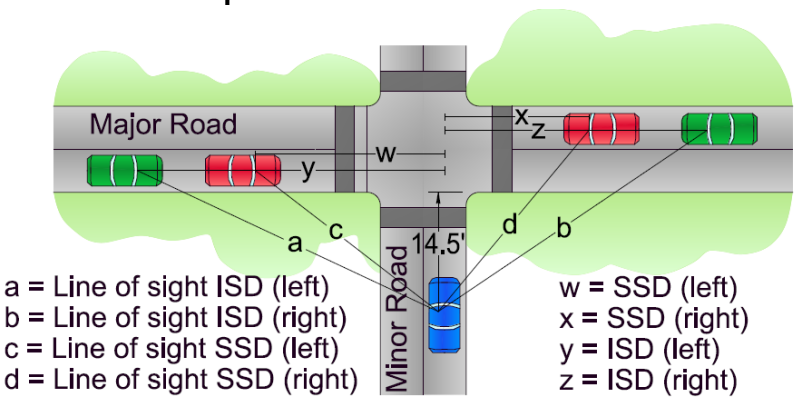
For procedures to determine sight distances at intersections according to different types of traffic control, refer to the Green Book, Section 9.5, *Intersection Sight Distance*.

Intersection Sight Distance (ISD) should also be provided at intersections controlled by traffic signals because of operational considerations, such as signal violations or malfunction, right turn on red, etc. A basic requirement of all controlled intersections is that drivers have enough intersection sight distance of approaching vehicles to decide when there is sufficient gap in the traffic flow to complete all legal turning or crossing maneuver.

3.1.9 – Intersections with Stop Control on the Minor Road

The driver of a vehicle stopped on a minor road and waiting to cross or enter a major road needs a clear line of sight that provides enough intersection sight distance for the driver to see oncoming vehicles and complete all legal maneuvers.

Exhibit 3.1.5 – Intersection Sight Distance - Stop Control on the Minor Road



Use **Exhibit 3.1.5** to determine the available Intersection Sight Distance (ISD) along a major road for a driver stopped on a minor road. The vertex (decision point) of each sight departure triangles shown is located 14.5 ft from the edge of the major road traveled way.

The sight triangles are determined as shown in Exhibit 3.1.5. For roads with horizontal curvature, the sight distance must be checked continuously for the entire length along the major road, i.e., to check for all intermediate points. The ISD must be checked vertically and horizontally combined graphically.

Within the sight triangle, flatten cut slopes and lower or remove hedges, and trees. Relocate signs away from the direct line of sight if feasible. Eliminate parking to remove obstructions to sight distance. To maintain the sight distance, the sight triangle must be within the right of way or a sight line easement.

The setback distance for the sight triangle is 14.5 ft from the major road edge of traveled way. This is based on the front end of a stopped vehicle being positioned 6.5 ft from the edge of

traveled way and the decision point (driver's eye) being positioned 8.0 ft from the front end of the vehicle.

Provide a clear sight triangle for a P vehicle (passenger car) at all intersections. In addition, provide a clear sight triangle for the SU-30 vehicle for rural highway conditions. If there is significant combination truck traffic, use the WB-67 rather than the SU-30 design vehicle, and evaluate the possible impact of elevated visual obstructions (e.g., tree branches, overhead structures, etc.). In areas where SU-30 or WB vehicles are minimal and right-of-way restrictions limit sight triangle clearing, only the P vehicle sight distance needs to be provided.

At an existing driveway (ADT < 400) or a low volume intersection (ADT < 2000) when sight obstructions within the sight triangle cannot be removed due to insurmountable conditions, the standard 14.5 foot setback from the major road may not be attained. Drivers who do not have the desired sight distance will inch forward until the sight distance is available. Publication 282, *Highway Occupancy Permit Operations Manual*, allows infringement within the 14.5 ft setback sight triangle, as long as the setback in not reduced below 10 ft, and the sight triangle established at a 10 ft offset is clear. Document the justification, such as right-of-way width, bridge barrier, guide rail, etc., and provide a brief analysis of the intersection sight distance clarifying the reasons for allowing a 10 ft setback. Verify and document that there is no identified crash trend at the driveway or low volume intersection.

For all intersections, if the intersection sight distance cannot be provided, the value (the actual distance along the major road) may be reduced to the stopping sight distance for determining the sight triangle. See Exhibit 3.1.5 for an example of this approach. See Green Book, Table 3-1, *Stopping Sight Distance on Level Roads*, for the stopping sight distance for a given design speed. Document the justification, such as right-of-way width, and provide a brief analysis and justification of the intersection sight distance clarifying the reasons for reduction. Verify and document that there is no identified crash trend at the intersection.

For more information about intersection sight distance, see the Green Book, Section 9.5, *Intersection Sight Distance*.

3.2 – Horizontal Alignment

3.2.1 – Baselines

A horizontal alignment is represented geometrically by its baseline (or center line) which indicates the bearings and lengths of tangents, the exact locations of Points of Intersection (PIs), and Points of Curvature (PCs), and Points of Tangency (PTs). Highway design software is used to calculate the precise coordinates of design features along the alignment. PennDOT uses the following two systems to locate features along a horizontal alignment.

3.2.1.a – Cartesian Coordinate System

Horizontal alignments are calculated using coordinates (Northings and Eastings). A project may be on the Pennsylvania State Plane Coordinate system or an imaginary coordinate system. The coordinates are calculated using coordinate geometry and tabulated on roadway construction plans for the purpose of construction stakeout.

3.2.1.b – Stations and Offsets

Stationing runs along the roadway baseline and is used to locate features along the baseline. The term “station” is used both as a unit of length (100 ft) and to designate that a position of a feature is in reference to a particular baseline. Every horizontal alignment must include baseline stationing to facilitate design and construction. Stationing enables designers to coordinate the horizontal and vertical alignments, to designate the locations of specific design features, identify the limits of typical sections, calculate quantities of construction material, and to locate roadway cross sections.

3.2.1.c – Survey and Construction Baseline Notes

1) Where spiralled curves are utilized as indicated in Section 3.2.5, all surveying and design computations on Survey and Construction Baselines (or Centerlines) shall be achieved utilizing spiralled curves except as indicated in item 3.a below.
2) For parallel roadways with median widths of 84 ft or less:
   (i) One Survey and Construction Centerline, located in the center of the median, shall be used for surveying of the cross sections and the design of the roadway.
   (ii) One grade profile shall be required for sections of roadway that have the same grade elevations at the "Grade Points" or a constant difference between the "Grade Points" of the two pavements.
3) For transition areas with variable width medians of 84 ft or less:
   (i) One Survey Centerline located in the center of the median shall be used for surveying the cross sections and the referencing of the right-of-way. The surveying on the survey Centerline shall be done utilizing simple curves.
   (ii) Two Construction Baselines located: on the median edges of four-lane pavements, on the pavements 12 ft from the median edges of the pavements of six-lane pavements, on the pavements 24 ft from the median edges of the pavements of eight-lane pavements, shall be used for the design of the roadways.
   (iii) Two Grade Profiles shall be developed at the same location as the Construction Baselines.
4) For roadways with medians in excess of 84 ft:

(i) Two Survey and Construction Baselines located: on the median edges of four-lane pavements, on the pavements 12 ft from the median edges of the pavements of six-lane pavements, on the pavements 24 ft from the median edges of the pavements of eight-lane pavements shall be used for surveying the cross sections, for the design of the roadways and for the referencing of the right-of-way.

(ii) Two grade profiles shall be developed at the same locations as the Survey and Construction Baselines.

5) Survey Baseline shall be established and staked for all side roads. For information on the placing of Fine Grade Stakes, see Publication 122M, *Surveying and Mapping Manual*.

All Survey Baselines shall be monumented as stated in Publication 122M, *Surveying and Mapping Manual*, Chapter 4, Section 4.3.

3.2.2 – Alignment Constraints

Ideally horizontal alignments should be designed to be as directional as possible and for continuous operation at a uniform design speed for substantial lengths of highway. Alignment alternatives may be constrained by the presence of natural, cultural, and socioeconomic resources, such as wetlands, farmlands, historic structures and properties, etc. The designer must attempt to avoid or minimize impacts to such resources. Impacts to such resources must be balanced with engineering considerations, ability to meet needs, public input, and agency consultation.

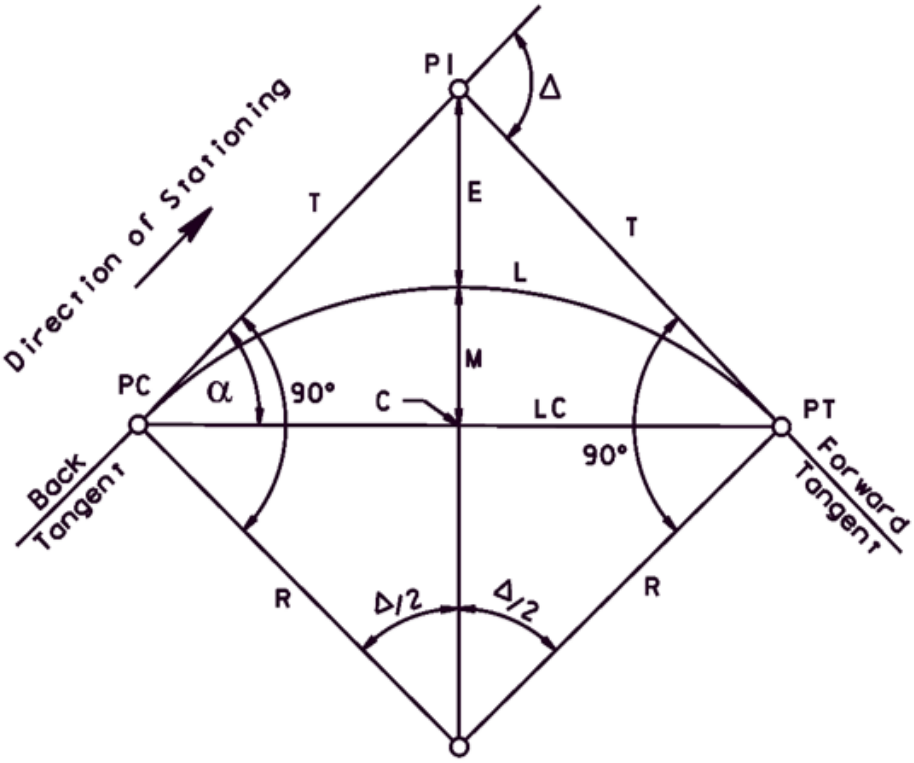
3.2.3 – Circular Curves

A properly designed highway alignment is a smooth and flowing series of straight lines (or tangents) connected by curves. Alignment design includes establishing the proper relationship between design speed and curvature. The circular curve is the most critical element of a horizontal alignment because it must provide a smooth change in direction that drivers can negotiate safely at the design speed of the highway. The two basic elements of horizontal curves are curve radius and superelevation rate. For safety and comfort, the radius of a curve must be large enough to accommodate the design speed of the highway. The minimum radius of a horizontal curve is computed based on design speed, superelevation, and side friction.

3.2.3.a – Elements of Circular Curves

Changes in direction along a highway are achieved by circular curves which are geometric segments of a complete circle. The mathematics of circular curves are largely based on trigonometry. The equations in **Exhibit 3.2.1** shall be used for all circular curve computations.

Exhibit 3.2.1 – Geometric Elements of a Horizontal Curve



$$T = R \times \text{Tan}\left(\frac{\Delta}{2}\right)$$

$$LC = 2 \times R \times \text{Sin}\left(\frac{\Delta}{2}\right)$$

$$E = T \times \text{Tan}\left(\frac{\Delta}{4}\right) = R \times \text{Sec}\left(\frac{\Delta}{4}\right) - R$$

$$M = E \times \text{Cos}\left(\frac{\Delta}{2}\right) = R \times \left[1 - \text{Cos}\left(\frac{\Delta}{2}\right)\right]$$

$$L = \frac{\pi \times R \times \Delta}{180}$$

$$D = \frac{5729.578}{R}$$

$$\alpha = \frac{\Delta}{2}$$

PI = Point of Intersection
PC = Point of Curvature
PT = Point of Tangency
Δ = Deflection Angle between Tangents
T = Tangent Distance
E = External Distance
R = Radius
M = Middle Ordinate
LC = Long Chord (Distance between PC and PT)
C = Midpoint of Long Chord
L = Length of Curve
π = pi
D = Degree of Curvature
For determining PC and PT stations
PC STA = PI STA – T
PT STA = PC STA + L

3.2.3.b – Circular Curve Terminology

Δ **Delta** (Central Angle and Deflection Angle) is also commonly referred to as the angle I (Intersection) in highway design and route surveying textbooks.

R **Radius.** The radius of the circle of which the curve is an arc, or segment. The radius is always perpendicular to back and forward tangents.

D **Degree of Curvature.** An alternative method of defining the curvature; inversely related to the curve radius. Highway curves are typically based on the arc definition. The chord definition is traditionally used for railroad curves.

PI **Point of Intersection.** The point of intersection is the theoretical location where the two tangents meet.

PT **Point of Tangency.** The point on the forward tangent where the curve ends.

PC **Point of Curvature.** The point of curvature is the point on the back tangent where the circular curve begins.

POC **Point on Curve.** The point on curve is any point along the curve.

L **Length of Curve.** The curve length from the PC to the PT

T **Tangent.** The length of the tangent from the PI to the PC or the PT. These lengths are equal on a simple curve.

C **Long Chord.** The straight-line distance from the PC to the PT. Other types of chords are designated as follows:

c **Subchord.** The sub-chord distance between the PC and the first station on the curve.

C' **Chord Distance.** Any distance between two points along a curve.

E **External Distance.** The external distance (also called the external secant) is the distance from the PI to the midpoint of the curve. The external distance bisects the interior angle at the PI.

M **Middle Ordinate.** The distance from the midpoint of the curve to the midpoint of the long chord. The extension of the middle ordinate bisects the central angle.

d **Deflection Angle.** The deflection angle for chord C'.

α **Alpha.** The angle between the Back Tangent and Long Chord (and between the Long Chord and Forward Tangent) is known as α.

3.2.3.c – Degree of Curvature

Degree of Curvature is used in the United States and has no metric counterpart because it is based on a 100-foot arc length or chord length. Traditionally degree of curvature was preferred by surveyors as a convenient way to stake-out long radius curves where the curve is a long distance from its center point.

There are two definitions of degree of curvature, D.

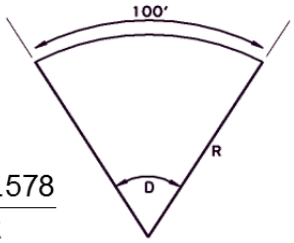
1) **Arc.** The curve central angle subtended by a 100 ft arc length; traditionally used for roadway design.

2) **Chord.** The curve central angle subtended by a 100 ft chord length; traditionally used for railroad design.

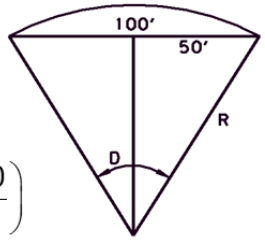
Many transportation agencies, including PennDOT, continue to use degree of curvature for circular curve design. It is therefore important to know the difference between the two definitions, and when working with existing roadway designs, to be able to recognize which method was used in preparing the original design computations. Regardless of which definition of degree of curvature is used, D can easily be converted to the corresponding, R, by using the appropriate equations.

The equations for converting from the arc and chord definitions to the corresponding radius are:

$$D = 360^\circ \frac{100'}{2\pi R} = \frac{5729.578}{R}$$



$$D = 2 \times \arcsin\left(\frac{50}{R}\right)$$



Note that in both equations, degree of curvature, D, and radius, R, are inversely related. The larger the radius, the smaller the degree of curvature. The larger the degree of curvature, the smaller the radius.

Many Pennsylvania roads were designed and built long before modern design methods became available. When designing improvements to such roadways, the designer must interpret historic data on original design plans that may have been prepared using degree of curvature. It is important to know which definition of degree of curvature was used, and to convert it to the correct radius. Some older Pennsylvania highways were designed with curves based on the chord definition. On those roads, accurate establishment of the legal right-of-way lines requires use of the chord definition.

3.2.3.d – Minimum Radius of a Horizontal Curve

When a vehicle moves along a circular path, it undergoes a centripetal acceleration that acts toward the center of curvature. This acceleration is sustained by a component of the vehicle's weight related to the roadway superelevation, by the side friction developed between the vehicle's tires and the pavement surface, or by a combination of the two. Centripetal acceleration is sometimes equated to centrifugal force. However, this is an imaginary force that motorists believe is pushing them outward while turning, when, in fact, they are truly feeling the vehicle being accelerated in an inward direction. In horizontal curve design, "lateral acceleration" is equivalent to "centripetal acceleration."

The minimum radius of horizontal curves is determined by the physics of a body traveling on a circular path. It is a limiting value of curvature for a given design speed and is determined from the maximum rate of superelevation and the maximum allowable side friction factor. Thus, the minimum radius is a significant value in alignment design and is an important control value for the determination of superelevation rates for flatter curves.

The minimum radius of a curve is determined mathematically based on the following factors: design speed, side friction factor, and rate of superelevation. Refer to the Green Book, Section 3.3.3, *Design Considerations*, for the minimum radius equation.

3.2.4 – Types of Circular Curves

This section discusses several types of circular curves that may be used on horizontal alignments, and some which should be avoided.

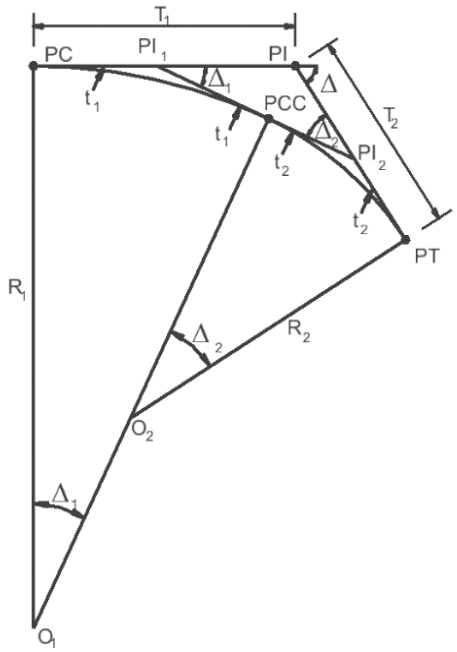
3.2.4.a – Simple Curves

Simple curves are continuous arcs of constant radius that achieve the necessary roadway deflection without an entering or exiting taper. The radius (R) defines the circular arc that a simple curve will transcribe. All angles and distances for simple curves are computed in a horizontal plane. Because of their simplicity and ease of design, survey, and construction, this is the most widely used type of circular curve.

3.2.4.b – Compound Circular Curves

As shown in **Exhibit 3.2.2**, a compound circular curve is a series of two or more adjacent simple curves that turn in the same direction. These curves are typically used at intersections, interchange ramps, and to avoid some control or obstacle which cannot be relocated. The following guidelines should be followed when using compound curves.

Exhibit 3.2.2 – Compound Circular Curve

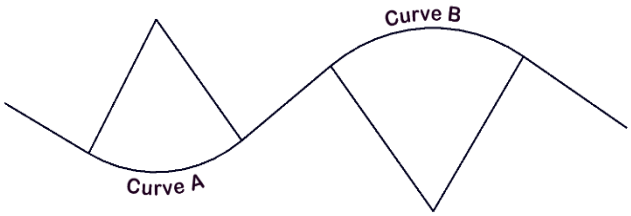


At intersections and interchange ramps, where drivers are typically willing to accept more rapid changes in direction and speed, it is important the drivers are not surprised by an abrupt increase in curvature. On single direction roadways (ramps), this applies only where traffic flows from a flatter curve onto a sharper curve. See the Green Book, Section 3.3.7, *Turning Roadways*, "Use of Compound Curves" for maximum ratios of flatter curve radius to sharper curve radius.

Superelevating a compound curve requires careful consideration. Often each radius requires a different rate

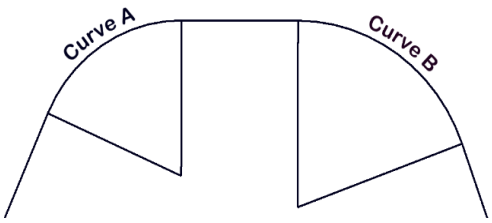
of superelevation. For the transition from one rate to another to be smooth and unnoticeable, the transition should occur entirely on the larger radius curve. See Section 3.3.4.c for further discussion of superelevation on compound curves.

3.2.4.c – Reverse Curves



Reverse curves are two simple curves, that curve in opposite directions and are joined by a relatively short (less than 300-foot) length of intervening tangent. They are not desirable and should be avoided. However, they may be applicable to accommodate bridge locations and mountainous terrain. If a reverse curve must be used, special attention must be given to superelevation development. This includes providing enough tangent length between curves to enable a smooth and sufficiently gradual transition length. If the length of intervening tangent is too short, one or both of the following adjustments may be needed. More than 1/3 of the superelevation transition may have to occur on each curve rather than on the intervening tangent. Typically, the transition length on the curve is limited to 1/3 the total transition length. Alternatively, the rate of superelevation may be reduced, which results in greater reliance on side friction and a reduction in driver comfort. It is undesirable to increase to the maximum relative gradient for the superelevation transition. See Section 3.3.4.d for discussion of methods of developing superelevation on reverse curves.

3.2.4.d – Broken-Back Curves



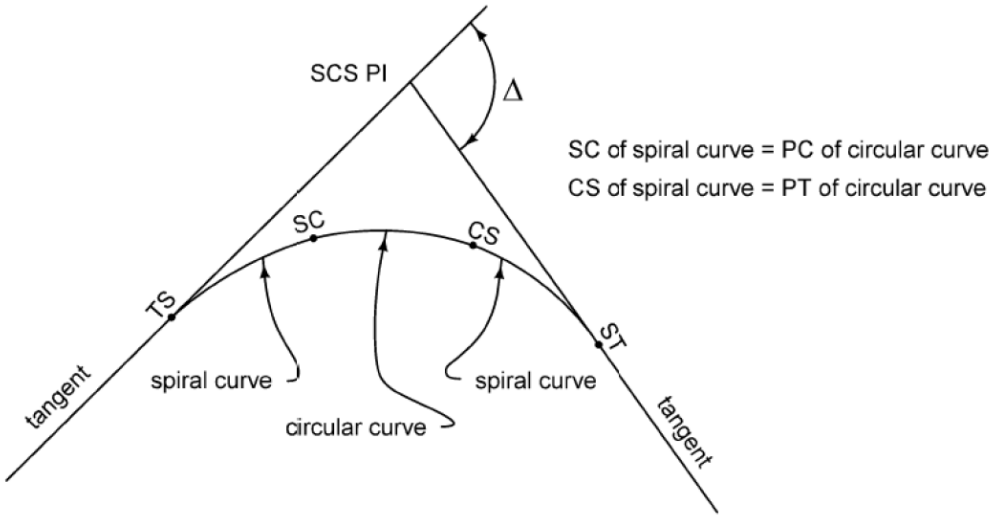
Broken-back curves are closely spaced horizontal curves curving in the same direction with a short length tangent section between curves. Use of broken back curves should be avoided because they may confuse drivers not expecting this layout. Also, the intervening tangent may be too short for a normal transition from full superelevation to normal crown and then back to full superelevation. Consequently, depending on the intervening tangent length, the superelevated section may need to extend across the entire tangent length, which in many cases may be a bridge. Also, the view of the roadway ahead is generally shorter and not as flowing as on a single longer curve and is and therefore less pleasing to drivers. Instead of a broken-back curve, use of a single longer curve or, if necessary, a compound curve, are preferred.

3.2.5 – Transition (Spiral) Curves

Transition spirals are horizontal curves that are often used in the design of high-speed horizontal alignments to provide more gradual transitions on entry and exit from circular curves. PennDOT recommends, but does not require the use of transition spirals on roadways with design speeds greater than 45 mph. The combination of high speed and sharp curvature can induce vehicles to drift laterally and sometimes even encroach on an adjacent lane or shoulder. Spirals provide longer and more gradual transitions which help drivers steer their vehicles and keep them from drifting. Spiral curves are generally desirable because they approximate the turning path of a vehicle's wheels from when a driver begins to turn the steering wheel until it reaches the maximum degree of curvature at the circular portion of the curve.

As shown in **Exhibit 3.2.3**, spiraled curves are typically divided into an entering spiral, a central circular curve, and an exiting spiral. The degree of curvature along a spiral is continuously increasing or decreasing, depending on whether the spiral is entering or exiting the central curve. In most cases the entering and exiting spirals are of equal length. The actual degree of curvature at a point on a spiral is in direct proportion to the distance along the spiral to the point from adjacent Tangent to Spiral (TS) or Spiral to Tangent (ST). A spiral curve is tangent to the central circular curve at the Spiral to Curve (SC) and the Curve to Spiral (CS) point where they share the same degree of curvature (or radius).

Exhibit 3.2.3 – Typical Locations of Spirals on a Spiraled Curve



They also benefit drivers because they:

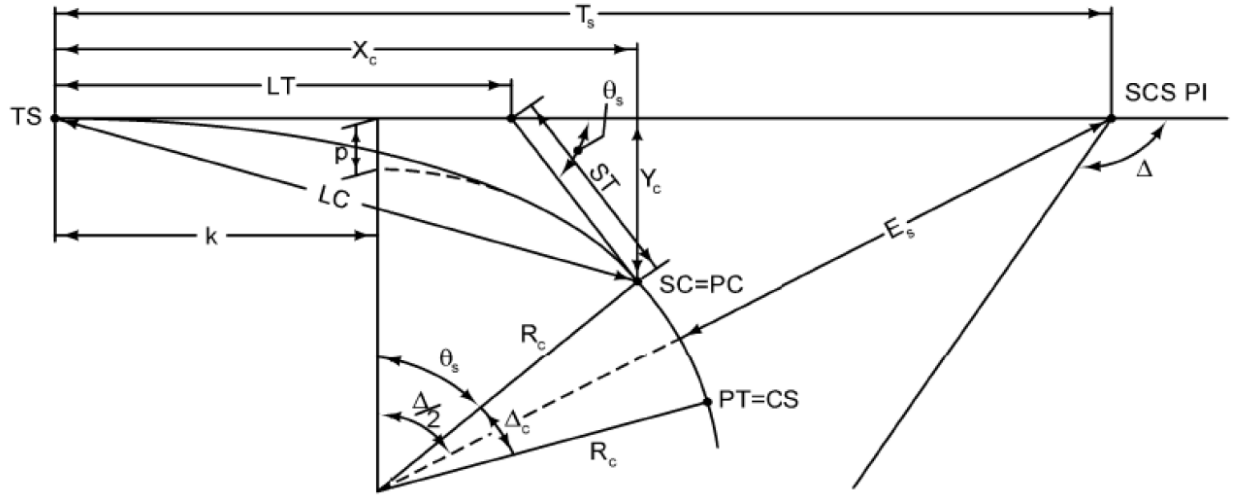
- Provide a gradual change in curvature from a straight to a circular path.
- Provide a natural, easy-to-follow path that more closely matches the turning path of the design vehicle
- Provide a suitable location for superelevation runoff
- Provide a smoother and more aesthetically pleasing appearance.
- Provides a transitional path to reduce the tendency to deviate from the traffic lane

On freeways and expressways, spirals may be used for curves with radii of 5729.58 ft and less (with degree of curves of 1° and greater) and on arterial roadways, spirals may be used for curves with radii of 2864.79 ft and less (with degree of curves of 2° and greater). Spiral curve lengths are generally determined by design speed and radius of the circular curve.

Generally spiral curves are not used for curves with radius less than 300 ft. The use of compound curves is preferred on interchange ramps where a 2:1 ratio of flatter curve radius to sharper curve radius in the direction of traffic is acceptable and minimum curve length criteria is met. Spiral transitions curves should be used in place of multiple compound curves where the 2:1 radius ratio and minimum curve length criteria cannot be met.

Exhibit 3.2.4 presents the components of a transition (spiral) curve.

Exhibit 3.2.4 – Components of a Transition (Spiral) Curve



3.2.5.a – Spiraled Curve Terminology

R_c = Radius of Circular Curve

D_c = Degree of Curvature

T_s = Tangent Distance

$\triangle$ = Delta – Deflection Angle

E_s = External Distance

LC = Long Chord

LT = Long Tangent

Ls = Length of Spiral

L = Length of Adjoining Circular Curve

θ_s = Central Angle of Spiral Arc Ls

$\triangle$ = Total Central Angle of the Circular Curve

$\triangle_c$ = Central Angle of Circular Curve

ST = Short Tangent

Xc = Tangent Distance to SC

Yc = Tangent Offset to SC

k = Abscissa Distance, TS to Shifted PC

p = Offset from Initial Tangent to Shifted PC

PI = Point of Intersection of Main Tangents

TS = Tangent to Spiral Point

SC = Spiral to Curve Point

CS = Curve to Spiral Point

ST = Spiral to Tangent Point

3.2.5.b – Spiraled Curve Equations

Exhibit 3.2.5 presents the equations for spiraled curve computations.

Exhibit 3.2.5 – Equations for Spiraled Curve Computations

$$D_c = \frac{18{,}000}{\pi \times R_c}$$

$$D_c = 200 \times \frac{\theta_S}{L_S}$$

$$L_S = 200 \times \frac{\theta_S}{D_c}$$

$$\theta_S = \frac{L_S \times D_c}{200}$$

$$\Delta = \frac{180 \times L}{\pi \times R_c}$$

$$\Delta_c = \Delta - 2 \times \theta_S$$

$$X_c = \frac{L_S}{100} \times (100 - 0.0030462\,(\theta_S)^2)$$

$$Y_c = \frac{L_S}{100} \times \left(0.58178\,\theta_S - 0.000012659\,(\theta_S)^3\right)$$

$$p = Y_c - R_c \times (1.0 - \cos\theta_S)$$

$$A = \frac{20{,}000 \times \theta_S}{(L_S)^2}$$

$$k = \frac{1}{2}L_S - 0.000127A^2 \times \left(\frac{L_S}{100}\right)^5$$

$$T_S = (R_c + p) \times \tan\frac{\Delta}{2} + k$$

$$E_S = (R_c + p) \times \left(\tan\frac{\Delta}{2}\right)\tan\frac{\Delta}{4} + p$$

$$LT = X_c - (Y_c \times \cot\theta_S)$$

$$ST = \frac{Y_c}{\sin\theta_S}$$

$$LC = Ls - 0.00034\,A^2 \times \left(\frac{L_S}{100}\right)^5$$

3.2.5.c – Example Spiral Curve Computations

Spiral Curve Example 1

Given the following data:	PI Sta = 436+89.20	Δ = 56° 00' 00" RT	Dc = 9° 00'	Ls = 300.00'
Use the equations in Exhibit 3.3.5 to compute the following. The Spiral Curve Data is listed at right.	R_c Δ_c D_c R_c L_c	θ_s Ls T_s E_s k	p X_c Y_c LT ST	LC TS Sta SC Sta CS Sta ST Sta

Spiral Curve Example 1 Computations

$$R_c = \frac{18{,}000}{\pi \times D_c} = \frac{18{,}000}{\pi \times 9^o} = 636.620' \qquad L = \frac{\Delta}{180^o} \times \pi R_c = \frac{56.000^o}{180^o} \times \pi 636.620' = 322.220'$$

$$\theta_S = \frac{L_S \times D_c}{200} = \frac{300.000 \times 9^o}{200} = 13.500^o$$

$$X_c = \frac{L_S}{100} \times \left(100 - 0.0030462\,(\theta_S)^2\right) = \frac{300.000}{100} \times \left(100 - 0.0030462\,(13.500^o)^2\right) = 298.334'$$

$$Y_c = \frac{L_S}{100} \times \left(0.58178\,\theta_S - 0.000012659\,(\theta_S)^3\right) = 23.469'$$

$$p = Y_c - R_c \times (1.0 - \cos\theta_S) = 23.469' - 636.620' \times (1.0 - \cos 13.500^o) = 5.879'$$

$$A = \frac{20{,}000 \times \theta_S}{(L_S)^2} = \frac{20{,}000 \times 13.5^o}{(300.000')^2} = 3.000$$

$$k = \frac{1}{2}L_S - 0.000127A^2 \times \left(\frac{L_S}{100}\right)^5 = \frac{1}{2}(300.000') - 0.000127(3.000)^2 \times \left(\frac{300.000'}{100}\right)^5 = 149.722'$$

$$T_S = (R_c + p) \times \tan\frac{\Delta}{2} + k = (636.620' + 5.879') \times \tan\frac{56^o}{2} + 149.722' = 491.345'$$

$$E_S = (R_c + p) \times \left(\tan\frac{\Delta}{2}\right)\tan\frac{\Delta}{4} + p = (636.620' + 5.879') \times \left(\tan\frac{56^o}{2}\right)\tan\frac{56^o}{4} + 5.879' = 91.055'$$

$$LT = X_c - (Y_c \times \cot\theta_S) = 298.334' - (23.469' \times \cot 13.5^o) = 200.579'$$

$$ST = \frac{Y_c}{\sin\theta_S} = \frac{23.469'}{\sin 13.500^o} = 100.532'$$

$$LC = Ls - 0.00034\,A^2 \times \left(\frac{L_S}{100}\right)^5 = 300.00' - 0.00034\,A^2 \times \left(\frac{L_S}{100}\right)^5 = 299.256'$$

$$\Delta_c = \Delta - 2 \times \theta_S = 56.000^o - 2 \times 13.500^o = 29.000^o$$

PI Sta	436+89.	SC	434+97.8
- Ts	-491.35	+ Lc	+322.22
TS Sta	431+97.	CS	438+20.0
+ Ls	+300.00	+ Ls	+300.00
SC Sta	434+97.	ST	441+20.0

Spiral Curve Example 2

A surveyor is staking out the spiral curve described in Example 1 and needs to set a point P on the 300-foot entry spiral. Point P is to be set 152.85 ft from the TS (measured along the spiral). Use the above spiral equations to determine the intersection angle (θ) between the tangent of the complete curve and the tangent to the spiral at an arbitrary point P.

$$\theta = \frac{L^2}{L_S^2} \times \theta_S = \frac{152.85^2}{300^2} \times 13.500^o = 3.5045^o = 3^o30'16.09"$$

$$x = \frac{L}{100} \times \left(100 - 0.0030462\,(\theta)^2\right) = \frac{152.85'}{100} \times \left(100 - 0.0030462\,(3.5045^o)^2\right) = 152.793'$$

$$y = \frac{L}{100} \times \left(0.58178\,\theta - 0.000012659\,(\theta)^3\right) = \frac{152.85'}{100} \times \left(0.58178\,(3.5045^o) - 0.000012659\,(3.5045^o)^3\right)$$

$$= 3.116'$$

3.2.6 – Maximum Baseline Deflection Angle Without a Horizontal Curve

Although long flowing curves are more aesthetically pleasing and clearly preferred, there are situations on open roads where for small (0.5° to 1.0°) deflection angles, a curve may not be practical. The maximum horizontal deflection angle without a curve depends on the roadway location (urban or rural) and design speed. On low design speed, urban locations, larger deflection angles (5° 30’ or less) may be acceptable, but on higher design speed, rural locations, deflection angles without curves are restricted to 1° 0’ or less.

Exhibit 3.2.6 presents the maximum baseline deflection angles without a horizontal curve that are acceptable for a range of design speeds. These angles are based on formulas for taper lengths in the *Manual of Uniform Traffic Control Devices*, Table 6C-4, and rounded to the closest 5 minutes.

Exhibit 3.2.6 – Maximum Baseline Deflection Angles Without a Horizontal Curve

Design Speed, V (mph)		Maximum Deflection Angle, △, Without Horizontal Curve
Low Speed	25	5°30’
	30	3°45’
	35	2°45’
	40	2°05’
	45	1°40’
High Speed	50	1°05’
	55	1°00’
	60	0°55’
	65	0°50’
	70	0°45’

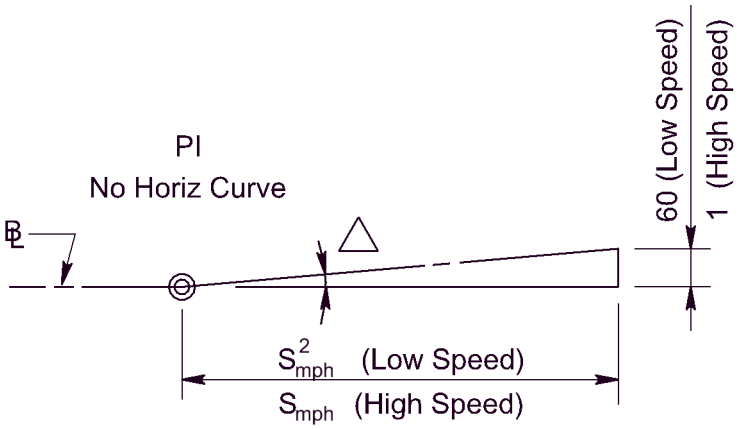
These maximum deflection angles are based on the following formulas for determining taper lengths:

Low Speed: $L = WS^2/60$; $Tan\triangle = 60/S$
High Speed: $L = WS$; $Tan\triangle = 1/S$

Where:

- S = Design Speed (mph)
- L = Taper Length (ft)
- W = Width of offset (ft)
- △ = Maximum Deflection Angle Without curve

Source: Ohio DOT, *Location and Design Manual*, 2013



The recommended minimum distances between consecutive horizontal deflections are:

- High Speed (45 mph or more): 200 ft
- Low Speed (less than 45 mph): 100 ft

3.2.7 – General Considerations for Horizontal Alignment Design

The following general considerations are important in attaining smooth flowing and aesthetically pleasing facilities. These practices as outlined below are particularly applicable to high-speed facilities.

1) To obtain balance in highway design, all geometric elements should be designed, as far as economically practical, to operate at a speed likely to be observed under the normal conditions for that roadway for the vast majority of motorists. This can be achieved through the use of design speed as an overall design control.
2) Abrupt reversals in alignment and sharp curvature on long, high fills should be avoided.
3) Curves should be designed based on an appropriate relationship between design speed and curvature and their joint relationships with superelevation and side friction. These

factors shall be properly balanced to produce an alignment that is safe, in harmony with the topography, and meets the design criteria.

4) Flatter than minimum curvature for a certain design speed should be used where possible, retaining the minimum guidelines for the most critical conditions.

5) Compound curves should be used with caution and should be avoided on mainlines where conditions permit the use of flat simple curves.

6) Alignment consistency should be sought. Sharp curves should not follow tangents or a series of flat curves.

7) Reverse curves on high-speed facilities should include an intervening tangent section of sufficient length to provide adequate superelevation transition between the curves.

8) Broken-back curves (two curves in the same direction connected with a short tangent) should be avoided. This type of curve is not expected by drivers and not pleasing in appearance.

9) Horizontal curves should be avoided on bridges when practical. These could cause design, construction, and operational challenges. When a curve is necessary on a bridge, a simple curve should be used on the bridge and any curvature or superelevation transitions placed on the approaching roadway when practical.

10) Alignment should be as directional as practical, but it should be consistent with the topography and with preserving developed properties and community values.

11) For small deflection angles, curves should be sufficiently long to avoid the appearance of a kink.

12) To avoid the appearance of inconsistent distortion, the horizontal alignment should be coordinated carefully with the vertical alignment as discussed in Section 3.5, *Controls for Combination Horizontal and Vertical Alignments*. Such coordination is especially important at railroad-highway grade crossings.

13) When practical, maintain a constant superelevation rate across a small structure instead of placing superelevation transitions on the bridge.

For more information about general considerations for horizontal alignment refer to the Green Book, Section 3.3.13, *General Controls for Horizontal Alignment*.

Horizontal alignment and its associated design speed should be consistent with other design features and topography. Coordination of the horizontal and vertical alignments is discussed in Section 3.5.

3.2.8 – Traveled Way Widening on Horizontal Curves

On horizontal curves vehicles may need a wider traveled way than on tangent sections to remain within their travel lanes because:

- The design vehicle occupies a greater width because the rear wheels generally track inside the front wheels (off-tracking) in negotiating curves.
- Drivers may experience difficulty in steering vehicles in the center of the lane.

The needed traveled way width has several variables including track width for passing or meeting vehicles, lateral vehicle clearance, width of inner lane vehicle front overhang, and a width allowance for the difficulty of driving a curve as discussed in the Green Book, Section 3.3.10, *Traveled-Way Widening of Horizontal Curves*.

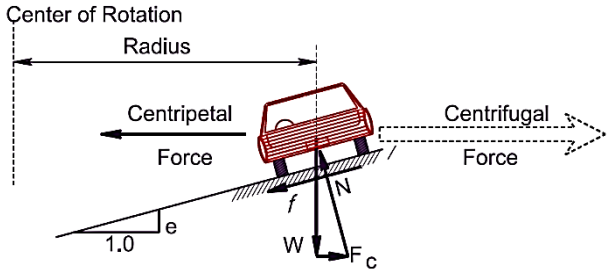
Widening should transition gradually on curve approaches to ensure a reasonably smooth alignment of the traveled way edge and to fit the turning path of the design vehicle as it enters and leaves the curve.

- On simple circular (non-spiraled) curves, widening should be applied on the inside edge of the traveled way only. On spiraled curves, widening may be applied on the inside edge or divided equally on either side of the lane centerline. The final marked centerline, and desirably any central longitudinal joint, should be placed midway between the edges of the widened traveled way.
- Curve widening should transition gradually over a length sufficient to make the whole of the traveled way fully usable. Preferably, widening should transition over the superelevation runoff length, but shorter lengths are sometimes used. Changes in width should be affected over a distance of 100 to 200 ft.
- The edge of the traveled way through the widening transition should be a smooth, graceful curve and a tangent transition edge should be avoided. The transition ends should avoid an angular break at the pavement edge.
- On highway alignments without spirals, smooth and fitting alignment results from attaining widening with one-half to two-thirds of the transition length along the tangent and the balance along the curve. The inside edge of the traveled way may be designed as a modified spiral, with control points determined by the width/length ratio of a triangular wedge, by calculated values based on a parabolic or cubic curve, or by a larger radius (compound) curve. On highway alignments with spiral curves, the increase in width is usually distributed along the length of the spiral.

Traveled way widening on an open roadway curve shall occur over the length of superelevation transition as shown in **Exhibit 3.3.1**.

3.3 – Superelevation

When a vehicle moves in a circular path, it undergoes a centripetal acceleration that acts toward the center of curvature. This acceleration is sustained by a component of the vehicle's weight related to the roadway superelevation, by the side friction developed between the vehicle's tires and the pavement surface, or by a combination of the two. The factor, known as superelevation, consists of tilting the roadway to provide safe and continuous vehicle operation.



A vehicle traveling at a constant speed on a curve superelevated for that specific speed, the side friction value is zero and the centripetal acceleration is sustained by the vehicle's weight resulting in no steering effort on the part of the vehicle operator. The curves on a given facility are designed for a certain running speed and vehicles traveling at that speed should be able to negotiate the turns with ease. Vehicles, however, travel at a wide range of speeds and therefore the drivers must exert themselves to successfully negotiate these curves. They are aided by side friction on the tires. From the minimum radius equation in the Green Book, Section 3.3.3, *Design Considerations*, it is evident that superelevation is based on design speed; therefore, the classes of highways shall be superelevated according to their speed rather than using a superelevation for a single radius for all design speeds.

3.3.1 – Maximum Superelevation

The maximum rate of superelevation shall be limited to 6.0% in urban areas, and 8.0% in rural areas. In densely populated urban areas where traffic congestion and extensive land development restrict design speeds to 45 mph or less, PennDOT recommends the use of low-speed urban design which is discussed in Section 3.3.2.

These maximum superelevation rates are based on consideration of climate, terrain, type of area (urban or rural), and frequency of very slow-moving vehicles. In urban areas where population densities are much higher than in rural areas, there is greater potential for traffic congestion. During cold weather months when traffic congestion coincides with snow and ice conditions, travel speeds are reduced, and there is a greater potential for stopped or slow-moving vehicles to slide across superelevated pavement. In rural areas there is less potential for traffic congestion, but the possibility of sliding due to cold weather conditions still exists.

Similarly, either a low maximum rate of superelevation or no superelevation is often recommended in intersection areas or where the posted speed limit (or running speeds) is less than 25 mph due to turning and crossing movements, warning devices and signals. In these areas, it may be difficult to warp crossing pavements for drainage without providing negative superelevation for some turning movements.

3.3.2 – Low-Speed Urban Superelevation Design

On low-speed (40 mph or less) urban streets where design speeds are relatively low and variable, designing superelevation based on the maximum rate for urban streets of 6% is often impractical. PennDOT recognizes these limitations and that drivers on low-speed urban streets are generally more accepting of the slight discomfort caused by lateral acceleration on

horizontal curves. PennDOT provides the following options for reducing the rate of superelevation on low-speed urban streets:

1) **The Green Book, Section 3.3.5, *Design Superelevation Tables*.** This approach limits the maximum superelevation rate to 4% and refers to Green Book, Table 3-8, *Minimum Radii for Design Superelevation Rates, Design Speeds, and e_{max} = 4%*. Green Book, Figure 3-3, "Side Friction Factors for Streets and Highways", shows the recommended side friction factors for low-speed streets and highways. These recommended side friction factors provide a reasonable margin of safety at low speeds and lead to somewhat lower superelevation rates as compared to the high-speed friction factors. The side friction factors vary with design speed from 0.38 at 10 mph to 0.15 at 45 mph. Based on the maximum allowable side friction factors in Green Book, Figure 3-4, *Side Friction Factors Assumed for Design*, Green Book, Table 3-8, gives the minimum radii for the maximum superelevation rate of 4.0%.

2) **The Green Book, Section, 3.3.6, *Design for Low-Speed Urban Streets*.** This approach is recommended for the design of horizontal curves where, through conditioning, drivers have developed a higher threshold of discomfort. Under this method, it is assumed that none of the lateral force is counteracted by superelevation, provided the side friction factor is less than the specified maximum for the radius of the curve and the design speed. Refer to Green Book, Table 3-13, *Minimum Radii and Superelevation for Low-Speed Streets in Urban Areas*.

3.3.3 – Design Superelevation Tables

Refer to the Green Book, Section 3.3.5, *Design Superelevation Tables*. When using these tables for a given radius, interpolation is not necessary because the design superelevation rate should be determined from a radius equal to, or slightly smaller than, the radius provided in the Table. The result is a superelevation rate that is rounded up to the nearest 0.2%.

The Green Book, Section 10.9.6.2, *General Ramp Design Considerations*, provides guidelines for the design of superelevation and cross slope on ramps. Guidelines for the development of superelevation at free-flow ramp terminals are found in Green Book, Section 10.9.6.2.14, *Superelevation and Cross Slope*.

3.3.4 – Length of Superelevation Transition

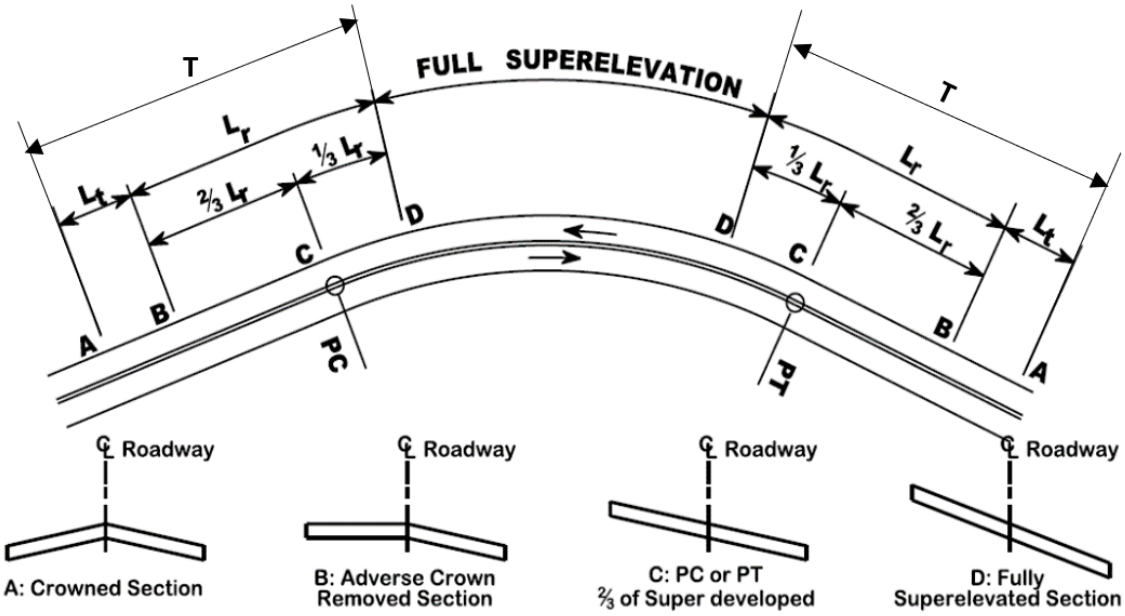
When a vehicle enters or leaves a horizontal curve, it generally follows a suitable transition path within the limits of normal lane width. However, combinations of high speed and sharp curvature lead to longer transition paths, which can result in shifts in lateral position and encroachment on adjoining lanes. As discussed in Section 3.3.4.b, for comfort and safety, incorporation of a transition curve (a flatter circular curve in low-speed streets or ramp roadways with expectant varying curvatures, or spiral curve in higher speed roadways) should be provided. The transition curve is between the tangent and a sharper circular curve. It could also be between circular curves of substantially different radii. Transition curves may be appropriate to make it easier for

a driver to keep their vehicle within its own lane. Singular spiral curves by themselves already have transitions built into the design.

The principal advantages to transitioning the superelevation of a roadway are:

- Provides a natural, easy-to-follow path for drivers such that the lateral force increases and decreases gradually as the vehicle enters and leaves a circular curve, minimizing encroachment on adjacent lanes and promoting uniformity in speed.
- Provides a suitable location for the superelevation runoff.
- Facilitates the transition in width where the traveled way is widened on a circular curve. Superelevation transitions provide flexibility in accomplishing the widening of sharp curves.
- Enhances the appearance of the highway or street by reducing or eliminating the noticeable breaks in the alignment as perceived by drivers at the beginning and ending of circular curves.

Exhibit 3.3.1 – Superelevation Transition Diagram



3.3.4.a – Superelevation Terminology

This section defines the component parts of a typical circular curve superelevation transition which are shown in Exhibit 3.3.1.

- **Total Superelevation Transition Length (T).** This is the total length needed to rotate lane(s) from a normal crown section to fully superelevated section. The length T is the sum of two component lengths: Tangent Runout (L_t) and Superelevation Runoff (L_r).

  The minimum length of superelevation transition is determined by the following equation:

$$T = L_r + L_t$$

where: T = minimum length of superelevation transition (ft)
L_r = minimum length of superelevation runoff (ft)
L_t = minimum length of tangent runout (ft)

- **Tangent Runout (L_t).** This is the length needed to rotate lane(s) from a normal crown section to a section with the adverse cross slope removed. To provide a smooth edge of traveled way profile, the rate of removal should be the same as the rate used to determine the minimum length of superelevation runoff (L_r). The minimum length of tangent runout, (L_t), is determined by the amount of adverse cross slope to be removed and the rate at which it is removed and is calculated using Green Book, Equation 3-24.

- **Superelevation Runoff (L_r).** This is the length needed to rotate lane(s) from a section with adverse cross slope removed to a fully superelevated section or vice versa. Minimum lengths of superelevation runoff (L_r) for one and two lanes rotated are presented in Green Book, Table 3-16a, *Superelevation Runoff L_r (ft) for Horizontal Curves*. These lengths should be increased only if needed. If L_r is increased, the length of tangent runout (L_t) should also be increased to maintain a smooth edge-of-traveled way profile.

  The L_r lengths provided in the Green Book, Table 3-16a, *Superelevation Runoff L_r (ft) for Horizontal Curves*, are based on 12-foot lanes. For other lane widths, the runoff length should be in proportion to the ratio of the actual lane width to 12 ft. Shorter runoff lengths may be used in designs with narrower (10- to 11- foot) lanes, but in the interest of consistency and practicality, the use of tabulated runoff lengths is recommended. For scenarios which are not applicable to the Green Book, Table 3-15, Equation 3-23, and the desirable maximum gradients in Green Book, Section 3.3.8.2.1, *Minimum Length of Superelevation Runoff*, can be used to calculate the minimum superelevation runoff length.

3.3.4.b – Distribution of Superelevation Runoff

As shown in **Exhibits 3.3.2**, **3.3.3** and **3.3.4**, there are several approved methods of superelevation transition. The following factors should be considered in selecting the most appropriate method: functional classification, number of lanes rotated, spiraled or non-spiraled curve, widened or non-widened pavement, and divided or undivided roadways.

- **Non-Spiraled, Non-Widened Designs.** On tangent-to-curve (non-spiraled, non-widened) designs, the superelevation runoff (L_r) should be distributed such that 2/3 of L_r is on tangent and the remaining 1/3 is on the curve. Full superelevation shall be reached at a point beyond the Point of Curvature (PC) at a distance not greater than 1/3 of the minimum length of superelevation runoff (L_r). The same procedure shall be followed at the Point of Tangency (PT). This method, which is illustrated in Exhibits 3.3.2 and 3.3.4 and discussed in the Green Book, Section 3.3.8, *Transition Design Controls*, is widely used and known as the “2/3-1/3 rule”.

- **Non-Spiraled, Widened Designs.** On tangent-to-curve (non-spiraled, widened) designs, as shown in Exhibits 3.3.4 (top), total superelevation shall be reached at a point beyond the Point of Curvature (PC) at a distance equal to 1/3 of the minimum length of superelevation runoff (L_r), and curve widening shall be placed on the inside edge of curve and shall be attained in a distance equivalent to 2/3 of the length of superelevation runoff (L_r) to the nearest 5 ft. The same procedure shall be followed at the Point of Tangency (PT).
- **Spiraled Designs.** On spiral curve transitions, the superelevation runoff (L_r) should occur over the length of the spiral. As shown in Exhibits 3.3.2 (bottom) and 3.3.3 (bottom), superelevation shall be applied by removing the adverse cross slope through the minimum length of tangent runout (L_t) distance to the Tangent to Spiral (TS). Full superelevation shall be attained along the length of spiral and held between the Spiral to Curve (SC) and Curve to Spiral (CS).

The minimum length of spiral (L_s) may be greater than but is typically not less than the minimum length of superelevation runoff (L_r) depending on the formula and factors used. The minimum length of superelevation runoff (L_r) is applicable to all superelevated curves and the values for L_r should be used for the minimum lengths of spiral required. Spirals are seldom used when the design superelevation rate is less than 3.0%.

3.3.4.c – Compound Curve Superelevation Transitions

On compound curves the superelevation transition (T) between the curves shall be located entirely within the curve of larger radius. The difference in the superelevation rates of the two curves shall be entered in Green Book, Equation 3-23, to determine the length of this transition.

3.3.4.d – Reverse Curve Superelevation Transitions

As discussed in Section 3.3.4.c, for superelevation transitions between reverse curves (i.e., two closely spaced simple curves that curve in opposite directions), a sufficient length of intervening tangent should be provided. Along this tangent, a normal crown section does not need to be achieved; rather, the roadway may be continuously rotated in a plane about its axis. In this situation, the minimum length of intervening tangent would be 2/3 the sum of the L_r lengths of the two curves. Alternatively, if this minimum tangent length cannot be provided, the following options may be considered:

1) Consider reducing the proportion of L_r length on tangent from 0.67 to 0.60, which increases the proportion of L_r length on curve from 0.33 to 0.40.
2) Consider reducing the design superelevation rate by 10%, which will result in greater reliance on side friction and a possible reduction driver comfort. A design exception may still be required.
3) Consider using a combination of above techniques (1) and (2).

3.3.4.e – Broken-Back Curve Transitions

As discussed in Section 3.3.4.d, for superelevation transitions on broken-back curves (i.e., two closely spaced simple curves that curve in the same direction), there are basically two possible conditions.

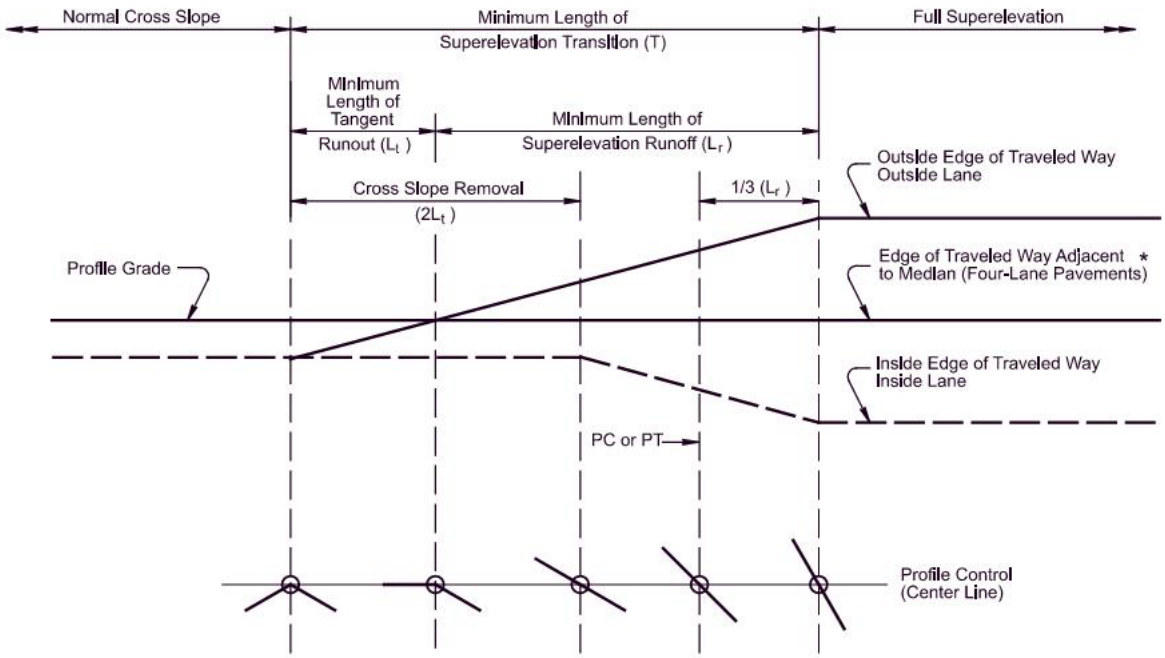
1) If the tangent length is relatively short (less than about 2/3 the sum of the L_r lengths of the two curves), on the intervening tangent section, maintain the design superelevation rate required by the larger radius curve and transition to the superelevation rate required by the shorter radius curve.
2) If the tangent length is relatively long (more than about 2/3 the sum of the L_r lengths of the two curves), consider transitioning the pavement to a 2% plane sloping in the direction of superelevation and extending across the entire cross section.

3.3.4.f – Methods of Attaining Superelevation

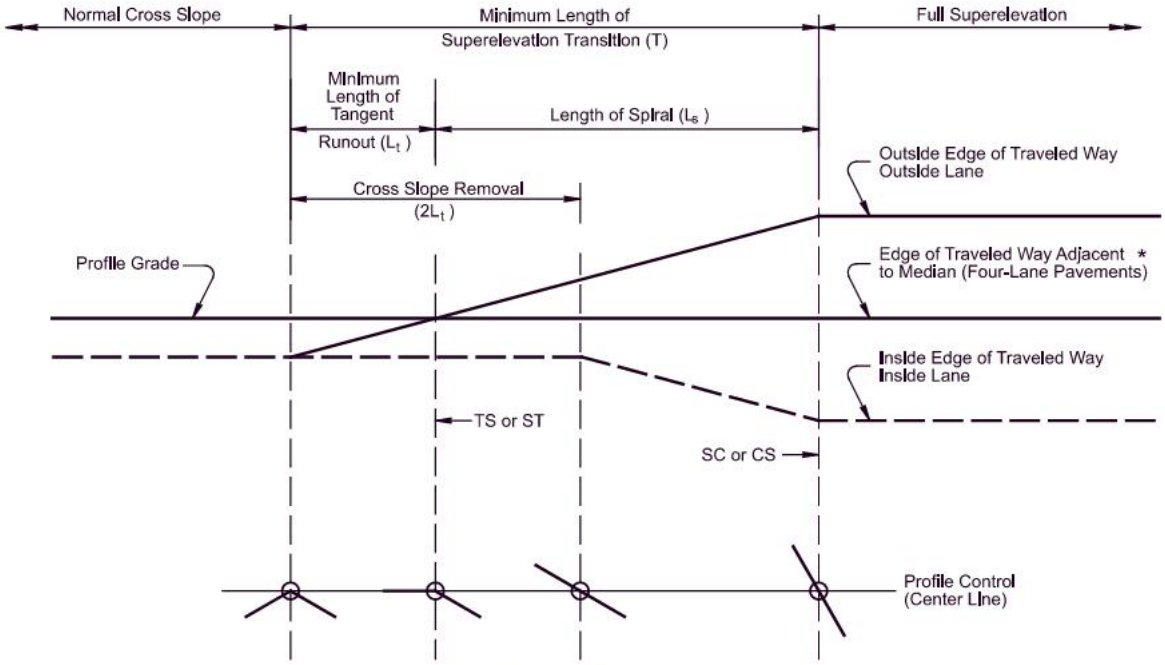
The PennDOT recommended method for superelevation transition is to revolve the traveled way about the inside edge of traveled way as shown in Exhibit 3.3.3. This method is particularly useful in situations where the superelevation design is affected by roadside features, such as curbing, median barrier, driveways, etc. However, another accepted method of attaining superelevation is by revolving about the centerline, as shown in Exhibit 3.3.2. This method results in less distortion than revolving about the inside edge. For more information about Transition Design Controls, including additional diagrammatic profile options. See the Green Book, Section 3.3.8.6, *Methods of Attaining Superelevation*.

Exhibit 3.3.2 – Diagrammatic Profiles Showing Method of Attaining Superelevation for all Functional Classifications**

Travelled Way Revolved About Centerline



(Non-Spiralled, Non-Widened)



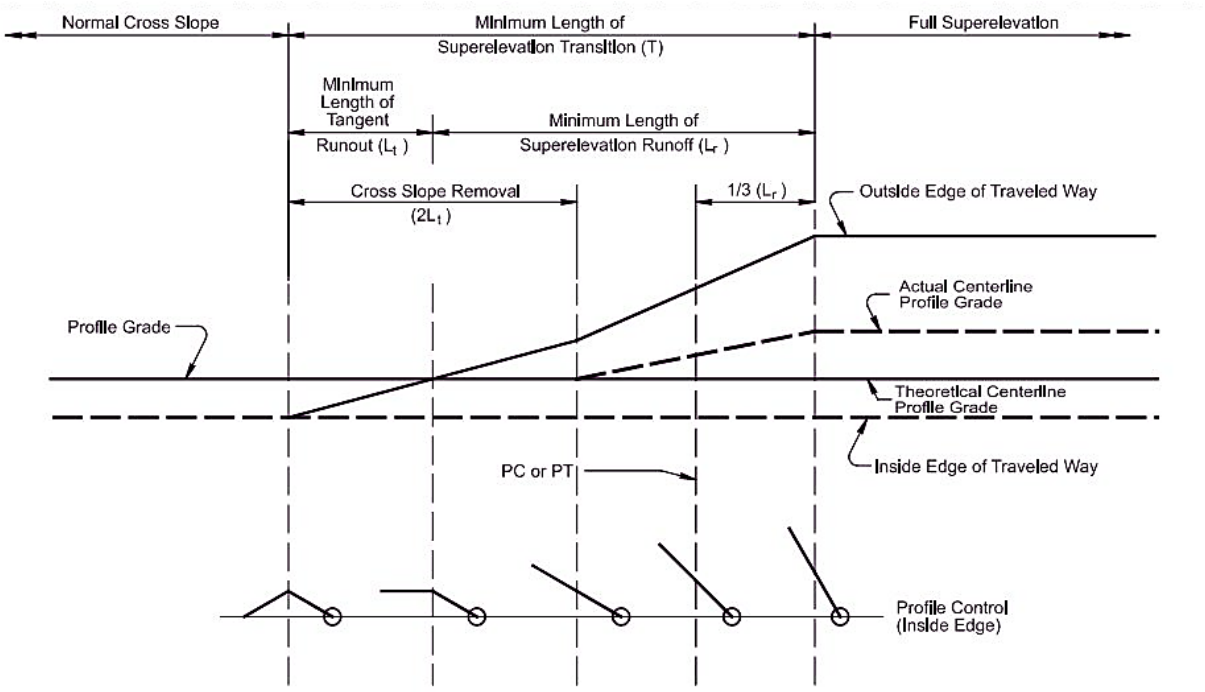
(Spiralled)

* For six and eight lane pavements, refer to Section 3.3.5.a for the location of this line.

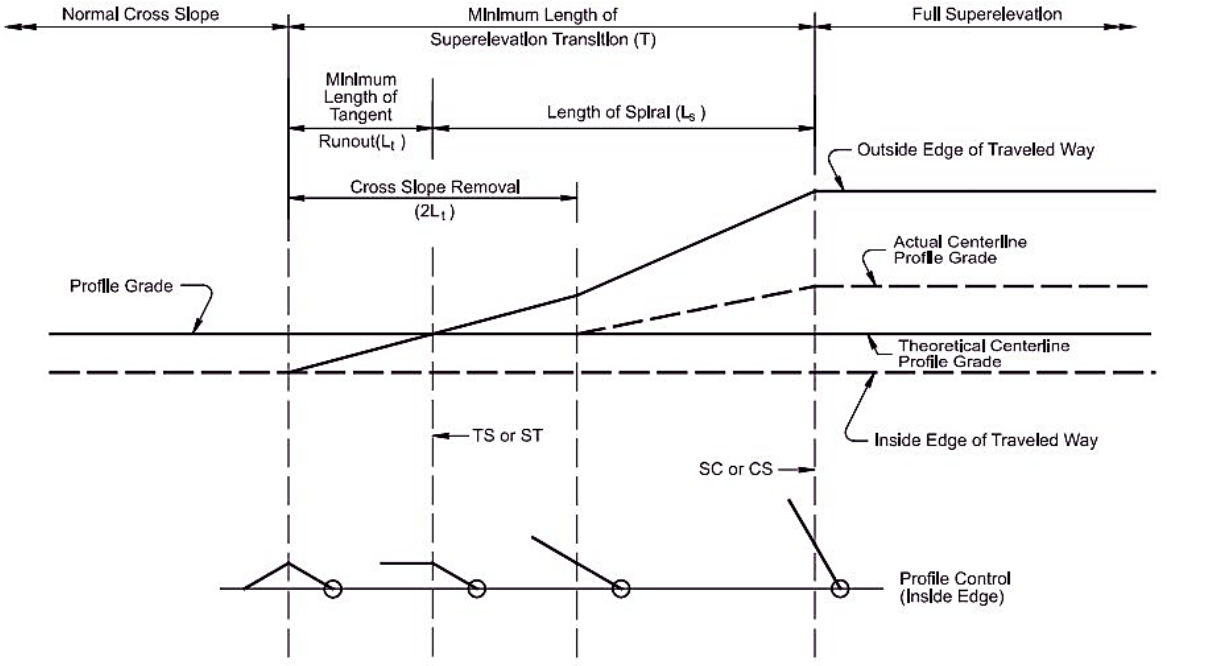
** When only two lanes are to be built initially.

Exhibit 3.3.3 – Diagrammatic Profiles Showing Methods of Attaining Superelevation for all Functional Classifications

Travelled Way Revolved About Inside Edge



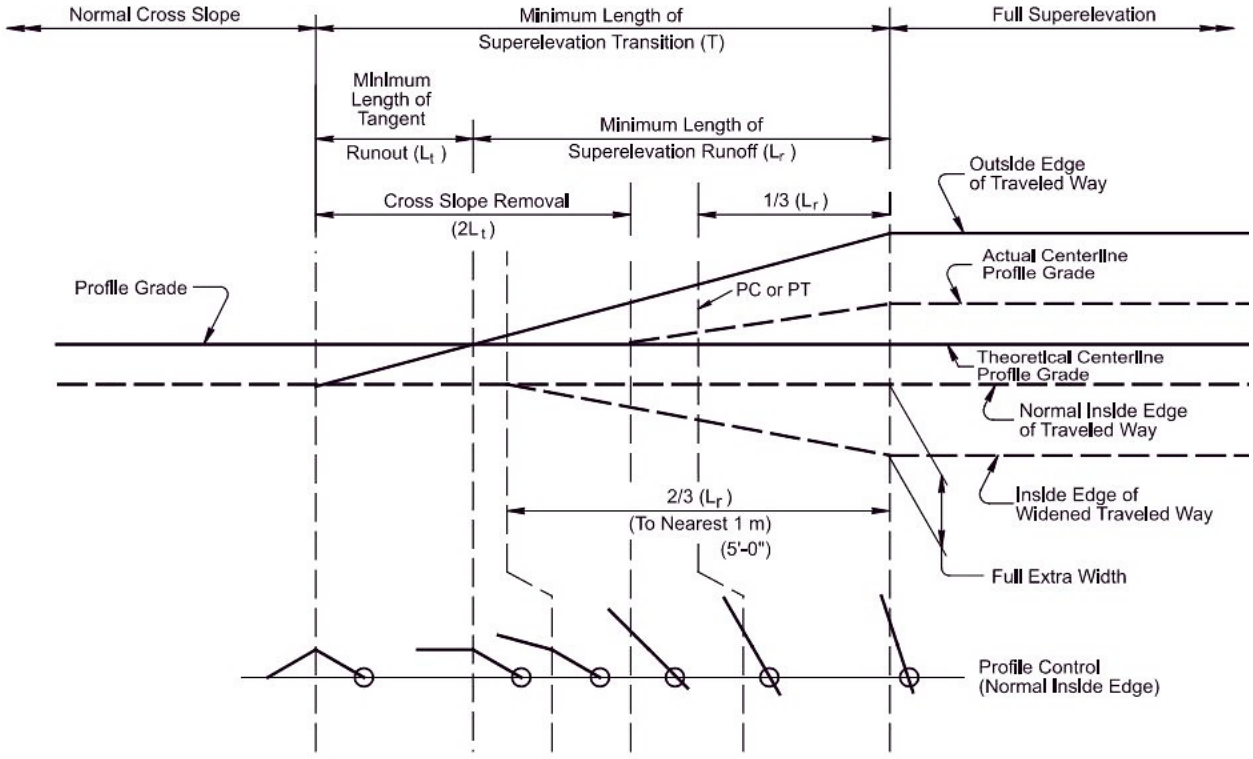
(Non-Spiralled)



(Spiralled)

Exhibit 3.3.4 – Diagrammatic Profiles Showing Method of Attaining Superelevation - Option for Collectors and Local Roads Only

Travelled Way Revolved About Inside Edge



(Non-Spiralled, Widened)

3.3.5 – Maximum Relative Gradients

For appearance and comfort, the length of superelevation runoff should be based on a maximum acceptable difference between the longitudinal grades of the axis of rotation and the edge of traveled way. This relationship is defined as the maximum relative gradient.

The maximum relative gradient varies with design speed and controls the rate at which the edges of travelled way pavement rise and fall relative to the roadway profile grade. It also varies with design speed to provide longer runoff lengths and more gradual pavement edge transitions at higher speeds and shorter lengths and less gradual transitions at lower speeds. Green Book, Section 3.3.8.2.1, *Minimum Length of Superelevation Runoff*, provides maximum relative gradients values for various design speeds. Runoff lengths determined on this basis are directly proportional to the total superelevation, which is the product of the lane width and superelevation rate.

Therefore, the minimum length of superelevation runoff should be determined using Green Book Equation 3-23. This equation can be used directly for undivided streets or highways where the cross section is rotated about the highway centerline.

A strict application of the maximum relative gradient criterion provides runoff lengths for four-lane undivided roadways that would be double those for two-lane roadways; those for six-lane undivided roadways would be triple those for those for two-lane roadways. While lengths of this order may be considered desirable, it is often not practical to provide such lengths. As explained in the Green Book, Section 3.3.8, *Transition Design Controls*, it is recommended that on multilane roadways minimum superelevation runoff lengths be adjusted downward to avoid excessive lengths.

Green Book Equation 3-23 includes an adjustment factor, b_w, which reduces the runoff length based on the number of lanes rotated, n_1. Recommended adjustment factors, b_w, for 1 to 3.5 lanes rotated, are presented in Green Book, Table 3-15, *Adjustment Factor for Number of Lanes Rotated*. In situations where more than 3.5 lanes are rotated, the Green Book provides the following equation:

$$b_w = \frac{[1 + 0.5(n_1 - 1)]}{n_1}$$

For divided multilane highway curves, there is no single method of developing superelevation transition that is consistently most appropriate in all situations. The designers should consider many factors, including drainage, rideability, aesthetics, direction (left or right) of curvature, and the locations of the profile grade line (PGL) and axis of rotation when evaluating alternative methods of superelevation transition.

Development of superelevation runoff for divided highways is discussed in more detail in the Green Book, Section 3.3.8.8, *Axis of Rotation with a Median*.

Section 3.3.4.f presents examples of superelevation design that use maximum relative gradients and alternative methods of developing superelevation transition on a five-lane directional freeway.

3.3.5.a – Location of Profile Grade Line

The Profile Grade Line (PGL) controls the roadway's vertical alignment through the horizontal curve. Although shown as a horizontal line in Exhibits 3.3.2, 3.3.3 and 3.3.4, the PGL may correspond to a tangent, a vertical curve, or a combination of the two. In Exhibit 3.3.2, the PGL corresponds to the centerline profile. In Exhibits 3.3.3 and 3.3.4, the PGL is represented as a "theoretical" centerline profile grade because it does not coincide with the axis of rotation.

For four-lane divided roadways with a paved or unpaved median-divisor, hold the profile grade on the edge of traveled way adjacent to the median-divisor, as shown in **Exhibit 3.3.5**. Cross sections A through E represent the following points in the superelevation transition.

A. Normal Crown

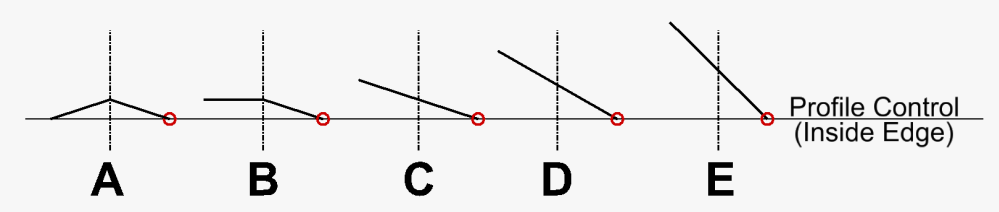
B. Adverse Crown Removed

C. Crown Removed

D. PC or PT (1/3 of L_r)

E. Full Superelevation

Exhibit 3.3.5 – Cross Sections Showing Profile Control at Inside Edge of Traveled Way



Also, see the Green Book, Figure 3-8, *Diagrammatic Profiles Showing Methods of Attaining Superelevation for a Curve to the Right – B –*, for profile control revolved about the inside edge of traveled way.

For six-lane pavements with paved or unpaved divisors, hold the profile grade one lane width from the median edges of the traveled way. For eight-lane pavements with paved or unpaved divisors, hold the profile grade on the traveled way two-lane widths from the median edges of the traveled way.

As shown in Section 3.3.6, Examples 4 and 5, the PGL may be for Freeways and Expressways.

3.3.5.b – Superelevation Transition on Divided Highway

Providing a median to create a divided highway may influence superelevation transition design. This influence stems from the several possible locations for the axis of rotation. The most appropriate location for this axis depends on the width of the median cross section. For a discussion of common combinations of these factors and the appropriate corresponding axis location, refer to the Green Book, Section 3.3.8.8, *Axis of Rotation with a Median*.

For narrow medians (less than 20 ft wide) on curved roadway sections with concrete median barrier, special attention is needed to assure that the median shoulder edge profiles are relative elevations. Depending on superelevation and shoulder slopes, it may be necessary to define the profile grade along the high side of the superelevation. At the same location, the low side of the superelevation would be defined as a graphic grade lower than and relative to the high side of the superelevation. For this design situation, the goal would be to install a standard concrete median barrier because it would: (1) provide the same elevations for the gutter lines on either side of the barrier; and (2) be less costly and time consuming than developing a specially designed and constructed bifurcated concrete median barrier to accommodate differences in elevations on either side of the barrier.

The locations of median crossovers should be selected in coordination with the design of the roadway profile and superelevation to provide adequate drainage and to avoid flat areas, excessively steep grades, or grade breaks. Crossovers located on narrow medians and superelevated curves may require particularly close coordination. To provide a suitable crossover profile, the designer should consider the crossover locations when setting the profile grades and may need to adjust shoulder cross slopes.

3.3.5.c – Additional Design Considerations

Low-Clearance Vehicle Hang-up at Intersections on Superelevated Curves. The design of intersections where one of the intersecting roadways is superelevated requires careful consideration of the grade break ("breakover" or "hump") on the high side of superelevation to avoid low-clearance vehicle hang-up or trailer dragging. A "hang-up" occurs when the underside of a vehicle scrapes or rests on the roadway surface at grade breaks in the vertical profile, such that the vehicle is immobilized or stuck on the vertical geometry.

Too abrupt a breakover between the superelevated section and the profile of the intersecting roadway can cause a vehicle with a long wheelbase and low ground clearance, typically trailers known as "lowboys" or "floats", to become "hung-up" on the break-over.

The National Transportation Safety Board (NTSB) has studied this problem and "warned that crossing profiles with hump-like vertical curves can impede the operation of a vehicle if the distance between any two axles of a vehicle spans the hump and the height of the hump exceeds the vehicle's ground clearance"

As shown in **Exhibit 3.3.6**, a similar problem can occur at highway-railroad grade crossings. The Green Book provides guidance on vertical alignments at highway-railroad grade crossings in Section 9.12.2, *Vertical Alignment*. This guidance should also be applied to avoid vehicle hang-ups at intersections on superelevated curves.

Exhibit 3.3.6 – Low-Clearance Vehicles





3.3.6 – Examples of Superelevation Design

Example 1: Determine the required design superelevation rate in the following situation.

- Design Speed of Horizontal Curve, V_d = 50 mph.
- Maximum Superelevation Rate, e_{Max} = 8.0%, Radius = 1432.39 ft

Solution: Per the Green Book, Table 3-10, for R = 1480 ft, e = 6.2%.
Select the design superelevation rate of the actual horizontal curve from the radius in Table 3-10 that is equal to or slightly smaller.

Since 1400 ft < 1432.39 ft, specify a design superelevation rate, e = 6.4%.

Example 2: Determine the required design superelevation rate in the following situation.

- Design Speed of Horizontal Curve, V_d = 60 mph
- Maximum Superelevation Rate, e_{Max} = 6.0%, Radius = 3819.72 ft

Solution: Per Green Book, Table 3-9, for R = 3940 ft, e=3.6%; for R = 3650 ft, e = 3.8%.
Select the design superelevation rate of the actual horizontal curve from the radius in Table 3-9 that is equal to or slightly smaller.

Since 3650 ft < 3819.72 ft, specify a design superelevation rate, e_d = 3.8%.

Example 3: Given the data provided to the right, Determine the following:

- Minimum Length of Superelevation Runoff (L_r)
- Minimum Length of Tangent Runout (Lt)
- Superelevation Transition (T)

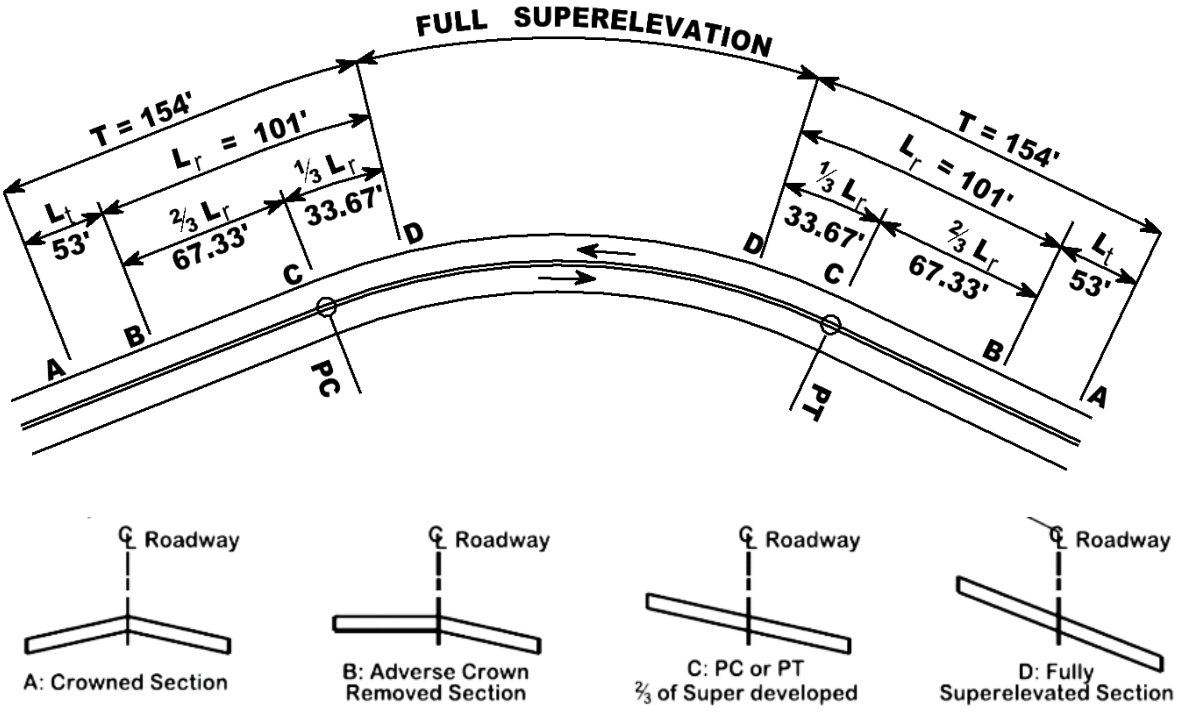
Urban Arterial Two 12 ft Lanes (Non-Spiraled, Non-Widened)	
V_d = 60 mph, R = 3819.72 ft	e_{Max} = 6.0%
Normal cross slope, e_{NC} = 2.0%	e = 3.8%

Solution:

1) Per Green Book, Table 3-16a, L_r = 101 ft (for one lane is rotated)
2) From Green Book, Equation 3-24,

$$L_t = \frac{e_{NC}}{e} L_r = \left(\frac{0.02}{0.038}\right)(101) = 53.16, \text{say } 53 \text{ ft}$$

3) Using the following equation, $T = L_r + L_t = 101 \text{ ft} + 53 \text{ ft} = 154 \text{ ft}$



Example 4: Given the information provided below, use relative gradients to find the total length of superelevation transition, T.

Urban Freeway – Curve to Left Five 12 ft Lanes in each Direction (Non-Spiraled, Non-Widened) Axis of Rotation (PGL) is located 24 ft from left edge of pavement (EOP)	
V_d = 60 mph R = 1400.00 ft	e_{Max} = 6.0% e = 6.0%
Normal cross slope, e_{NC} = 2.0%	

Solution: This transition is shown in a profile diagram and cross sections in **Exhibit 3.4.7**.

Complete the superelevation transition, T, in two parts:

Part 1. Normal Crown to Crown Removed

Part 2. Crown Removed to Full Super

Use the Green Book, Equation 3-23, Table 3-15, and the relative gradients in Section 3.3.8.2.1.

$$L_r = \frac{(w\ n_1)\ e}{\Delta}(b_w)$$ Green Book Equation 3-23

where:

w = width of one traffic lane width (feet)

n_1 = number of lanes rotated about axis: 3 lanes in Part 1 and 3 lanes in Part 2.

e_d =design superelevation rate (percent)

Δ =Maximum Relative Gradient (percent) 0.45% per Green Book Section 3.3.8.2.1

b_w=Adjutment Factors: 0.67 (for 3 lanes rotated) per Green Book Table 3-15

Part 1 – Normal Crown to Crown Removed. Rotate 3 lanes to right of crown about Axis of Rotation.

$$L_{r\,1} = \frac{(wn_1)e}{\Delta}(b_w) = \frac{(12)(3)(0.04)}{0.0045}(0.67) = 215\ \text{ft}$$

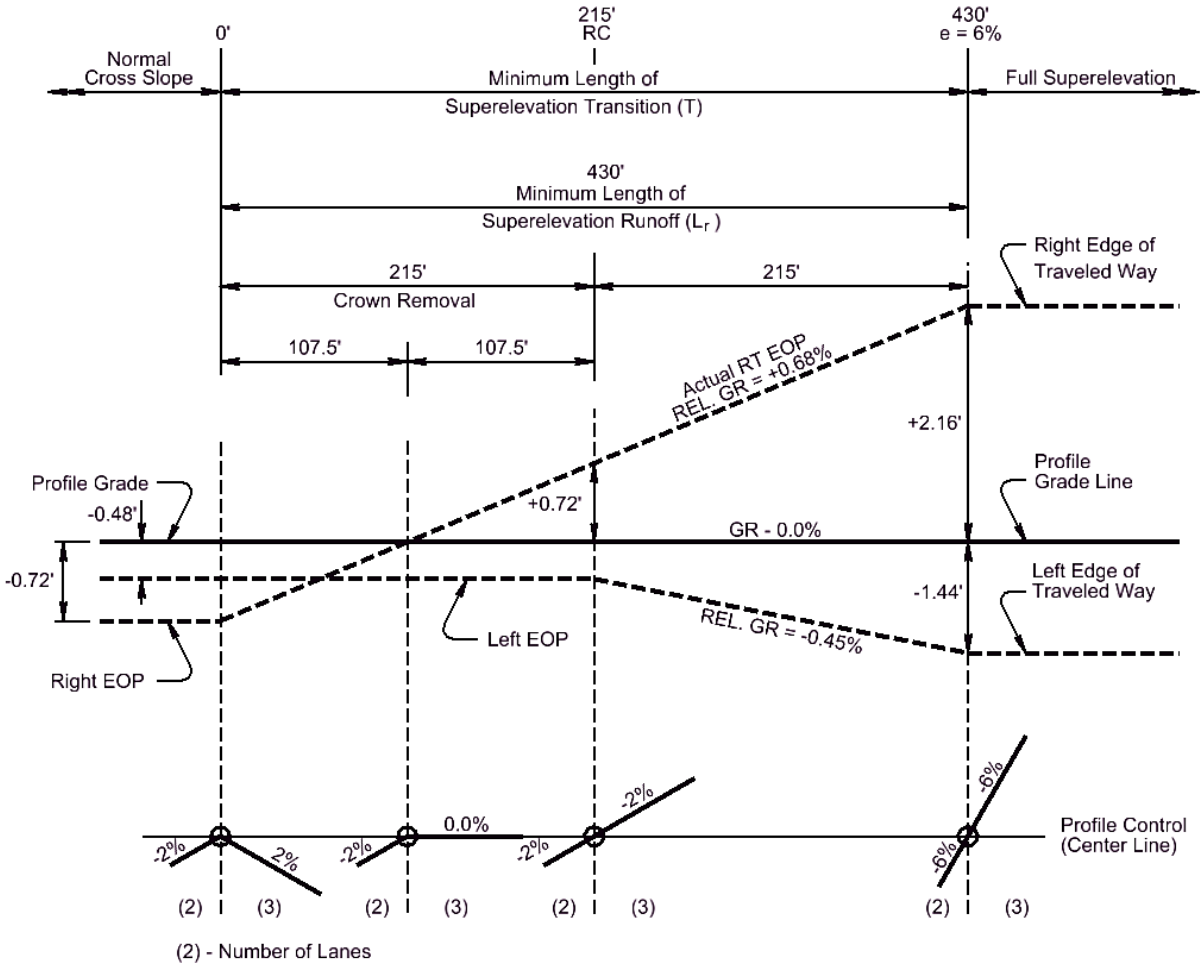
Part 2 – Crown Removed to Full Superelevation. Rotate all 3 right lanes about the Axis of Rotation.

$$L_{r\,2} = \frac{(wn_1)\ e}{\Delta}(b_w) = \frac{(12)(3)(0.04)}{0.0045}(0.67) = 215\ \text{ft}.$$ Note the 3 lanes on right controls. $n_1 = 3$.

$$T = L_{r\,1} + L_{r\,2} = 215\ \text{ft} + 215\ \text{ft} = 430\ \text{ft}$$

As shown in Exhibit 3.3.7, the actual edge of pavement gradients is +0.68% along the right edge, and -0.45% on the left edge. The right edge of pavement rotates +4% (-2% to 2%) in part 1 and 4% (2% to 6%) in part 2 and determines the total length of transition. The left side remains unchanged in Part 1 and rotates -4% (from -2% to -6%) in Part 2.

Exhibit 3.3.7 – Example 4, Profile Diagram of Superelevation Transition



Example 5: Given the information provided at right, use relative gradients to find the total length of superelevation transition, T.

Urban Freeway – Curve to Left Five 12 ft Lanes in each Direction (Non-Spiraled, Non-Widened) Axis of Rotation (PGL) is located: 1) at the crown, 24 ft from left EOP. 2) the left edge of the travelled way.	
V_d = 60 mph R = 1400.00 ft	e_{Max} = 6.0% e = 6.0%
Normal cross slope, e_{NC} = 2.0%	

Solution: The transition is shown in a profile diagram and cross sections in **Exhibit 3.3.8**. Complete the superelevation transition, T, in two parts:

Part 1. Normal Crown to Crown Removed; and,

Part 2. Crown Removed to Full Super

Use the Green Book, Equation 3-23, Table 3-15, and the relative gradients in Section 3.3.8.2.1.

$$L_r = \frac{(wn_1)e}{\Delta}(b_w)$$ Green Book, Equation 3-23

where:
w = width of one traffic lane width (feet)
n_1 = number of lanes rotated about axis: 3 lanes in Part 1 and 5 lanes in Part 2
e_d = design superelevation rate (percent)
Δ = Maximum Relative Gradient (%) 0.45 percent per Green Book Section 3.3.8.2.1
b_w = Adjustment Factor: 0.67 (for 3 lanes rotated);
0.60 (for 5 lanes rotated) See equation under Green Book Table 3 − 15

Part − Normal Crown to Crown Removed. Rotate 3 lanes to right of crown about Axis of Rotation

$$L_{r\,1} = \frac{(wn_1)\,e_d}{\Delta}(b_w) = \frac{(12)(3)(0.04)}{0.0045}(0.67) = 215 \text{ ft } *$$

$*$ Note: In Part 1, $e_d = 0.04$ because the 3 lanes on the right are rotated from -0.02 to $+0.02$.

Part 2
− Crown Removed to Full Superelevation. Note that the axi s of rotation shifts to the Left EOP.
Rotate all 5 lanes about the Axis of Rotation. $b_w = \frac{[1 + 0.5(n_1 - 1)]}{n_1} = \frac{[1 + 0.5(5 - 1)]}{5} = 0.60$

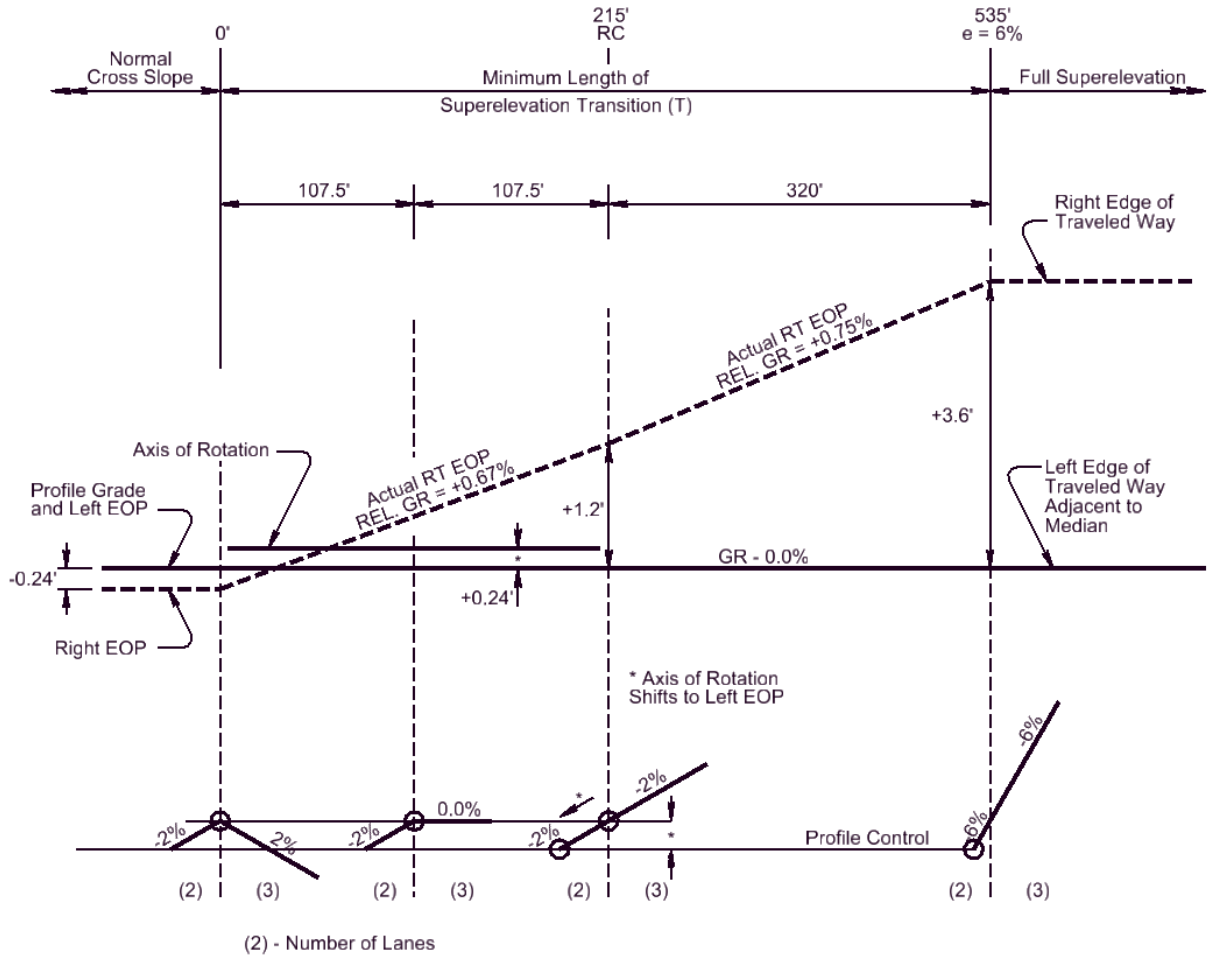
$$L_{r\,2} = \frac{(wn_1)\,e_d}{\Delta}(b_w) = \frac{(12)(5)(0.04)}{0.0045}(0.60) = 320 \text{ ft}$$

$*$ Note: In Part 2, $e_d = 0.04$ because the 3 lanes on the right are rotated from $+0.02$ to $+0.06$.

$$T = L_{r\,1} + L_{r\,2} = 215 \text{ ft} + 320 \text{ ft} = 535 \text{ ft}$$

As shown in Exhibit 3.3.8, the left EOP remains on the PGL and therefore has zero relative gradient. In Part 1 the Right EOP rotates up +4% (from -2% to +2%) and the actual Right EOP gradient is +0.67%. In Part 2 the number of lanes rotated increases from 3 to 5 and the actual Right EOP is rotated 4% (from 2% to 6%) and the relative gradient increases to +0.75%. The total length of transition is 105 ft longer than in Example 4.

Exhibit 3.3.8 – Example 5, Profile Diagram of Superelevation Transition



3.4 – Vertical Alignments

The vertical alignment of a highway is represented by its profile grade line (PGL) which is a reference line used to set the elevations of pavement, roadside grading, drainage structures, and other features. Many factors should be considered in the design of a vertical alignment, including terrain, sight distance, topography, highway functional classification, horizontal alignment, design speed, performance of heavy vehicles, right of way costs, safety, construction costs, adjacent land use, drainage, and aesthetics. While concept of sight distance is introduced in Section 3.2, this section describes the direct relationship between sight distance, design speed, and vertical curve length. For safety, all portions of a vertical alignment must meet sight distance requirements for the design speed of the roadway.

3.4.1 – Terrain

The topography of the land traversed has an influence on the vertical and horizontal alignments of roadways and streets. To characterize variations, topography is separated into three classifications according to terrain which include: (1) level terrain, (2) rolling terrain and (3) mountainous terrain.

In level terrain, highway sight distances, as governed by both horizontal and vertical restrictions, are generally long or can be made to be so without construction difficulty or major expense.

In rolling terrain, natural slopes consistently rise above and fall below the road or street grade, and occasional steep slopes offer some restriction to normal horizontal and vertical roadway alignment.

In mountainous terrain, longitudinal and transverse changes in the elevation of the ground with respect to the road or street are abrupt and benching and side hill excavations are frequently needed to obtain acceptable horizontal and vertical roadway alignment.

Terrain classifications pertain to the general character of a specific route corridor. Routes in valleys, passes, or mountainous areas that have all the characteristics of roads or streets traversing level or rolling terrain should be classified as level or rolling. In general, rolling terrain generates steeper grades than level terrain causing trucks to reduce speeds below those of passenger cars; mountainous terrain has even greater effects, causing some trucks to operate at crawl speeds.

3.4.2 – Grades

Ideally, open roadways should be designed to enable a driver to operate a vehicle at a constant speed throughout with few locations where the driver needs to brake. Establishing a single design speed for a roadway provides an effective means of achieving a unified “speed rating” for all geometric elements. Designing all elements for a single design speed improves safety because it greatly simplifies the driving task by reducing how often drivers need to evaluate the speed ratings of individual elements and adjust their running speed accordingly. Grades are a

critical element that can directly affect operating speeds, particularly of trucks. This section presents the vehicle-operating characteristics on grades and the control grades for design.

Passenger Cars. The effect of grades on passenger cars varies greatly due to the practices of individual drivers. It is generally accepted that nearly all passenger cars can readily negotiate upgrades as steep as 4 to 5 percent without an appreciable loss in speed below that normally maintained on level roadways. Operation on a three percent upgrade has only a slight effect on passenger car speeds compared to operations on level terrain. On steeper upgrades, speeds decrease progressively with increases in the grade. On downgrades, passenger car speeds are generally slightly higher than on level sections.

Trucks. The effect of grades on truck speeds is more pronounced than on passenger car speeds. On upgrades, trucks generally decrease speed by seven percent or more, dependent primarily on the length and steepness of the grade and the trucks weight/power ratio. On downgrades, heavy vehicles generally increase speed by up to five percent. The effect of rate and length of grade on the deceleration of a typical heavy truck is illustrated in the Green Book, Figures 3-15, *Speed-Distance Curves for Acceleration of a Typical Heavy Truck of 140 lb/hp [85 kg/kW] for Deceleration on Upgrades*. Also, the effect of rate and length of grade on the acceleration of a typical heavy truck is illustrated in the Green Book, Figure 3-16, *Speed-Distance Curves for Acceleration of a Typical Heavy Truck of 140 lb/hp [85 kg/kW] on Upgrades and Downgrades*. The data presented in these figures can serve as a valuable design guide to apprise the effect of trucks on traffic operations for a given set of profile conditions.

The speed of trucks on grades is directly related to the weight/power ratio which is expressed in terms of gross weight and net power in units of weight/horsepower. Trucks with weight/horsepower ratios of about 200 lb/hp typically provide acceptable operating characteristics. This assures a minimum speed of about 35 mph on a three percent upgrade.

Recreational Vehicles (RVs). The effect of grades on recreational vehicles (RVs) is not as critical as the effect on trucks. However, on certain routes, such as designated recreational routes, where a low percentage of trucks may not warrant a truck climbing lane, enough recreational vehicle traffic may indicate a need for an additional lane.

Maximum Grades. Design criteria for grades, specifically maximum and minimum grades, depend on topography, roadway functional classification and typology. These grade controls are presented in the Matrices of Design Values in Exhibits 3.8.1 through 3.8.4. The maximum design grade should be avoided when feasible.

Minimum Grades. A minimum grade of 0.5% is required for drainage. Particular attention should be given to the design of drainage inlets and their spacing to keep the spread of storm runoff on the traveled way within tolerable limits. For more discussion of vehicle-operating characteristics on grades and control grades (maximum and minimum) for design, refer to the Green Book, Section 3.4.2, *Grades*.

3.4.3 – Critical Length of Grade

The term "critical length of grade" is used to indicate the maximum length of a designated upgrade on which a loaded truck can operate without a 10-mph speed reduction. If the desired appropriate speed is to be maintained on grades longer than critical, design adjustments such as a change in location to reduce grades or the addition of extra lanes should be considered.

To establish design values for critical lengths of grade where gradeability of trucks is the determining factor, the following data are required:

1) The size and power of a representative truck or truck combination for use as a design vehicle including grade data. A representative vehicle would be a loaded truck with a weight/horsepower ratio of 200 lb/hp and grade data based on the Green Book, Figures 3-21, *Critical Lengths of Grade for Design, Assumed Typical Heavy Truck of 200 lb/hp [120 kg/KW], Entering Speed = 70 mph [110 km/h]*, and Green Book, Figure 3-22, *Critical Lengths of Grade Using an Approach Speed of 55 mph [90 km/h] for Typical Recreational Vehicle*.

2) Speed at entrance to critical length of grade. The average running speed, as related to design speed, can be used to approximate vehicle speed beginning an uphill climb subject to adjustments such as approach conditions.

3) Minimum speed on the upgrade below which interference with following vehicles is considered unreasonable. Although no specific data is available for minimum tolerable speeds of trucks on upgrades, such minimum speeds should be in direct relation to the design speed. Minimum truck speeds of about 25 mph to 40 mph on most highways (with design speeds of 40 mph to 60 mph) are not unreasonable if the time interval during which they are unable to pass is not excessive.

The suggested design criterion for determining the critical length of grade is a 10-mph reduction in truck running speed below the average running speed of traffic. The procedure for determining the critical length of grade is discussed in the Green Book, Section 3.4.2.3, *Critical Lengths of Grade for Design*. For critical lengths of grade controlled by heavy trucks and recreational vehicles, see Green Book, Figures 3-21 and 3-22, respectively.

Steep descending grades on roadways with high traffic volumes and numerous heavy trucks can reduce the traffic capacity and increase crash frequency. Some downgrades are long and steep enough that some heavy vehicles travel at crawl speeds to avoid loss of control on the grade. Therefore, there are instances where consideration should be given to providing a truck lane for downhill traffic. Procedures have been developed in the *Highway Capacity Manual* (HCM) to analyze this situation.

The suggested design criterion to determine the critical length of grade is a guideline, rather than a rigid requirement. In some instances, the terrain or other physical controls may preclude shortening or flattening grades to meet these controls. Where the length of critical grade is exceeded, consideration should be given to adding a climbing lane. Climbing lanes are discussed in Section 3.4.3, *Climbing Lanes*.

3.4.4 – Climbing Lanes

On two-lane highways, climbing lanes are additional lanes used to accommodate slow moving vehicles and to improve operations and safety on an ascending grade. Adding a climbing lane can correct the decline in level of service caused by the combined effects of the grade, traffic volume, and heavy vehicles. A two-lane highway with a climbing lane is not considered a three-lane highway, but a two-lane highway with a limited length of added lane. A climbing lane enables passing and is typically a more cost-effective solution than designing a standard two-lane section to meet passing sight distance criteria. Climbing lanes are particularly cost effective on highway reconstruction projects where a significant investment has already been made in existing pavement and drainage structures.

The following three criteria reflect economic considerations and should be satisfied to justify a climbing lane:

1) Ascending grade traffic volume exceeds 200 vehicles per hour.
2) Ascending grade truck volume exceeds 20 vehicles per hour.
3) One of the following conditions exists:
   (i) A 10 mph or greater speed reduction is expected by a typical heavy truck.
   (ii) Level of Service E or F exists on the ascending grade section.
   (iii) A reduction of two or more levels of service is experienced when moving from the approach segment to the ascending grade section.

At locations with high crash frequencies, a safety study may identify a climbing lane as an effective crash modification factor, and its construction may be justified regardless of grade or traffic.

Freeways and Expressways. On freeways and expressways with ascending grades that exceed the critical length of grade, a climbing lane analysis should be performed and climbing lanes added where appropriate.

In addition to evaluating speed reduction, the Level-of-Service should be considered from the standpoint of highway capacity to justify the inclusion of a climbing lane. Also, high crash frequencies may justify the addition of a climbing lane regardless of grade or traffic volumes. For more information on the principal determinants of need and the applicable criteria and detailed methodology for the inclusion of climbing lanes, refer to the Green Book, Section 3.4.3, *Climbing Lanes*, and the *Highway Capacity Manual*.

3.4.5 – Vertical Curves

General Considerations. Vertical curves are used to effect gradual changes between tangent grades at their point of intersection. These curves should be simple in application and should result in a design that enables the driver to see the road ahead, enhances vehicle control, is adequate for drainage, and is pleasing in appearance. The major design control for crest vertical curves is the provision of ample sight distances for the design speed. Minimum stopping sight

distances should be provided in all cases. Wherever practical, longer stopping sight distances should be used.

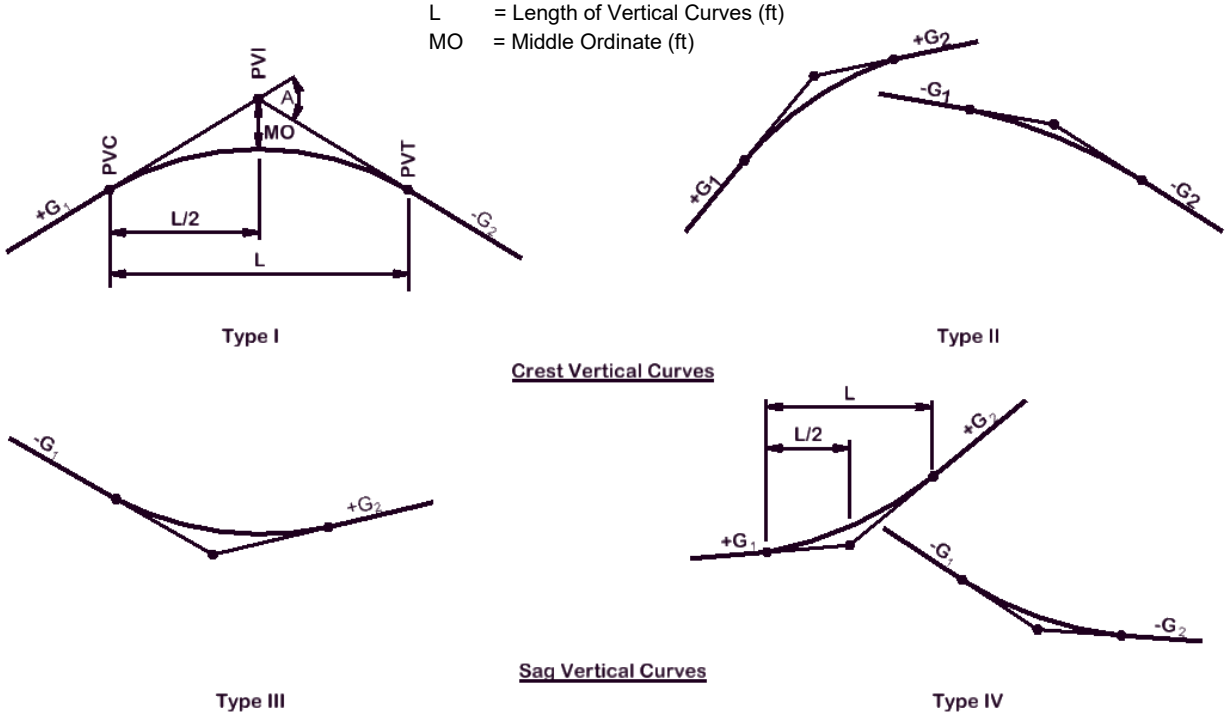
For simplicity, a parabolic curve with an equivalent vertical axis centered on the Point of Vertical Intersection (PVI) is usually used in roadway profile design. In certain situations, because of critical clearance or other controls, the use of asymmetrical vertical curves may be appropriate. The derivation and use of the relevant equations for computing symmetrical and asymmetrical vertical curves can be found in numerous highway engineering texts.

As shown in **Exhibit 3.4.1**, a vertical curve is located at a PVI of grades, G_1 and G_2. A vertical curve located below the PVI is a crest vertical curve and a curve located above the PVI is a sag vertical curve. Depending on the signs of the entering and exiting grades, there are a total of four types of vertical curve.

3.4.5.a – Types of Vertical Curves

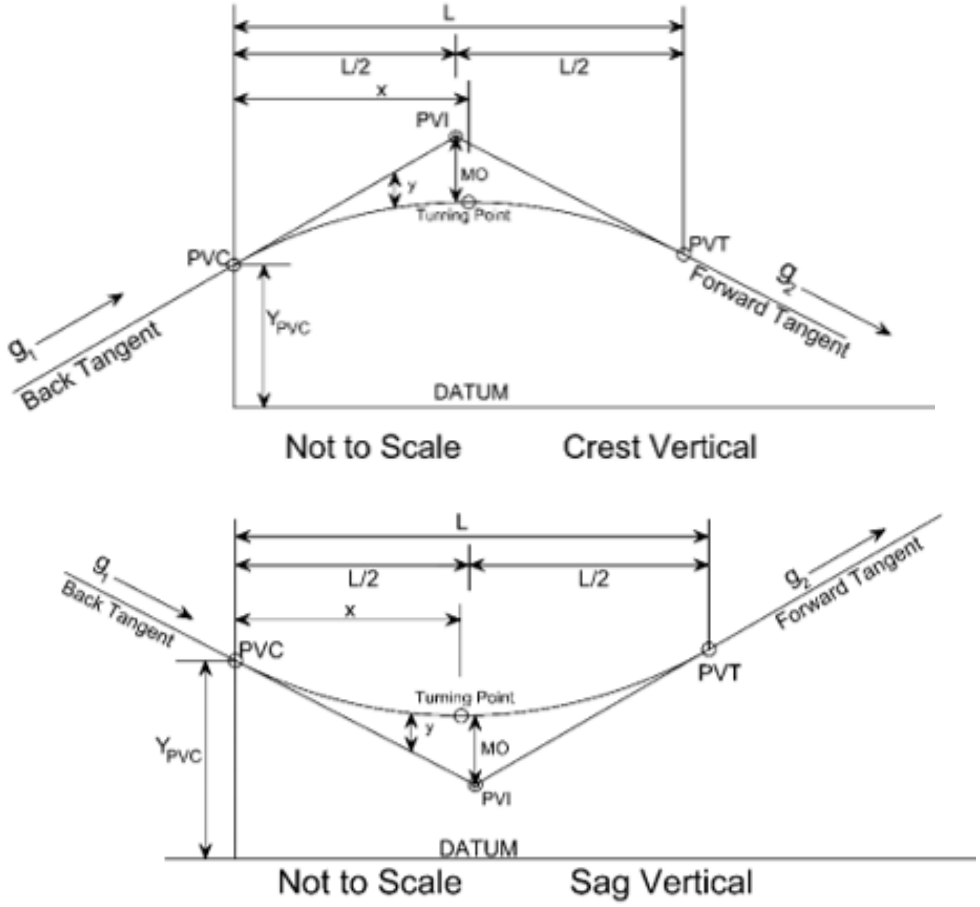
Exhibit 3.4.1 – Types of Vertical Curves

G_1 and G_2 = Tangent Grades (%)
A = Algebraic Difference in Grades
L = Length of Vertical Curves (ft)
MO = Middle Ordinate (ft)



Type I and Type III vertical curves have turning points (high points or low points) where the slope of a line tangent to the curve is zero as the slope changes sign (+ / -). Type II and Type IV vertical curves do not have turning points because grades G_1 and G_2 have the same sign and consequently there is no point where the slope of a line tangent to the curve is zero.

Exhibit 3.4.2 – Vertical Curve Elements



- **L** – Length of Curve
- **PVC** – Point of Vertical Curvature
- **PVI** – Point of Vertical Intersection
- **PVT** – Point of Vertical Tangency
- **g_1** – Grade of Back Tangent
- **x** – Horizontal Distance from PVC to a Point on the Vertical Curve.
- **g_2** – Grade of Forward Tangent
- **y** – Offset from Back Tangent Grade
- **MO** – Tangent Offset at PVI = AL/800

Length of Vertical Curve. Unlike a horizontal curve, the length of a vertical curve, L, is not measured along the actual curve. As shown in **Exhibit 3.4.2**, L is the length of the projection of the vertical curve onto a horizontal plane, or more precisely, L is the length of a straight, horizontal line between the Point of Vertical Curvature (PVC) and the Point of Vertical Tangent (PVT). L does not include the increase in roadway length due to curvature. This simplification is purely practical and needed to ensure that the stationing along a roadway's vertical alignment exactly matches the stationing on its (the roadway's) horizontal alignment. Stationing on vertical curves increases from PVC to PVT.

Symmetry of Vertical Curves. The PVI is typically located at the midpoint of a straight horizontal line between the PVC and PVT. Consequently, if the PVI station and the vertical curve length, L, are known, the PVC Station and PVT station can easily be established. The PVC station is equal to the PVI station minus L/2. The PVT station is equal to the PVI station plus L/2. In certain unusual situations, because of vertical clearance or other controls, the use of asymmetrical vertical curves may be appropriate.

3.4.6 – Stationing on Vertical Alignments

Although roadways are three-dimensional, common design practice is to design the horizontal alignment first in two dimensions and then design the vertical alignment (also in two dimensions) to complement the horizontal alignment. This assures one set of stationing is used for both the horizontal and vertical alignments.

3.4.7 – Elements of Vertical Curves

The following equations are used to compute key features of vertical curves.

Exhibit 3.4.3 – Vertical Curve Equations

Horizontal distance from PVC to a specific point.	$x = \frac{-g_1}{2a} = \frac{g_1 L}{g_1 - g_2}$
Absolute value of algebraic difference in grade.	$A = \lvert g_2 - g_1 \rvert$
Offset to curve from back tangent gradient, g_1.	$y = \frac{rx^2}{2}$
Horizontal distance from PVC to turning point.	$x_t = \frac{-g_1}{r}$
Rate of grade change along a vertical curve.	$r = \frac{g_2 - g_1}{L}$
Elevation of point on vertical curve.	$Y_{point} = Y_{PVC} + g_1 x = Y_{PVC} + g_1 x + \left(\frac{g_2 - g_1}{2L}\right) x^2$
Elevation on back tangent Gradient	$Y_{g1} = = Y_{PVC} + g_1 x = Y_{PVI} + g_2 \left(x - \frac{L}{2} \right)$
Middle Ordinate (Offset to curve at PVI).	$MO = (g_2 - g_1)\frac{L}{8}$
Rate of vertical curvature.	$K = \frac{L}{A}$

As shown in **Exhibit 3.4.3**, the vertical offset, y, from gradient g_1 varies as the square of the horizontal distance, x, from the Point of Vertical Curvature (PVC). The vertical offset, y, at any

point along the curve is calculated as a proportion of the Middle Ordinate (MO), which is the vertical offset of the curve at the PVI.

The rate of grade change (r), is the algebraic difference in grades (A), divided by the length of the vertical curve, (L), and is a constant rate for equal increments of horizontal distance. The reciprocal of r (or A/L) is L/A, which is the horizontal distance (in ft) needed to make a 1 percent change in grade and is therefore a measure of vertical curvature.

The ratio, L/A, (generally known as simply, "K"), is very useful for determining the horizontal distance from the PVC to a turning point (high point or low point) on the curve where the longitudinal slope is zero. **Turning points occur at a distance from the PVC equal to K times the approach gradient.** Locating turning points is necessary for establishing drainage areas and is therefore needed for roadway drainage design. The term, "K" is also very useful as a design control in determining minimum lengths of curves for various design speeds and curve types.

Minimum K values are determined by required sight distance under various conditions, including, design speed, curve type (crest or sag) and traffic operations (stopping or passing). Therefore, the K value used to determine the length of sag vertical curve needed for stopping sight distance and a 50-mph design speed, cannot be used to determine the length of crest vertical curve under the same operating condition and design speed. Each curve type and operating condition has its own set of design controls.

Exhibit 3.4.4 lists the approved sources of K values for various curve types and operating conditions.

Exhibit 3.4.4 – Approved References for Vertical Curve Design Controls

Traffic Operations:	Stopping Sight Distance	Passing Sight Distance	Stopping Sight Distance
Curve Type:	Crest Vertical Curve	Crest Vertical Curve	Sag Vertical Curve
K values	Green Book: Figure 3-36 Table 3-35	Design Manual 2, Exhibit 3.1.2	Green Book: Figure 3-37 Table 3-37
Equations for Minimum Curve Lengths	Green Book: Equations (3-42 and 3-43)		Green Book: Equations (3-48 and 3-50)

3.4.7.a – Minimum Length of Vertical Curve

The minimum length of a vertical curve is generally governed by sight distance and traffic operations, but headlight sight distance, passenger comfort, drainage control, and general appearance should also be considered. All vertical curves must meet stopping sight distance criteria, but crest vertical curves designed for passing must meet PennDOT's passing sight distance criteria which exceeds Green Book criteria and is presented in Exhibit 3.1.2. The Green Book, Section 3.4.6.2.1, *Design Controls: Stopping Sight Distance* and Section 3.4.6.3, *Sag Vertical Curves*, recommend a minimum curve length (in ft) of three times the design speed

(in mph) for both crest and sag vertical curves. These sections also provide further discussion of vertical curve design general considerations.

Short vertical curves or no curves are undesirable, but in some situations are accepted as a practical solution, especially at intersections and reconstruction project tie-in points. See Section 3.4.9 for maximum profile grade change without a vertical curve.

- Crest curve lengths based upon a minimum K value for small values of A result in short curve lengths or no curve length at all because the sight line passes over the high point.
- Sag vertical curves are affected by additional considerations, including the need for illumination during nighttime driving and driver comfort, and are discussed below.

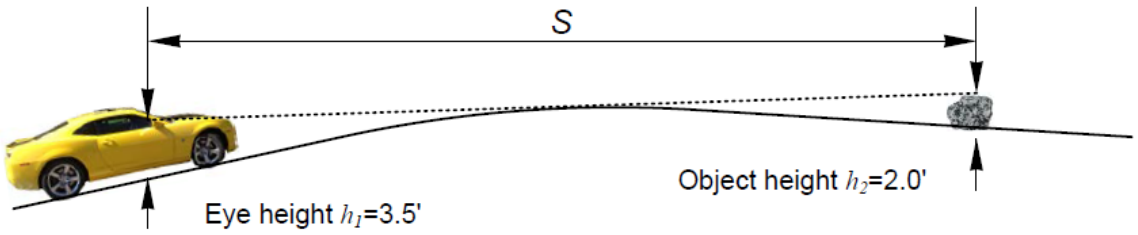
3.4.7.b – Maximum Length of Vertical Curve

Generally, vertical curves should be designed to be as long as practical to maximize sight distance and comfort, but excessive curve length can cause problems, specifically in areas with insufficient longitudinal slope for proper drainage. Pennsylvania's northern climate requires a minimum vertical slope of +/- 0.50%. Pavement surface drainage should be considered in the design of both crest and sag vertical curve because the minimum grade required for drainage is the same for crest and sag vertical curves.

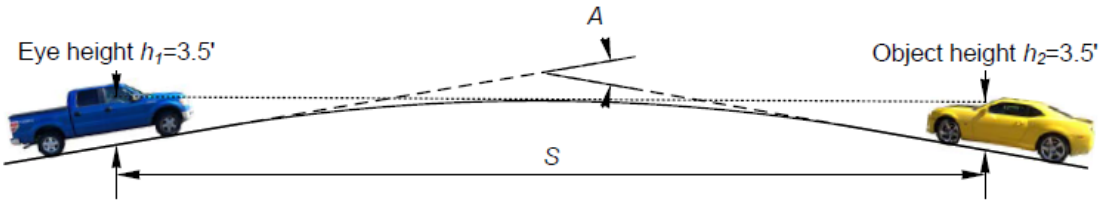
If a roadway is curbed and on a Type III vertical curve, special attention to drainage is needed, especially if the rate of vertical curvature is greater than 51 (K > 51). For drainage the critical areas are near the turning points of curves; specifically, the high point of a crest curve or low point of a sag curve. Designers should be particularly attentive to the pavement drainage near these points to confirm sufficient cross-slope to drain the pavement surface adequately. This is particularly important if a low point on the roadway profile coincides or is near a section where adverse crown is removed.

3.4.7.c – Crest Vertical Curves

The primary design control on crest vertical curves is sight distance. Minimum stopping sight distance should be provided in all cases as indicated in the Green Book, Table 3-35, *Design Controls for Crest Vertical Curves Based on Stopping Sight Distance*. When the design speed is less than 20 mph, the stopping sight distances indicated in the Green Book, Table 9-19, *Stopping Sight Distance for Turning Roadways* should be used.



The design controls for crest vertical curves based on stopping sight and the general formulas to determine minimum lengths of crest vertical curves are contained in the section *Crest Vertical Curves* in the Green Book, Chapter 3.

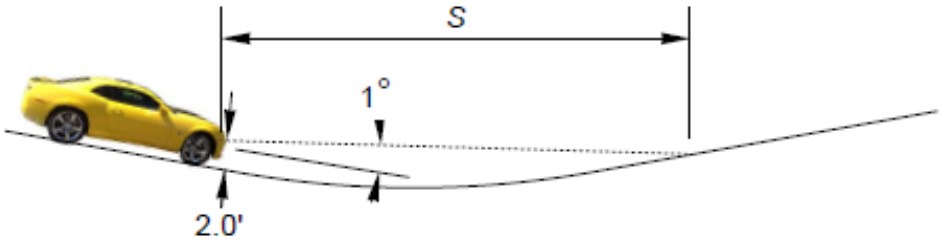


On two lane rural highways, consideration should be given to providing passing zones. As discussed in Section 3.1.3, the design controls for passing sight distances along crest vertical curves are based on criteria specified in the Pennsylvania Vehicle Code. Exhibit 3.1.2 lists the minimum passing sight distances and the minimum rate of vertical curvature.

3.4.7.d – Sag Vertical Curves

At least four different criteria to establish the lengths of sag vertical curves are recognized that include:

1) Headlight sight distance
2) Passenger comfort
3) Drainage control
4) General appearance



Passenger Comfort. The effect on passenger comfort due to change in vertical direction is greater on sag than on crest vertical curves because gravitational and centripetal forces are combining rather than opposing. The Green Book advises that for comfort the centripetal acceleration should not exceed 1 ft/s^2, and provides Equation 3-51, which enables computation of the minimum length of sag vertical curve needed to meet this criterion.

For other sag vertical curve equations and general design consideration refer to the Green Book, Section 3.4.6.3, *Sag Vertical Curves*.

3.4.8 – General Considerations for Vertical Alignment Design

The following are general considerations for vertical alignment design. As with other design elements, the characteristics of vertical alignment are influenced greatly by basic controls related to design speed, highway functional classifications and terrain conditions. Within these basic controls, there are several general controls for vertical alignment that should be considered:

1) A smooth grade line with gradual changes, as consistent with the type of highways, roads or streets and the character of terrain, is preferred to a line with numerous breaks and short lengths of grades.
2) The "roller-coaster" or the "hidden-dip" type of profile should be avoided.
3) Undulating grade lines involving substantial lengths of momentum grades should be evaluated for their effect on traffic operation.
4) A broken-back grade line (two vertical curves in the same direction separated by a short section of tangent grade) generally should be avoided, particularly in sags where the full view of both vertical curves is undesirable.
5) It may be preferable, on long grades, to place the steepest grades at the bottom and flatten the grades near the top of the ascent or to break the sustained grade by short intervals of flatter grade.
6) Where an at-grade intersection or railroad-highway grade crossing occurs on a roadway section with moderate to steep grades, reduce the roadway grade through the intersection or crossing area.
7) Sag vertical curves should be avoided in cuts unless adequate drainage can be provided.

For more discussion of general considerations for vertical alignment design, refer to the Green Book, Section 3.4.6.1, *General Considerations*.

3.4.9 – Maximum Profile Grade Change Without Vertical Curve

On roadway reconstruction projects, including bridge replacements and other local roadway improvements, it is often necessary to tie into the existing profile grade by either inserting a vertical curve or allowing a slight deflection (“break”) in the existing profile grade at the tie-in point.

Grade breaks are desirable because they are simple to design and require less length than vertical curves and help reduce the length of a project. They are typically identified on roadway profiles as a “PVI – No Curve”.

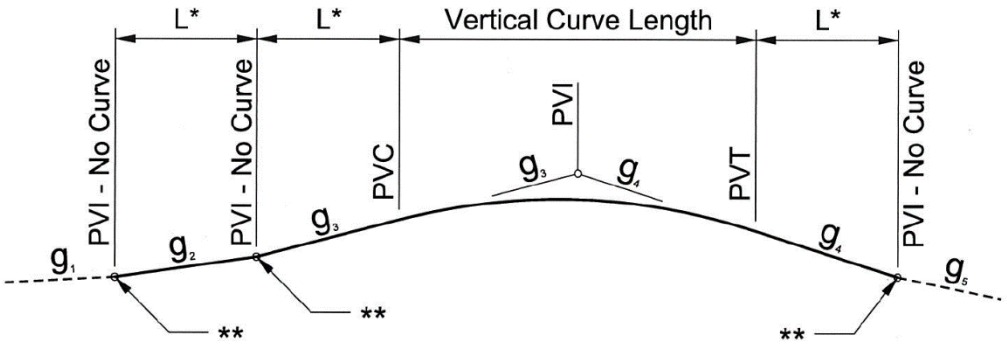
This section provides guidance on maximum acceptable breaks or deflections in this situation.

Grade breaks that may be acceptable or barely noticeable at lower speeds are too large for higher speed roadways which require smoother profiles with smaller grade breaks. The following table lists the maximum change in grade without using vertical curve.

Design Speed (mph)	25	30	35	40	45	50	55	60	65	70
Maximum Change in Grade in Percent	1.85	1.30	0.95	0.75	0.55	0.45	0.40	0.30	0.30	0.25

Exhibit 3.4.5 – Maximum Profile Grade Change Without Vertical Curve

RELATIONSHIP BETWEEN VERTICAL CURVES AND GRADE BREAKS



* The recommended minimum distance between consecutive deflections is:
100' where design speed is 50 mph or greater
50' where design speed is less than 50 mph

** Allowable grade break location.

Δ ROUNDED TO NEAREST 0.05%

Based on the following formula:

$A = 46.5 L / V^2 = 1162.5 / V^2$

Where:

A = Maximum Grade Change (%)

L = Length of Vertical Curve (assume 25')

V = Design Speed (mph)

When a grade change without vertical curve is specified, the construction process typically results in a short vertical curve being built (i.e., the actual point of intersection is “smoothed” in the field).

Conditions where grade changes without vertical curves are NOT recommended include:

- Bridge approach transition to roadway.
- Other locations requiring carefully detailed grades, such as locations frequently used by low vertical clearance vehicles (e.g., low-boy and car carrier trailers) that could be hung-up on an excessive profile grade break.

3.4.10 – Vertical Clearance Requirements

Vertical clearance is a controlling criterion in the geometric design of highways, bridges, sign structures, and utility lines. A summary of required vertical clearances at structures over roadways on new construction and reconstruction projects is presented in **Exhibit 3.4.6**. These criteria shall apply to the required clearance over the entire traveled way width and the usable width of the shoulder including auxiliary lanes, where applicable, to structures passing over the highway facility. The minimum vertical clearance required shall preferably be maintained within recovery areas beyond the shoulders. Strong consideration for attaining 16'-0" should be given where the potential for large vehicles crossing beneath a roadway exists. This is especially true for structures near Freeways and STRAHNET roadways because reasonable access to services from these roadways is typically one mile.

Exhibit 3.4.6 – Minimum Vertical Clearances for Structures Over Highways

Type of Project (1)	STRAHNET	Freeways and Expressways	Arterials	Collectors and Local Roads	Overhead Sign Structures and Pedestrian Overpasses (2)	Through-Truss Cross Bracing
New Construction, Reconstruction CIRT and NoCIRT, and Superstructure Replacements	16'-6"	16'-6"	16'-6"	14'-6"	17'-6"	18'-0"
3R	16'-0"	16'-0"	16'-0" (4)	14'-0"	17'-0"	17'-6" (5)
Deck Replacement, Pavement Preservation & Bridge Preservation (3)	16'-0"	16'-0"	16'-0" (4)	14'-0"	17'-0"	17'-6" (5)

(1) For vertical clearance under pedestrian bridges, see Section 3.4.10.c.

(2) Details regarding the vertical clearance requirements are presented in Publication 218M, *Standards for Bridge Design*, BD-600 (Dual Unit).

(3) Existing vertical clearances less than the New Construction, Reconstruction CIRT and NoCIRT, and Superstructure Replacements minimum criteria may remain, but shall not be further reduced by a Deck Replacement, a Pavement Preservation, or a Bridge Preservation project. Vertical clearances exceeding this minimum criteria may be reduced, but not to the extent that they are less than the 3R criteria. Refer to Publication 15M, Design Manual Part 4, *Structures*, (DM-4) for work eligible for Bridge Preservation

projects. For Pavement Preservation Guidelines, see Publication 242, *Pavement Policy Manual*.

(4) Existing vertical clearances below 16'-0", but over 14'-0" can remain for arterials but are not to be further reduced. Strong consideration for attaining 16’-0” should be given where the potential for large vehicles crossing beneath a roadway exists. This is especially true for structures near Freeways and STRAHNET roadways because reasonable access to services from these roadways is typically one mile.

(5) The District Bridge Engineer's concurrence is required prior to requesting a design exception (refer to Publication 10X, DM-1X, Appendix P, *Design Exceptions*).

3.4.10.a – Strategic Highway Network (STRAHNET)

The STRAHNET is a system of highways that provides defense access, continuity, and emergency capabilities for movements of personnel and equipment in both peacetime and wartime. STRAHNET routes include all interstate highways in Pennsylvania (including the Pennsylvania Turnpike interstate highways), strategic highway network routes and major strategic highway network connectors. For a map of the STRAHNET see:

https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/STRAHNET/Pennsylvania.pdf

All highway facilities on the STRAHNET require the vertical clearances as noted in Exhibit 3.4.6. When a vertical clearance of less than 16’-0” is created because of a highway construction project on the STRAHNET, it is considered an exception. All exceptions to the 16’-0” vertical clearance standard on rural Interstate routes or on a single Interstate route through urban areas require coordination with the Surface Deployment and Distribution Command Transportation Engineering Agency (SDDCTEA) of the Department of Defense. Coordination should occur whether it is a new construction project, a project that does not provide for correction of an existing substandard condition, or a project which creates a substandard vertical clearance. This applies to the full roadway width including shoulders, ramps, and collector roadways for Interstate-to-Interstate interchanges.

A request for coordination may be forwarded by FHWA to the SDDCTEA at any time during project development prior to taking any action on the design exception. The FHWA office initiating a request for coordination to the SDDCTEA should verify receipt of the request by telephone or e-mail. If the SDDCTEA does not respond within 10 working days after receipt, the FHWA should conclude that the SDDCTEA does not have any concerns with the proposed exception. If comments are coming, the FHWA and the Department will consider mitigation to the extent feasible.

Appendix 3A provides a form and instructions that should be used when requesting vertical clearance design exception coordination with the SDDCTEA. FHWA submits this form to the SDDCTEA.

3.4.10.b – Bridges over Railroads

The vertical clearance requirements for all bridges over railroads shall conform with the criteria presented in Publication 15M, Design Manual Part 4, *Structures*, (DM-4) Section D2.3.3.4, and Publication 10C, Design Manual Part 1C, *Transportation Engineering Procedures*, (DM-1C) Section 4.11.D.

3.4.10.c – Sign Structures and Pedestrian Overpass Structures

Sign structures and pedestrian overpass structures are typically designed to carry less loads than roadway bridges, and consequently have less resistance to impact. Therefore, the vertical clearance required for all sign structures and pedestrian overpass structures shall be one foot greater than the vertical clearance required for the roadway over which the structure is to be located.

3.4.10.d – Traffic Signals

The vertical clearance requirements for traffic signals shall conform to the criteria presented in Publication 149, *Traffic Signal Design Handbook*.

3.4.10.e – Aerial Utility Lines

The vertical clearance requirements for aerial utility lines shall conform to the criteria presented in Publication 16, Design Manual Part 5, *Utility Relocation*, (DM-5) Appendix A.

3.4.11 – Airport – Highway Clearances

The Administrator for the Federal Aviation Administration has established specific clearance requirements and criteria for highways and other structures adjacent to airports that are identified in Part 77 of the Federal Aviation Regulations - Federal Aviation Administration. The document is available from the Federal Aviation Administration, Washington, DC or the Superintendent of Documents, US Government Printing Office, Washington, DC and shall be used as a guide in the preparation of the design of highways adjacent or near airports to provide adequate clearance between the highways and the navigable airspace. For additional guidelines on the preparation of data, plans and other pertinent information relative to airport clearance requirements, refer to Publication 10C, Design Manual Part 1C, *Transportation Engineering Procedures*, (DM-1C), Section 4.8.F.

3.5 – Controls for Combination Horizontal and Vertical Alignments

The proper combination of horizontal and vertical alignment is obtained by considering the following general guidelines:

1) The horizontal alignment should be balanced with the vertical alignment and the superelevation of the roadway cross section. A balanced design is accomplished through cross sectional analysis, which involves developing cross sections at key points along the alignment for the purpose of evaluating the effects of the design on the existing topography. Adjustments to the vertical and horizontal geometry should be considered where impacts are significant.

2) Vertical curvature superimposed on horizontal curvature, or vice versa, generally results in a more pleasing facility, but such combinations should be analyzed for their effect on traffic. Successive changes in profile not in combination with horizontal curvature may result in a series of humps visible to the driver for some distance which represents an undesirable condition.

3) Sharp horizontal curvature should not be introduced at or near the top of a sharp crest vertical curve. This condition is undesirable because the driver may not perceive the horizontal change in alignment, especially at night. The disadvantages of this arrangement are avoided if the horizontal curvature leads the vertical curvature, i.e., the horizontal curve is made longer than the vertical curve. Suitable designs can also be developed by using design values well above the minimum values for the design speed.

4) Sharp horizontal curvature should not be introduced near the bottom of a steep grade approaching or near the low point of a pronounced sag vertical curve. Because the view of the road ahead is diminished, any horizontal curvature other than a very flat curve assumes an undesirable, distorted appearance. Further, vehicle speeds, particularly for trucks, are often high at the bottom of grades and erratic operations may result, especially at night.

5) On two-lane roads and streets, the need for passing sections at frequent intervals and including an appreciable percentage of the length of the roadway often supersedes the general guidelines for combinations of horizontal and vertical alignment. In such cases, it is appropriate to work toward long tangent sections to assure sufficient passing sight distance in design.

6) Horizontal and vertical curves should be made as flat as practical at intersections and at railroad-highway grade crossings where sight distance is limited, and vehicles may have to slow or stop.

7) On divided highways and streets, variation in width of median and the use of independent profiles and horizontal alignments for the separate one-way roadways are desirable. A superior design, without additional cost, generally results from this practice where traffic justifies provision of four lanes.

8) The alignment should be designed to minimize nuisance to the neighborhood in residential areas. A depressed facility should make a highway less visible and less noisy to adjacent residents. Minor horizontal adjustments can sometimes be made to increase the buffer zone between the highway and clusters of homes.

9) The alignment should be designed to enhance scenic views of the natural and manmade environment, such as rivers, rock formations, parks, and outstanding structures. The highway should head into, rather than away from, those views that are outstanding. The highway should fall toward those features of interest at a low elevation, and it should rise toward those features best seen from below or in silhouette against the sky.

10) On curbed sections (with gutter lines created by curbing or concrete median barrier), the effects of superelevation transitions on gutter line profiles should be examined thoroughly. The effects of superelevation can be particularly significant when flat grades

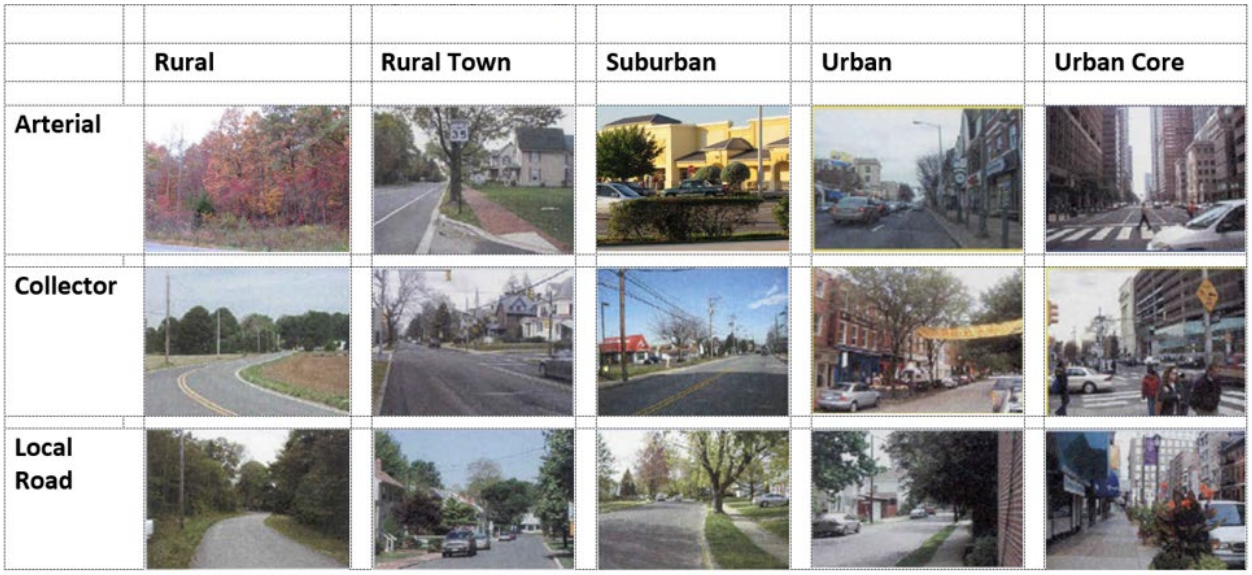
are involved and can result in local depressions. Slight lateral shifts of the profile grade line on horizontal curves can sometimes eliminate the problem.

For more guidance on the controls and general considerations for the combination of horizontal and vertical alignment, refer to the Green Book, Section 3.5, *Combinations of Horizontal and Vertical Alignment*.

3.6 – Roadway Typologies

Roadway typologies exist within the framework of functional classifications, but they are more varied in recognition of subtle differences in settings (example: rural versus rural town, and urban versus urban core) to better fit actual project-specific conditions. Typologies shown in **Exhibit 3.6.1** correspond to the classifications of arterial, collector, and local roads, as described in the Green Book. Refer to Chapter 2, *Design Controls*, of this manual for guidance on how to determine which typology to use for a project.

Exhibit 3.6.1 – Illustrated Roadway Typologies



3.7 – Matrix of Design Values

Matrix of design values tables are found in the following exhibits. Please note that the values shown on the tables are to give a general range. The designer should consider the context of the project and not choose a minimum or maximum value. Additionally, other chapters should be reviewed to determine acceptable values. (For example, if the project will be used for a transit route, see Chapter 15, *Transit Facilities*, to determine acceptable lane widths).

The Matrix of Design Values includes the following tables.

- **Exhibit 3.7.1 – Freeways and Expressways**

- **Exhibit 3.7.2 – Arterials**
- **Exhibit 3.7.3 – Collectors**
- **Exhibit 3.7.4 – Local Roads**

EXHIBIT 3.7.1 – MATRIX OF DESIGN VALUES – FREEWAYS and EXPRESSWAYS

<table>
<tr><th colspan="2"></th><th>Rural
Interstate</th><th>Rural
Non-Interstate</th><th>Urban
Interstate</th><th>Urban
Non-Interstate</th></tr>
<tr><td rowspan="11">Roadway</td><td rowspan="2">Design Speed (mph)</td><td>70 (minimum)</td><td>70 (minimum)</td><td>Preferred: 70
Minimum: 50</td><td>Preferred: 70
Minimum: 50</td></tr>
<tr><td colspan="4">Where terrain is mountainous, a design speed from 50 to 60 mph may be used.</td></tr>
<tr><td>Mainline Lane Width (ft)</td><td colspan="4">12</td></tr>
<tr><td>Auxiliary Lane Width (ft)</td><td colspan="4">12</td></tr>
<tr><td>Ramp Lane Width</td><td colspan="4">Refer to Exhibit 3.7.6 - Minimum Ramp Lane Widths</td></tr>
<tr><td>Mainline Paved Shoulder Widths (minimum)</td><td colspan="4">
<table>
<tr><th>No. Through Lanes / Direction</th><th>Terrain</th><th>Left Shoulder (ft)</th><th>Right Shoulder (ft)</th></tr>
<tr><td>2-lane</td><td>Level or Rolling</td><td>4</td><td>10</td></tr>
<tr><td>3-lane or more</td><td>Level or Rolling</td><td>10</td><td>10</td></tr>
<tr><td>2 or 3-lane</td><td>Mountainous</td><td>4</td><td>8</td></tr>
<tr><td>4-lane or more</td><td>Mountainous</td><td>8</td><td>8</td></tr>
</table>
1. Where truck traffic exceeds 250 DDHV, a paved 12 ft wide right shoulder should be provided, and if there are 3 or more lanes in one direction, then a 12 ft left shoulder should be considered.

2. Provide a 4 ft graded shoulder or median barrier adjacent to 4 ft paved shoulders.
</td></tr>
<tr><td>Auxiliary Lane Paved Shoulder Width</td><td colspan="4">Refer to the Green Book.
Also:
1. On Interstates, the minimum paved shoulder widths are the same as mainline minimum paved shoulder widths noted above.
2. On Non-Interstate freeways: Preferred: Equal to width of through lane shoulder. Minimum: 6 ft paved.</td></tr>
<tr><td>Ramp Paved Shoulder Width</td><td colspan="4">Left Shoulder: 4 ft Paved / 4 ft Graded (or barrier); Right Shoulder: 8 ft (minimum) Paved</td></tr>
<tr><td>Emergency Crossover Width</td><td colspan="4">35 ft</td></tr>
<tr><td>Horizontal Curvature</td><td colspan="4">Refer to the Green Book.</td></tr>
<tr><td>Stopping Sight Distances (minimum)</td><td colspan="4">Refer to the Green Book.</td></tr>
<tr><td>Cross Slopes (minimum)</td><td colspan="4">2.0%</td></tr>
<tr><td>Cross Slopes (maximum)</td><td colspan="2">8%</td><td colspan="2">6%</td></tr>
</table>

EXHIBIT 3.7.1 – MATRIX OF DESIGN VALUES – FREEWAYS and EXPRESSWAYS

		Rural Interstate	Rural Non-Interstate	Urban Interstate	Urban Non-Interstate
Roadway	Median Widths	10'-0" to 50'-0" (Mountainous) 50'-0" to 100'-0" (Level or Rolling)	10'-0" to 100'-0"	10'-0" (minimum)	10'-0" (minimum)
		1. The sum of paved shoulder widths plus 2 ft for barrier width may substitute for the above 10'-0" designations. 2. All median widths 20 ft or less should be paved. When Type 1 shoulders are specified for the 4 ft median shoulders, Type 3 shoulders may be used for the remainder if the remaining width is 8 ft or greater. Underground drainage should be provided under these paved medians. 3. The 100 ft dimension shown in the Green Book, Figure 8-2B permits the designer to use independent profiles in rolling terrain to blend the freeway more appropriately with the environment while maintaining recoverable slopes.			
	Vertical Grades (minimum)	0.5%			
	Vertical Grades (maximum)	1. For Non-Interstates, refer to the Green Book. Also, for Non-Interstates, grades up to 1% steeper than the value shown in the Green Book, Table 8-1 may be provided in urban areas. 2. For Interstates, refer to AASHTO, *A Policy on Design Standards – Interstate System*.			
	Vertical Clearance (minimum)	16'-6" Refer to Section 3.4.10.			
Roadside	Clear Zone Widths	Refer to Chapter 12, *Roadside Design.*			
Bridge	Bridge Widths	Refer to Chapter 5, *Bridges and Tunnels.*			

EXHIBIT 3.7.2 – MATRIX OF DESIGN VALUES – ARTERIAL

			Rural			Rural Town	Suburban	Urban	Urban Core
Roadway	Lane Width (ft) - Minimum	Design Speed (mph)	Under 400 ADT	400-2000 ADT	Over 2000 ADT				
		20-35	10	11	12	Preferred: 12 Minimum: 10	11	10	10
		40-45	10	11	12		11	11	11
		50	11	11	12		11	11	11
		55+	11	12	12		12	12	12
			1. 12 ft preferred for transit routes, and heavy truck volumes > 5%, particularly for design speeds of 35 mph or greater.						
	Paved Shoulder Width (ft) - Minimum		Under 400 ADT	400-2000 ADT	Over 2000 ADT				
		≤ 45	4	6	8	4	8	Preferred: 6 Minimum: 4	
		1. A full width shoulder may be used in curbed sections. However, the curb offset should not be less than 2 ft.							
		>45	4	8	8	8	8	8	
		2. When bike usage is expected, consider shoulder width guidance provided in Chapter 14.							
	Right or Left Turn Lane (ft)		Preferred: 12 Minimum: 11		Preferred: 12 Minimum: 10	Preferred: 12 Minimum: 11		Preferred: 12 Minimum: 10	
	Two-Way Left-Turn Lane (ft)		Preferred: 16 Minimum: 14		Preferred: 12 Minimum 10	Preferred: 16 Minimum: 14		Preferred: 12 Minimum: 10	
	Median Refuge Area for Pedestrians Only (ft)		Preferred: 8 Minimum: 6						
	Bike / Shared Use Lane		Refer to Chapter 14, *Bicycle Facilities.*						
	Transit Bus Route Lanes		Refer to Chapter 15, *Transit Facilities.*						

EXHIBIT 3.7.2 – MATRIX OF DESIGN VALUES – ARTERIAL

		Rural	Rural Town	Suburban	Urban	Urban Core
Roadway	Freight Corridors	Refer to Chapter 16, Section 16.5.1, for recommended lane and shoulder widths.				
	Plain People Community	Refer to Chapter 17, *Plain People Community Considerations.*				
	Parking / Loading Lane	Refer to Chapter 19, *Parking.*				
	Horizontal Curvature	Refer to the Green Book.				
	Stopping Sight Distances (Minimum)	Refer to the Green Book.				
	Passing Sight Distances (Minimum)	Refer to Exhibit 3.1.2				
	Cross Slopes (minimum)	2.0% Also: 1. In curbed areas with longitudinal slopes of 1.0 % or less, 3.0% cross slopes may be used on tangents				
	Cross Slopes (maximum)	8.0%	6.0% to 8.0%		6.0%	4.0%
		For Low Speed Urban and Urban Core, refer to the Green Book, *Low-Speed Streets in Urban Areas*				
	Vertical Grades (minimum)	0.5% Recommended minimum grade of 0.75% on curbed sections.				
	Vertical Grades (maximum)	Refer to the Green Book.				
	Vertical Clearance (minimum)	16'-6" Refer to Section 3.4.10.				
Roadside	Sidewalk	Refer to Chapter 13, *Pedestrian Facilities.* Also: 1. Where pedestrian traffic is anticipated, provisions for a sidewalk should be considered (also Chapter 13). 2. The preferred curb height is 6 inches. However, a curb height of 8 inches may be used to accommodate future resurfacing.				
	Buffer					
	Curb					
	Clear Zone Widths	Refer to Chapter 12, *Roadside Design.*				
Bridge	Bridge Widths	Refer to Chapter 5, *Bridges and Tunnels.*				

EXHIBIT 3.7.3 – MATRIX OF DESIGN VALUES – COLLECTOR

			Rural			Rural Town	Suburban	Urban	Urban Core
Roadway	Lane Width (ft) - Minimum	Design Speed (mph)	Under 400 ADT	400-2000 ADT	Over 2000 ADT	Preferred: 11 Minimum: 10	Preferred: 12 Minimum: 10	Preferred: 11 Minimum: 9	
		20-30	10	10	11				
		35-50	10	11	11				
		55+	11	11	11				
			1. The AASHTO Guidelines for Geometric Design of Low-Volume Roads may be used on Minor Collectors with an ADT of 2000 or less. 2. 11 ft or 12 ft preferred for heavy truck volumes > 5% and transit routes.						
	Shoulder Width (ft) - Minimum		2	4	6	4	Preferred: 8 Minimum: 4	Preferred: 6 Minimum: 4	
			1. A full width shoulder may be used in curbed sections. However, the curb offset should not be less than 2 ft. 2. When bike usage is expected, consider shoulder width guidance provided in Chapter 14.						
	Right or Left Turn Lane (ft)		Preferred: 12 Minimum: 10					Preferred: 12 Minimum: 9	
	Two-Way Left Turn Lane (ft)		Preferred: 16 Minimum: 11						
	Median Refuge Area for Pedestrians Only (ft)		Preferred: 8 Minimum: 6						
	Bike / Shared Use Lane		Refer to Chapter 14, *Bicycle Facilities.*						
	Transit Bus Route Lanes		Refer to Chapter 15, *Transit Facilities.*						
	Freight Corridors		Refer to Chapter 16, Section 16.5.1, for recommended lane and shoulder widths.						
	Plain People Community		Refer to Chapter 17, *Plain People Community Considerations.*						
	Parking/ Loading Lane		Refer to Chapter 19, *Parking.*						
	Horizontal Curvature		Refer to the Green Book. Also: The AASHTO *Guidelines for Geometric Design of Low-Volume Roads* may be used on Minor Collectors with an ADT of 2000 or less						

EXHIBIT 3.7.3 – MATRIX OF DESIGN VALUES – COLLECTOR

		Rural	Rural Town	Suburban	Urban	Urban Core
Roadway	Stopping Sight Distance (minimum)	Refer to the Green Book.				
	Passing Sight Distance (minimum)	Refer to Exhibit 3.1.2.				
	Cross Slopes (minimum)	2.0% Also: In curbed areas with longitudinal slopes of 1.0% or less, 3.0% cross slopes may be used on tangents				
	Cross Slopes (maximum)	8.0%	6.0% to 8.0%		6.0%	4.0%
		1. For Low-Speed Urban and Urban Core, refer to the Green Book, *Low-Speed Streets in Urban Areas*.				
	Vertical Grades (minimum)	0.5%; Recommended minimum grade of 0.75% on curbed sections.				
	Vertical Grades (maximum)	Refer to the Green Book Also: 1. For short grades less than 500 ft, one-way downgrades, and grades on low-volume rural or urban collectors, maximum grades may be up to 2% steeper.				
	Vertical Clearance (minimum)	14'-6" at non-interchange locations. Consider providing 16'-6" clearance if within 1200 ft of an interchange Refer to Section 3.4.10.				
Roadside	Sidewalk Buffer Curb	Refer to Chapter 13, *Pedestrian Facilities.* Also: 1. Where pedestrian traffic is anticipated, provisions for a sidewalk should be considered (also Chapter 13). 2. The preferred curb height is 6 inches. However, a curb height of 8 inches may be used to accommodate future resurfacing.				
	Clear Zone Widths	Refer to Chapter 12, *Roadside Design.*				
Bridge	Bridge Widths	Refer to Chapter 5, *Bridges and Tunnels*				

EXHIBIT 3.7.4 – MATRIX OF DESIGN VALUES – LOCAL ROAD

			Rural			Rural Town	Suburban	Urban	Urban Core
Roadway	Lane Width (ft)	Design Speed (mph)	Under 400 ADT	400-2000 ADT	Over 2000 ADT	Preferred: 11 Minimum: 9	Preferred: 11 Minimum: 10	Preferred: 11 Minimum: 9	
		15-40	9	10	11				
		45-50	10	11	11				
		55+	11	11	11				
			1. The AASHTO Guidelines for Geometric Design of Low-Volume Roads may be used on all Local Road classifications with an ADT of 2000 or less. 2. 11 ft to 12 ft recommended for industrial areas.						
	Shoulder Width (ft)		2	4	6	Preferred: 4 Minimum: 2	Preferred: 6 Minimum: 2		
			1. A full width shoulder may be used in curbed sections. However, the curb offset should not be less than 2 ft. 2. When bike usage is expected, consider shoulder width guidance provided in Chapter 14.						
	Right or Left Turn Lane (ft)		Match Lane Width			Preferred 12 Minimum 9			
	Two-Way Left Turn Lane (ft)		Preferred: 16 Minimum: 11						
	Median Refuge Area for Pedestrians Only (ft)		Preferred: 8 Minimum: 6						
	Bike / Shared Use Lane		Typically, not applicable. Refer to Chapter 14, Bicycle Facilities.						
	Transit Bus Route Lanes		NA						
	Freight Corridors		Refer to Chapter 16, Section 16.5.1, for recommended lane and shoulder widths.						
	Plain People Community		Refer to Chapter 17, *Plain People Community Considerations.*						
	Parking / Loading Lane		Refer to Chapter 19, *Parking.*						
	Horizontal Curvature		Refer to the Green Book. Also: 1. The AASHTO *Guidelines for Geometric Design of Low-Volume Roads* may be used on all Local Road classifications above with an ADT of 2000 or less.						
	Stopping Sight Distance (minimum)		Refer to Green Book.						
	Passing Sight Distance (minimum)		Refer to Exhibit 3.1.2.						

EXHIBIT 3.7.4 – MATRIX OF DESIGN VALUES – LOCAL ROAD

		Rural	Rural Town	Suburban	Urban	Urban Core
Roadway	Cross Slopes (minimum)	2.0% Also: 1. In curbed areas with longitudinal slopes of 1.0% or less, 3.0% cross slopes may be used on tangents.				
	Cross Slopes (maximum)	8.0%	6.0% to 8.0%		6.0%	4.0%
		1. For Low-Speed Urban and Urban Core, the Green Book, *Low-Speed Streets in Urban Areas* may also be used.				
	Vertical Grades (minimum)	0.5%; Recommended minimum grade of 0.75% on curbed sections				
	Vertical Grades (maximum)	Refer to the Green Book Also: 1. For short grades less than 500 ft, one-way downgrades, and grades on low-volume rural or urban collectors, maximum grades may be up to 2% steeper. 2. The gradient for local suburban and urban residential streets should be less than 15%. For streets in commercial and industrial areas, gradient design should be less than 8%.				
	Vertical Clearance (minimum)	Refer to Section 3.4.10. Also: 14'-6" at non-interchange locations. Consider providing 16'-6" clearance if within 1200 ft of an interchange.				
Roadside	Sidewalk Buffer Curb	Refer to Chapter 13, *Pedestrian Facilities.* Also: 1. Where pedestrian traffic is anticipated, provisions for a sidewalk should be considered (also Chapter 13). 2. The preferred curb height is 6 inches. However, a curb height of 8 inches may be used to accommodate future resurfacing.				
	Clear Zone Widths	Refer to Chapter 12, *Roadside Design.*				
Bridge	Bridge Widths	Refer to Chapter 5, *Bridges and Tunnels*				

3.7.1 – Roadway Cross Section Elements

A roadway cross section consists of lateral design elements such as lanes, shoulders, medians, bike facilities, sidewalks, curbing, and roadside swales. Roadway cross section design requires selecting and dimensioning these elements according to design criteria and controls, and typology.

This section discusses and provides additional criteria for the roadway cross section elements presented in the Matrix of Design Values in Section 3.7.

3.7.1.a – Lane and Shoulder Tapers

This section describes the different types of tapers and their uses.

The following equations are used when determining taper lengths for Lanes:

45 mph or more: $L = W \times S$
40 mph or less: $L = W \times S^2 / 60$

where: L = Base taper length in ft
W = Width of offset in ft
S = Posted speed in mph

The taper length formulas above apply to ideal conditions (flat grades, straight alignment, etc.) and should be adjusted to provide adequate sight distances on approaches to channelization. Other field restrictions, such as proximity of ramps or crossroads to the work site, may warrant adjustment of the taper lengths. Better traffic operation will result when the taper lengths are increased rather than decreased below the minimum desirable lengths.

Publication 111, TC-8600 provides a minimum taper length of L/6 prior to the formation of a left turn lane.

Shoulder taper lengths are 1/3 L.

At the project limits on non-expressways, non-interstates and non-freeways, shoulder taper lengths may be reduced to match the lane taper lengths in order to have uniform paving limits. If a transition lane taper is not needed, but a shoulder taper is needed for transition, then the shoulder taper length is 1/3 L.

3.7.1.b – Shoulder Widths

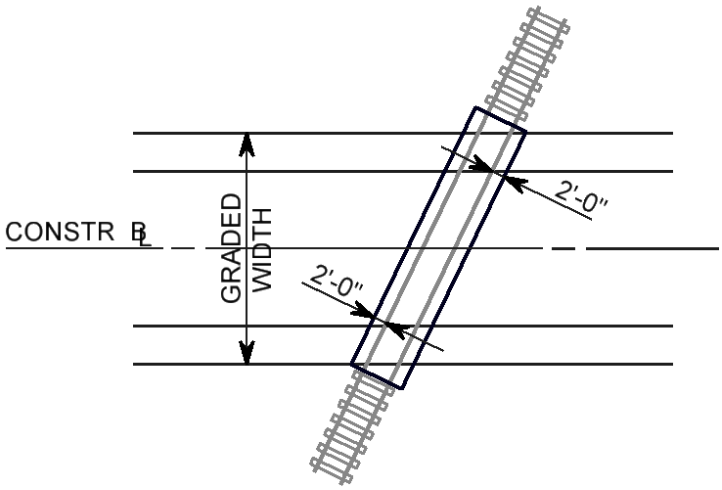
As described in the Green Book, Section 4.4, *Shoulders*, paved and unpaved shoulders serve a variety of functions. The shoulder is part of the clear zone. It also serves to improve capacity, provide safe refuge for disabled vehicles, enable crash avoidance maneuvers, and provide structural pavement support for the traveled way. Studies have shown run-off-the-road and multi-vehicle crash rates decrease as the shoulder width is increased.

The advantage of paving part or all the shoulder helps reduce crash rates further. The paved shoulder can be used by bicyclists. Shoulder paving also reduces maintenance requirements compared to an unpaved shoulder. Consistent shoulder width throughout a corridor is preferred for roadway consistency and driver expectations. For minimum paved shoulder widths, including barrier offset distances, see Exhibits 3.7.1 through 3.7.4, in Section 3.7.

3.7.1.c – Shoulders at Railroad Grade Crossings

As shown in **Exhibit 3.7.5**, at railroad grade crossings paving shall extend 2 ft beyond the outer rails for the full graded width of the highway.

Exhibit 3.7.5 – Railroad Grade Crossing Limits of Paving



RAILROAD GRADE CROSSING
LIMITS OF PAVING
NOT TO SCALE

3.7.2 – Freeways and Expressways

Freeways and expressways are divided highways with two or more through traffic lanes in each direction that are designed for higher speed travel and less land access than arterials, collectors, and local roads. Freeways have full control of access whereas expressways may have partial control of access. MUTCD defines an “expressway” as divided highway with partial control of access.

For the purpose of selecting cross section design elements (through lanes, auxiliary lanes, shoulders, medians, and pavement cross slopes), there are no significant differences between freeways and expressways, except at the expressway intersections where turn lanes are provided. Freeways, expressways, and ramps are generally not curbed except for unusual conditions such as drainage. Full required shoulder width must be provided if curbs are needed.

Expressways use freeway criteria for their limited access sections. Arterial criteria shall be used where a break in access exists such as an at-grade intersection.

3.7.2.a – Ramp Lane Widths

Ramps are roadways designed to connect traffic between two intersecting legs of an interchange. They typically include one or more curves and are used by a wide range of design vehicles.

This section applies to interchange ramps designed for one-way traffic operations only and does not apply to turning lanes at intersections.

The design considerations affecting ramp lane widths are like those affecting the design of curved roadways that require traveled way widening. For ramp designs involving large design vehicles on short (< 250 ft) radii, the designer should check the proposed lane width by preparing a turning template for the selected design vehicle. This may warrant minimum shoulder widths greater than those in Exhibit 3.7.1. It is preferable to add the extra width to the shoulder rather than the lane width.

Ramp lane widths are determined by the following factors: operations, traffic conditions, and inner edge pavement radius. **Exhibit 3.7.6** is based on Green Book, Table 3-27, *Design Widths of the Traveled Way for Turning Roadways*, Case II (provisions for passing a stalled vehicle), Traffic Condition C (WB-40 design vehicle) and minimum shoulder widths provided in the Matrix of Design Values in Section 3.7. Shoulders wider than minimum widths may be necessary if these conditions do not apply to a ramp.

Exhibit 3.7.6 – Minimum Ramp Lane Widths

Radius at inner edge of pavement (ft)	One Lane (ft)	Two or More Lanes (ft)
100 to 149	18	16
150 to 199	17	15
200 to 299	16	14
300 to 599	15	13
600 to 3,999	14	12
4,000 to tangent	12	12

1) For single lane ramps with multiple curves, the width for the smallest radius should typically be used throughout the entire length of the ramp. Lane widths for acceleration lanes, deceleration lanes, auxiliary lanes and terminal areas should be evaluated separately.

2) For ramp radii less than 100 ft, use truck turning templates and/or turning roadway widths provided in the Green Book, Table 3-26a, *Derived Traveled Way Widths for Turning Roadways for Different Design Vehicles*.

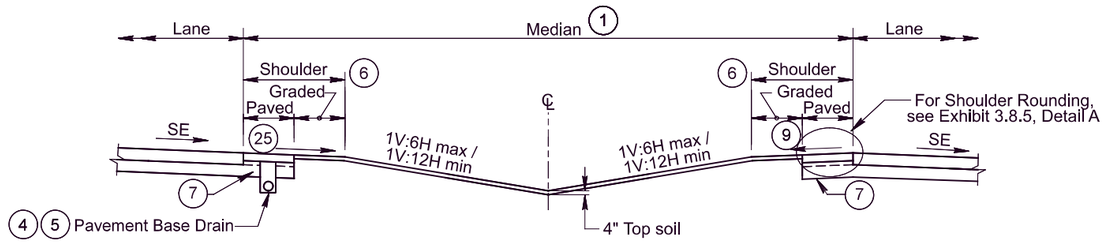
3) In the rare case where the provision for passing a stalled vehicle is not necessary, or where trucks do not govern the design, refer to the Green Book, Table 3-27, Case I.

Further guidance on ramp traveled way widths is presented in the Green Book, Section 10.9.6, *Ramps*.

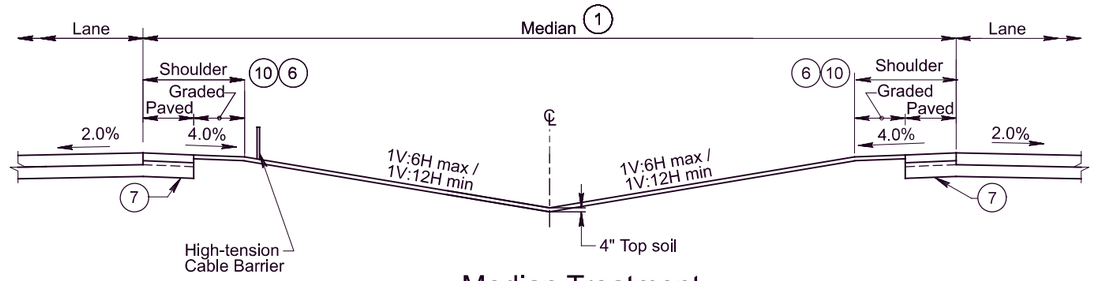
3.8 – General Design Elements

3.8.1 – Typical Roadway Cross Sections

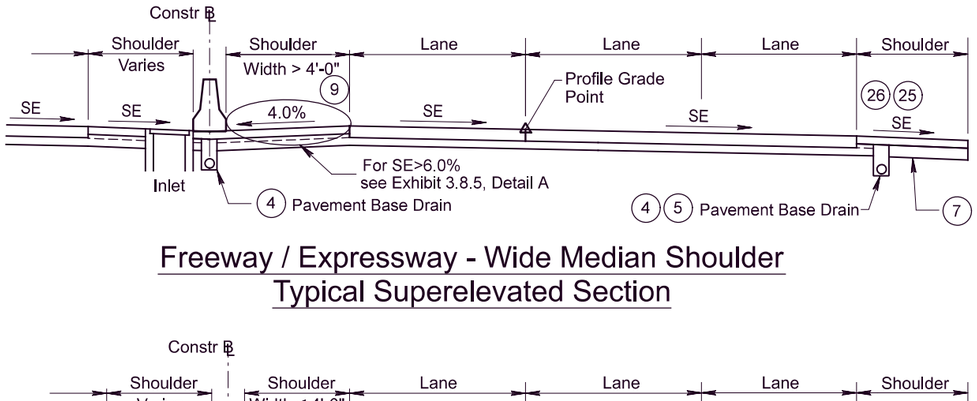
The Typical Roadway Cross Sections exhibits contained in this section should be used to develop typical sections for new construction and reconstruction projects. The designer should use appropriate engineering judgement when considering developing the typical sections for a project. The typical sections provided here are meant as a general guide and are not intended to be copied or duplicated exactly. The designer is responsible for making sure the design meets project specific needs and conditions.



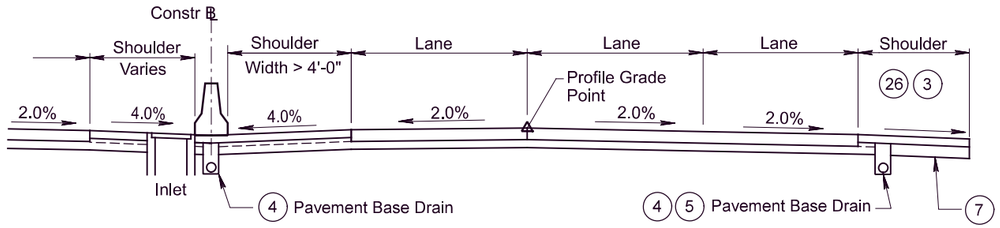
Median Treatment
Typical Superelevated Section



Median Treatment
Typical Tangent Section

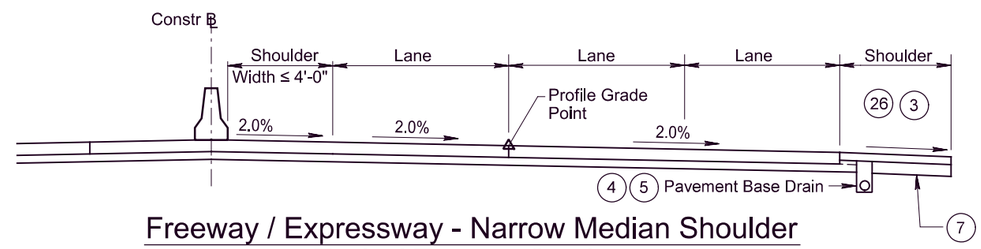


Freeway / Expressway - Wide Median Shoulder
Typical Superelevated Section



Freeway / Expressway - Wide Median Shoulder
Typical Tangent Section

Freeway / Expressway - Narrow Median Shoulder
Typical Superelevated Section



Freeway / Expressway - Narrow Median Shoulder
Typical Tangent Section

(1) For median widths see Exhibit 3.7.1.

(3) Paved shoulders shall have a cross slope in the range of 2.0% to 4.0% (4.0% preferred) and shall not have a cross slope less than the cross slope of the adjacent lane.

(4) Provide Pavement Base Drain in cuts and fills on all Freeways, Expressways, and Arterials. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" shown on Exhibit 3.8.2 shall be used, or slope the subgrade towards the base drain.

(5) The distance from the edge of the travel lane shall be equal to the subbase depth.

(6) Special consideration shall be given to median shoulder treatments at approaches to structures to ensure that they match the structure pavement edges. This shall apply to medians up to 30'-0" on superelevated sections. Adequate length for shoulder slope transition between the roadway cross section and structure cross section should be provided.

(7) For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.

(9) Cross Slope is 4.0% up to SE=4.0%. For SE > 4.0%, rotate shoulder about the lane pavement edge so the break-over between traveled way and shoulder does not exceed 8.0%. See the Green Book, Figure 4-2, Typical Cross Section, Superelevated.

(10) Where there are roadside barriers, walls, or other vertical elements, it is desirable to provide a graded shoulder wide enough that the vertical elements will be offset a minimum of 2'-0" from the edge of the useable shoulder.

(25) The shoulder on the low side of a superelevated section shall be sloped at the same rate as the travel lane when the rate of travel lane slope exceeds the required shoulder slope.

(26) See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.

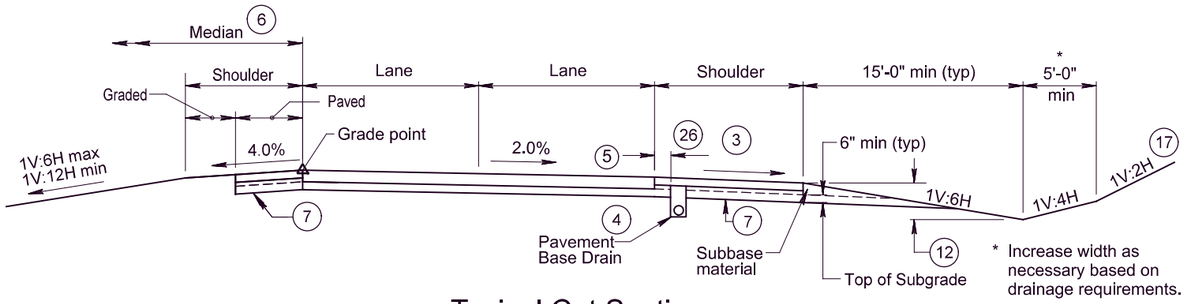
Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.

FREEWAYS AND EXPRESSWAYS

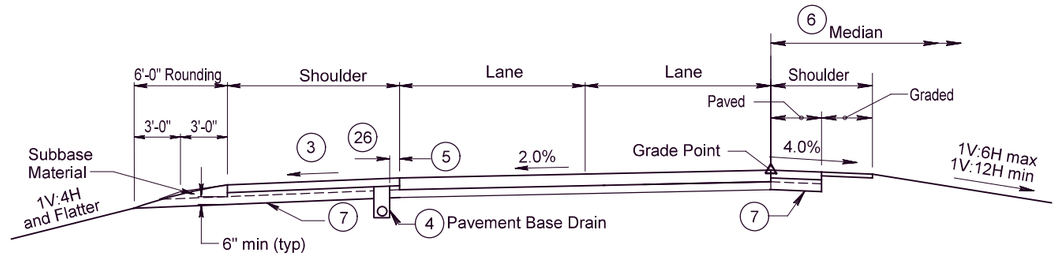
TYPICAL MEDIAN TREATMENT AND TYPICAL SECTIONS

(URBAN AND RURAL)

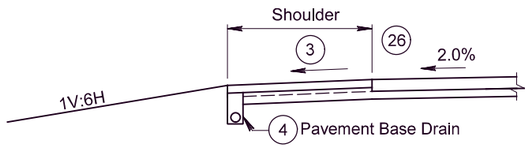
Exhibit 3.8.1



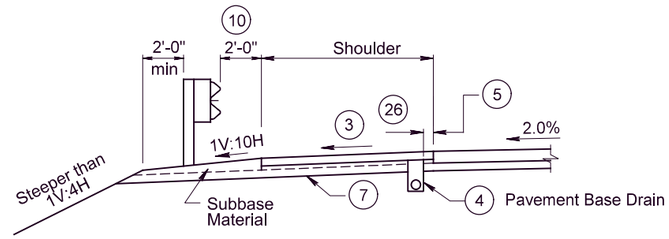
Typical Cut Section



Typical Fill Section



Alternate Subsurface Drainage Treatment



Alternate Typical Fill Section

(3) **Paved shoulders shall have cross slope in the range of 2.0% to 4.0% (4.0% preferred) and shall not have a cross slope less than the cross slope of the adjacent lane.**

(4) **Provide Pavement Base Drain in cuts and fills on all Freeways, Expressways and Arterials. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" shown on this exhibit shall be used, or place the base drain as shown in the Typical Cut Section and slope the subgrade towards the base drain.**

(5) **The distance from the edge of the pavement shall be equal to the subbase depth.**

(6) **Special consideration shall be given to median shoulder treatments at approaches to structures to ensure that they match the structure pavement edges. This shall apply to medians up to 30'-0" on superelevated sections. Adequate length for shoulder slope transition between the roadway cross section and structure cross section should be provided.**

(7) **For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.**

(10) **Where there are roadside barriers, walls, or other vertical elements, it is desirable to provide a graded shoulder wide enough that the vertical elements will be offset a minimum of 2'-0" from the edge of the useable shoulder.**

(12) **Maintain a minimum depth of 2'-6" below the outside edge of shoulder or 6 inches below top of subgrade, whichever is lower. Where it is not practical to construct a sufficiently deep swale, a Combination Storm Sewer and Underdrain should be constructed along the ditch line. The minimum depth of the Combination Storm Sewer and Underdrain (measured to the top of the pipe's bell) shall be either 12 inches below the ditch line invert measured to the top of the pipe's bell or 6 inches below the grade of the immediately adjacent subgrade, also measured to the top of the pipe's bell, whichever is lower. Provide a minimum of 6 inches of tamped soil with appropriate Seeding and Soil Supplements placed over the Combination Storm Sewer and Underdrain.**

Where subbase cannot be outlet, the pavement base drain shall be installed as indicated on the "Alternate Subsurface Drainage treatment" detail on this Exhibit.

(17) **Cut slope shall be 1V:2H unless otherwise indicated in the Geotechnical Engineering Report.**

(26) **See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.**

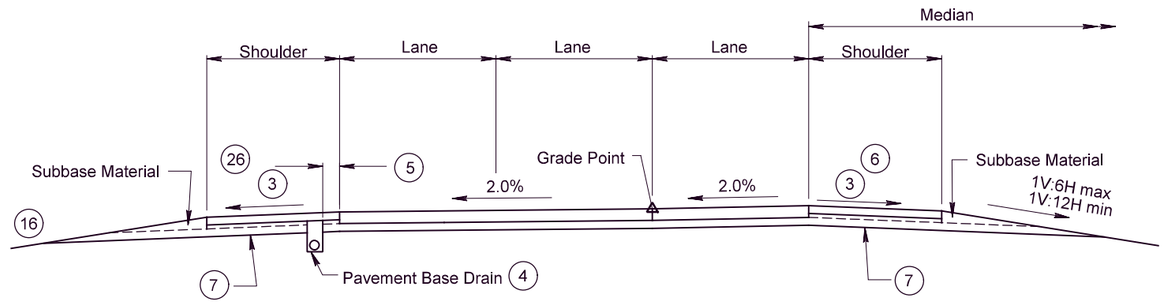
Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.

FREEWAYS AND EXPRESSWAYS

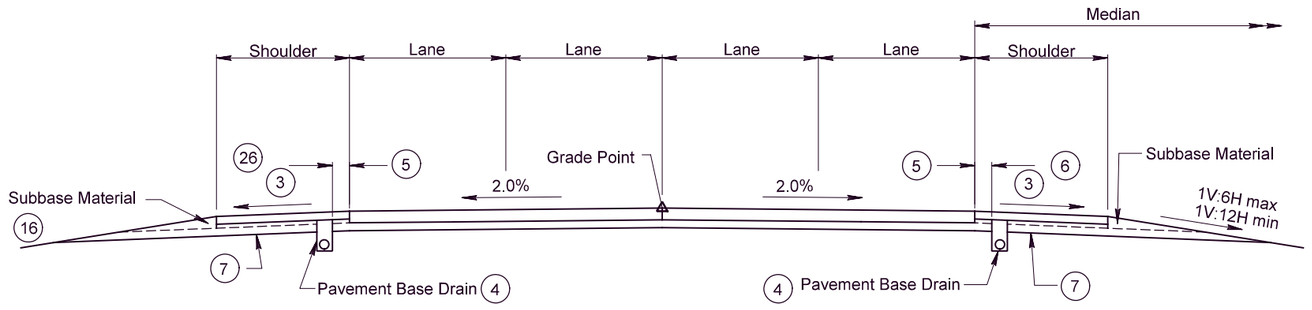
TYPICAL CUT AND FILL SECTIONS

(URBAN AND RURAL)

Exhibit 3.8.2



Typical Three Lane Directional Section



Typical Four Lane Directional Section

(3) Paved shoulders shall have cross slope in the range of 2.0% to 4.0% (4.0% preferred) and shall not have a cross slope less than the cross slope of the adjacent lane.

(4) Provide Pavement Base Drain in cuts and fills on all Freeways, Expressways, and Arterials. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" shown on Exhibit 3.8.2 shall be used, or slope the subgrade towards the base drain.

(5) The distance from the edge of the pavement shall be equal to the subbase depth.

(6) Special consideration shall be given to median shoulder treatments at approaches to structures to ensure that they match the structure pavement edges. This shall apply to medians up to 30'-0" on superelevated sections. Adequate length for shoulder slope transition between the roadway cross section and structure cross section should be provided.

(7) For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.

(16) For slope treatment in cut and fill sections, see Exhibit 3.8.2.

(26) See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension widening pavement structure into the shoulder area.

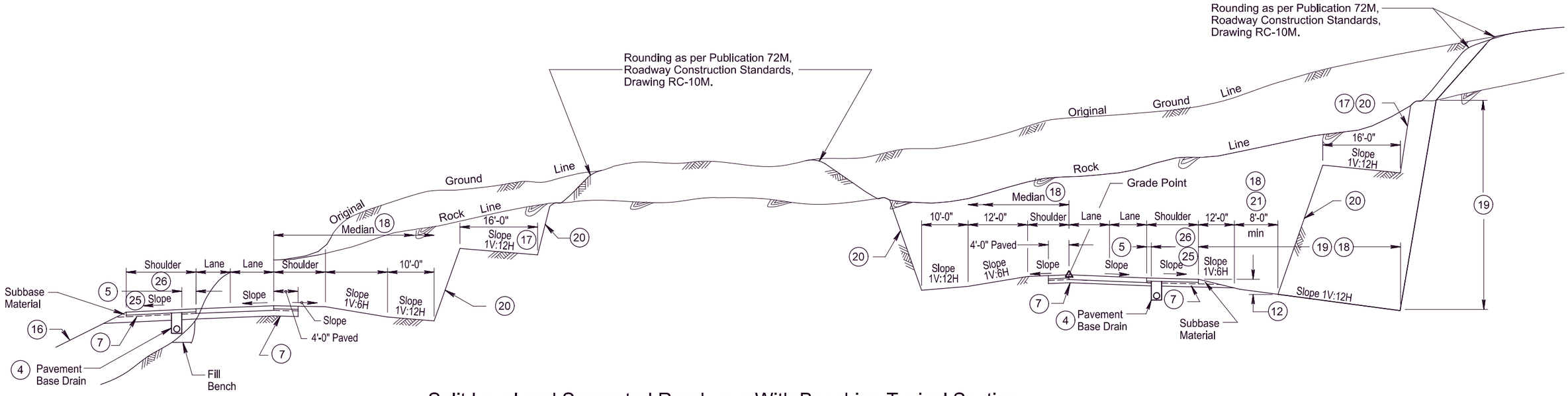
Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.

FREEWAYS AND EXPRESSWAYS

THREE AND FOUR LANE
DIRECTIONAL ROADWAYS

(URBAN AND RURAL)

Exhibit 3.8.3



Split Level and Separated Roadways With Benching Typical Section

(4) Provide Pavement Base Drain in cuts and fills on all Freeways, Expressways, and Arterials. Where subsurface water is a potential problem, Underdrain Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, andat the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" on Exhibit 3.8.2 shall be used, or slope the subgrade towards the base drain.

(5) The distance from the edge of the pavement shall be equal to the subbase depth.

(7) For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.

(12) Maintain a minimum depth of 2'-6" below the outside edge of shoulder or 6 inches below top of subgrade, whichever is lower. Where it is not practical to construct a sufficiently deep swale, a Combination Storm Sewer and Underdrain should be constructed along the ditch line. The minimum depth of the Combination Storm Sewer and underdrain will be either 12 inches below the ditch line invert measured to the top of the pipe's bell or 6 inches below the grade of the immediately adjacent subgrade, also measured to the top of the pipe's bell, whichever is lower. Provide a minimum of 6 inches of tamped soil with appropriate seeding and soil supplements placed over the Combination Storm Sewer and Underdrain.

Where subbase cannot be outlet, the pavement base drain shall be installed as indicated on the "Alternate Subsurface Drainage treatment" detail on Exhibit 3.8.2.

Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.

(16) For slope treatment in cut and fill sections, see Exhibit 3.8.2.

(17) Fill bench details and bench height shall be dependent upon recommendations of the Geotechnical Engineering Report.

(18) Inside horizontal curve to be daylighted as required for necessary sight distance.

(19) Where benches are eliminated, width and depth dimensions are dependent upon recommendations of the Geotechnical Engineering Report.

(20) Slope 2V:1H or variable as per recommendations of the Geotechnical Engineering Report.

(21) Increase width as necessary based on drainage requirements.

(25) The shoulder on the low side of a superelevated section shall be sloped at the same rate as the travel lane when the rate of travel lane slope exceeds the required shoulder slope.

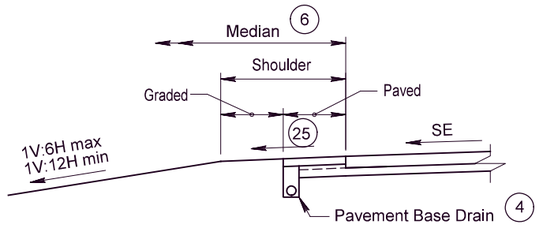
(26) See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.

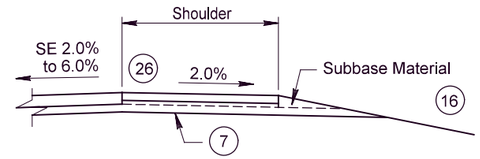
FREEWAYS AND EXPRESSWAYS

TYPICAL ROCK CUT AND BENCH DETAILS

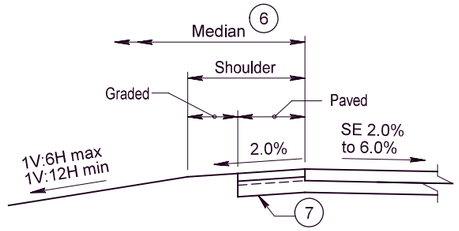
(RURAL)

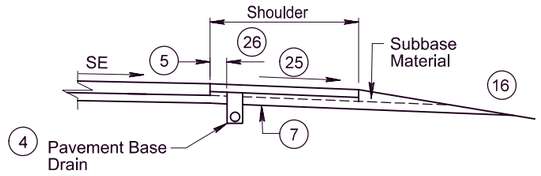
Exhibit 3.8.4



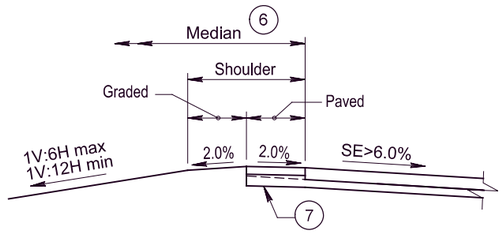


Typical Superelevated Section
Median on Low Side of Superelevation

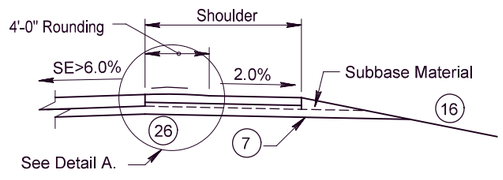




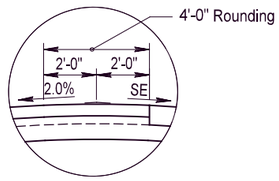
Typical Superelevated Section
Median on High Side of Superelevation



Typical Superelevated Section SE > 6%
Median on High Side of Superelevation



Typical Superelevated Section SE > 6%
Right Shoulder on High Side of Superelevation



Detail A

(4) **Provide Pavement Base Drain in cuts and fills on all Freeways, Expressways, and Arterials. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" shown on Exhibit 3.8.2 shall be used or slope the subgrade towards the base drain.**

(5) **The distance from the edge of the pavement shall be equal to the subbase depth.**

(6) **Special consideration shall be given to the median treatment on the approach to structures to insure the elevation of the edges of the structure division are the same. This shall apply to medians up to 30'-0" on superelevated sections. Adequate length for shoulder slope transition between the roadway cross section and structure cross section should be provided.**

(7) **For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.**

(16) **For slope treatment in cut and fill sections, see Exhibit 3.8.2.**

(25) **Slope shoulder at 6% for shoulder widths less than or equal to 8'-0". The shoulder on the low side of a superelevated section shall be sloped at the same rate as the travel lane when the rate of travel lane slope exceeds the required shoulder slope.**

(26) **See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.**

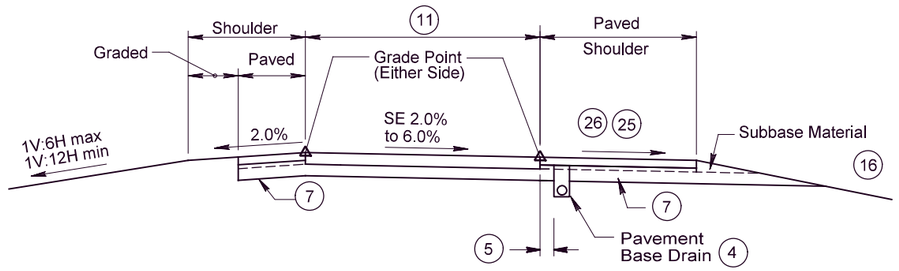
Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.

FREEWAY, EXPRESSWAYS AND ARTERIALS

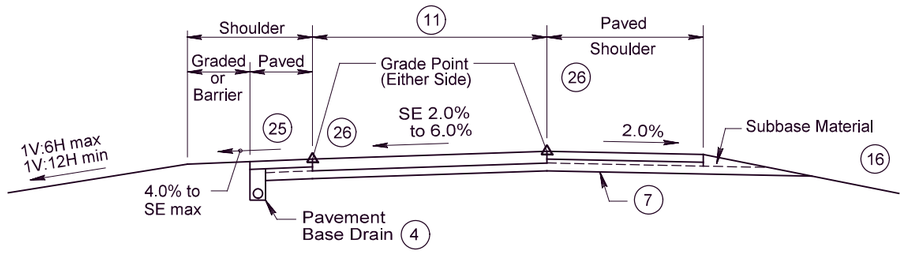
TYPICAL SUPERELEVATED SECTIONS

(URBAN AND RURAL)

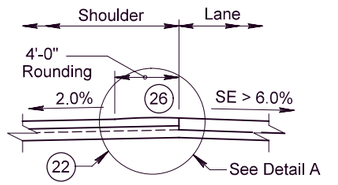
Exhibit 3.8.5



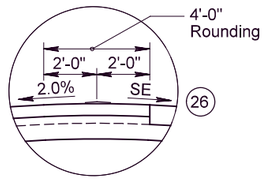
Typical Superelevated Section
Left Shoulder on High Side of Superelevation



Typical Superelevated Section
Right Shoulder on High Side of Superelevation



Typical Superelevation Section
SE > 6.0%



Detail A

(3) Paved shoulders shall have cross slope in the range of 2.0% to 4.0% (4.0% preferred) and shall not have a cross slope less than the cross slope of the adjacent lane.

(4) Provide Pavement Base Drain in cuts and fills on all Freeways, Expressways, and Arterials. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" shown on Exhibit 3.8.2 shall be used or slope the subgrade towards the base drain.

(5) The distance from the edge of the pavement shall be equal to the subbase depth.

(7) For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.

(11) Refer to Section 3.7.2.a for Ramp Lane Widths.

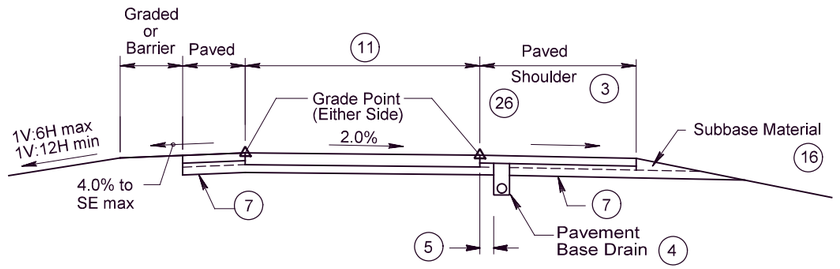
(14) Provide Pavement Base Drain on only where subbase cannot be outlet. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" on Exhibit 3.8.2 shall be used or slope the subgrade towards the base drain.

(16) For slope treatment in cut and fill sections, see Exhibit 3.8.2.

(25) The shoulder on the low side of a superelevated section shall be sloped at the same rate as the travel lane when the rate of travel lane slope exceeds the required shoulder slope.

(26) See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.

Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.



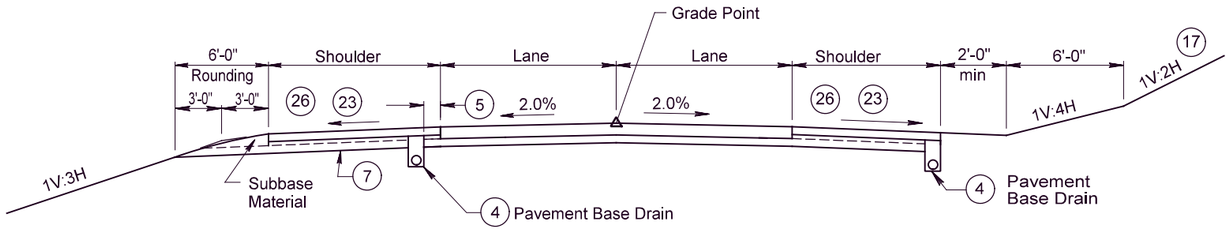
Typical Tangent Section

FREEWAY, EXPRESSWAYS AND ARTERIALS

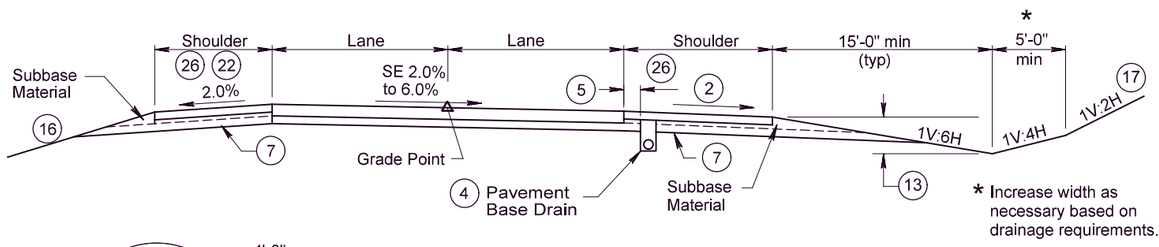
TYPICAL RAMP SECTIONS

(URBAN AND RURAL)

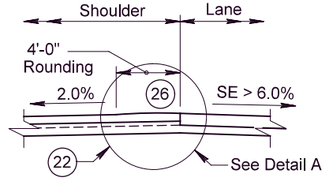
Exhibit 3.8.6



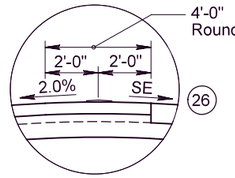
Typical Tangent Section
Design Speeds ≤ 40 mph



Typical Superelevated Section



Typical Superelevation Section
SE > 6.0%



Detail A

(2) **The shoulder on the low side of a superelevated section shall be sloped at the same rate as the travel lane when the rate of travel lane slope exceeds the required shoulder slope of 4.0% or 6.0%. The shoulder cross slope may match the cross slope of the travel lane when the shoulder width is less than or equal to 3'-0".**

(4) **Provide Pavement Base Drain in cuts and fills on all Freeways, Expressways, and Arterials. Where subsurface water is a potential problem, Underdrain Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, andat the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" on Exhibit 3.8.2 shall be used, or slope the subgrade towards the base drain.**

(5) **The distance from the edge of the pavement shall be equal to the subbase depth.**

(7) **For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.**

(10) **Where there are roadside barriers, walls, or other vertical elements, it is desirable to provide a graded shoulder wide enough that the vertical elements will be offset a minimum of 2'-0" from the edge of the useable shoulder.**

(13) **Maintain a minimum depth of 2'-6" below the outside edge of shoulder or 6 inches below top of subgrade, whichever is lower. Where it is not practical to construct a sufficiently deep swale, a Combination Storm Sewer and Underdrain should be constructed along the ditch line. The minimum depth of the Combination Storm Sewer and Underdrain will be either 12 inches below the ditch line invert measured to the top of the pipe's bell or 6 inches below the grade of the immediately adjacent subgrade, also measured to the top of the pipe's bell, whichever is lower. Provide a minimum of 6 inches of tamped soil with appropriate Seeding and Soil Supplements placed over the Combination Storm Sewer and Underdrain.**

(15) **An alternate 1V:4H slope without guide rail may be used based on economic analysis. See " Alternate Tangent Section Detail - Fill Height 15'-0" and over on this sheet.**

(16) **For slope treatment in cut and fill sections, see Exhibit 3.8.2.**

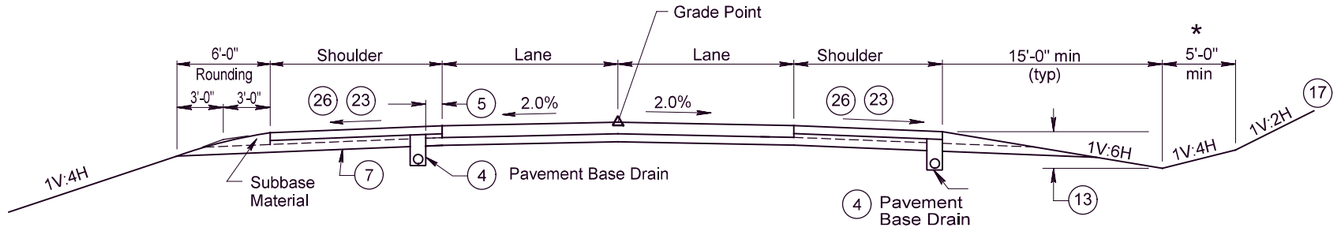
(17) **Cut slope shall be 1V:2H unless otherwise indicated in the Geotechnical Engineering Report.**

(22) **For shoulder rounding details when superelevation is greater than 6.0%, see Exhibit 3.8.6.**

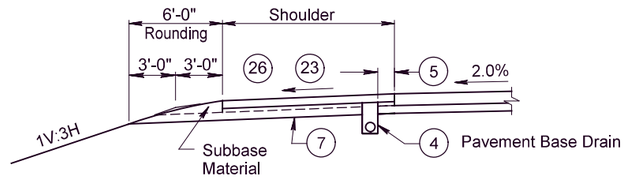
(23) **Slope shoulder at 6% for shoulder widths less than or equal to 8'-0". Slope shoulder at 4.0% for shoulder widths greater than 8'-0". The shoulder cross slope may match the cross slope of the travel lane when the shoulder width is less than or equal to 3'-0".**

(26) **See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.**

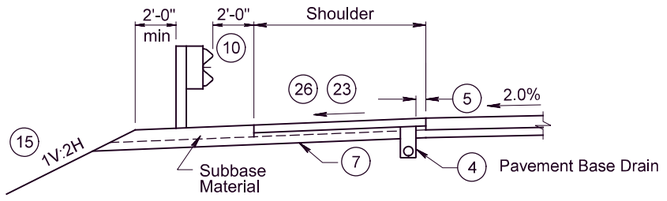
Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.



Typical Tangent Section - Fill Height 15'-0" and Under
Design Speeds > 40 mph



Tangent Section - Fill Height 15'-0" and Over
Design Speeds > 40 mph



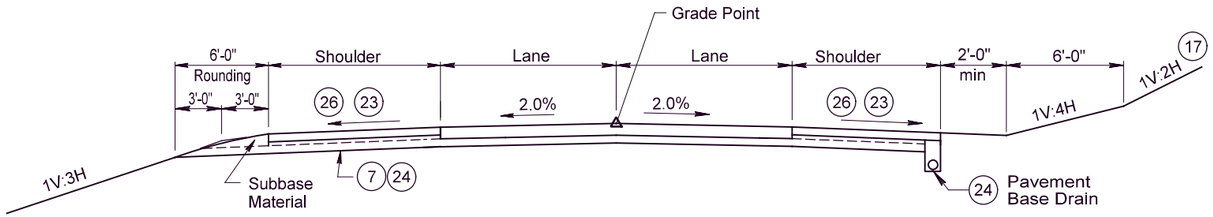
Typical Tangent Fill Section

ARTERIALS

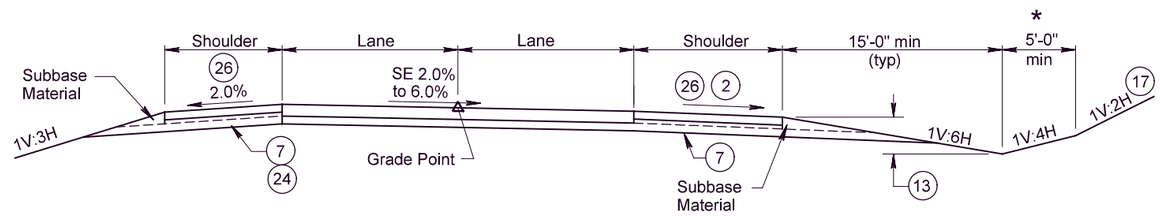
TYPICAL SECTIONS

(URBAN AND RURAL)

Exhibit 3.8.7

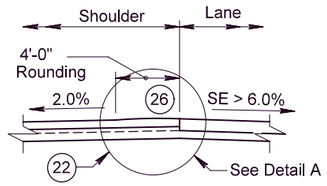


Typical Tangent Section
Design Speeds ≤ 40 mph

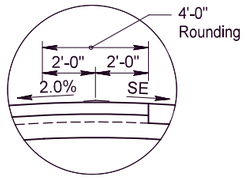


Typical Superelevated Section

* Increase width as necessary based on drainage requirements.



Typical Superelevation Section
SE > 6.0%



Detail A

(2) **The shoulder on the low side of a superelevated section shall be sloped at the same rate as the travel lane when the rate of travel lane slope exceeds the required shoulder slope of 4.0% or 6.0%. The shoulder cross slope may match the cross slope of the travel lane when the shoulder width is less than or equal to 3'-0".**

(7) **For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.**

(10) **Where there are roadside barriers, walls, or other vertical elements, it is desirable to provide a graded shoulder wide enough that the vertical elements will be offset a minimum of 2'-0" from the edge of the useable shoulder.**

(13) **Maintain a minimum depth of 2'-6" below the outside edge of shoulder or 6 inches below top of subgrade, whichever is lower. Where it is not practical to construct a sufficiently deep swale, a Combination Storm Sewer and Underdrain should be constructed along the ditch line. The minimum depth of the Combination Storm Sewer and Underdrain will be either 12 inches below the ditch line invert measured to the top of the pipe's bell or 6 inches below the grade of the immediately adjacent subgrade, also measured to the top of the pipe's bell, whichever is lower. Provide a minimum of 6 inches of tamped soil with appropriate Seeding and Soil Supplements placed over the Combination Storm Sewer and Underdrain.**

(17) **Cut slope shall be 1V:2H unless otherwise indicated in the Geotechnical Engineering Report.**

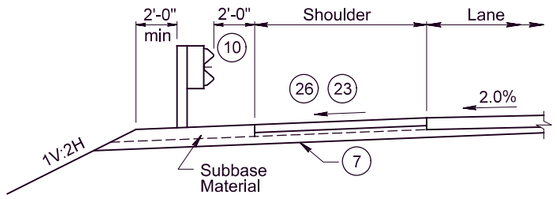
(22) **For shoulder rounding details when superelevation is greater than 6.0%, see Exhibit 3.8.6, Detail A.**

(23) **Slope shoulder at 6% for shoulder widths less than or equal to 8'-0". Slope shoulder at 4.0% for shoulder widths greater than 8'-0". The shoulder cross slope may match the cross slope of the travel lane when the shoulder width is less than or equal to 3'-0".**

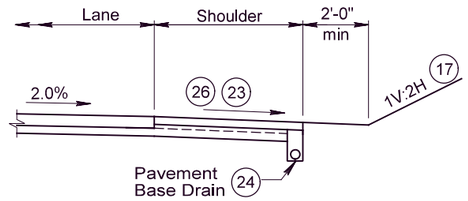
(24) **Provide Pavement Base Drain on Collectors and Local Roads only where subbase cannot be outlet. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" on Exhibit 3.8.2 shall be used or slope the subgrade towards the base drain.**

(26) **See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.**

Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.



Typical Tangent Fill Section



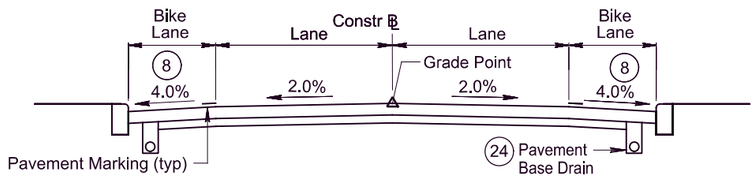
Alternate Shoulder Swale
Design Speed < 40 mph

COLLECTORS AND LOCAL ROADS

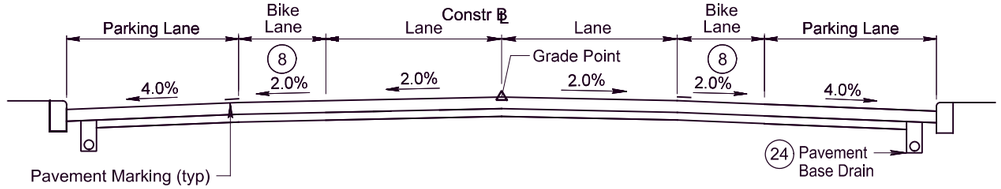
TYPICAL SECTIONS

(URBAN AND RURAL)

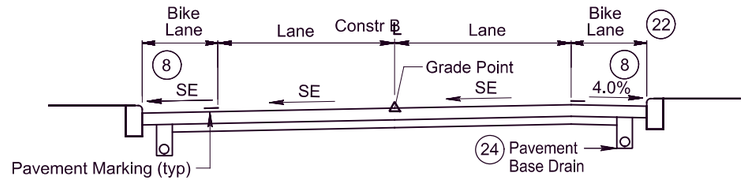
Exhibit 3.8.8



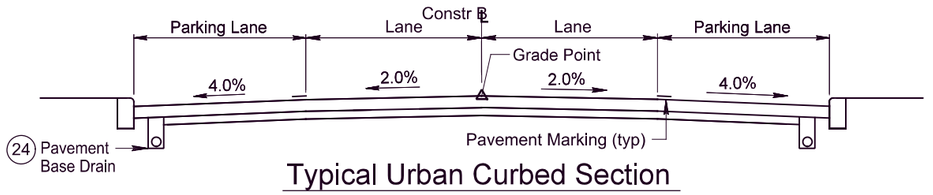
Typical Curbed Bike Lane Section



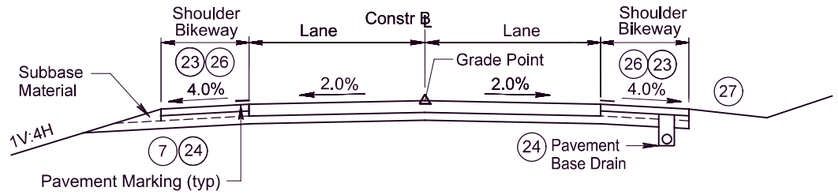
Typical Bike Lane with Parking Section



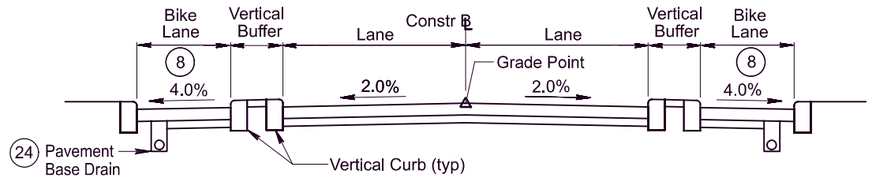
Typical Superelevated Curbed Bike Lane Section



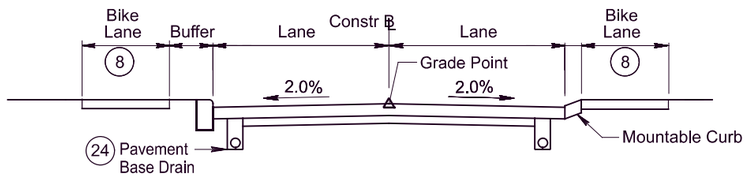
Typical Urban Curbed Section



Typical Shoulder Bikeway Section



Typical Protected Bike Lane With Vertical Buffer Section



Typical Curb-Separated Bike Lane Section

(7) For ease of construction, the subgrade slope under the lane should match the lane pavement slope, and the subgrade slope under the shoulder should match the shoulder slope.

(8) For bike lane width criteria see DM-2, Sections 14.3.3. and 14.3.4.

(22) For shoulder rounding details when superelevation is greater than 6.0%, see Exhibit 3.8.6, Detail A.

(23) Slope shoulder at 6.0% for shoulder widths less than or equal to 8'-0". Slope shoulder at 4.0% for shoulder widths greater than 8'-0". The shoulder cross slope may match the cross slope of the travel lane when the shoulder width is less than or equal to 3'-0".

(24) Provide Pavement Base Drain on Collectors and Local Roads only where subbase cannot be outlet. Where subsurface water is a potential problem, Underdrain or Combination Storm Sewer shall be used. Where the subbase cannot be outlet, the subgrade slope shall be in the direction of, and at the same rate as, the shoulder slope and the "Alternate Subsurface Drainage Treatment" on Exhibit 3.8.2 shall be used or slope the subgrade towards the base drain.

(26) See shoulder criteria in Publication 242, *Pavement Policy Manual* for extension of widening pavement structure into the shoulder area.

(27) Provide 1V:6H maximum to shoulder slope minimum.

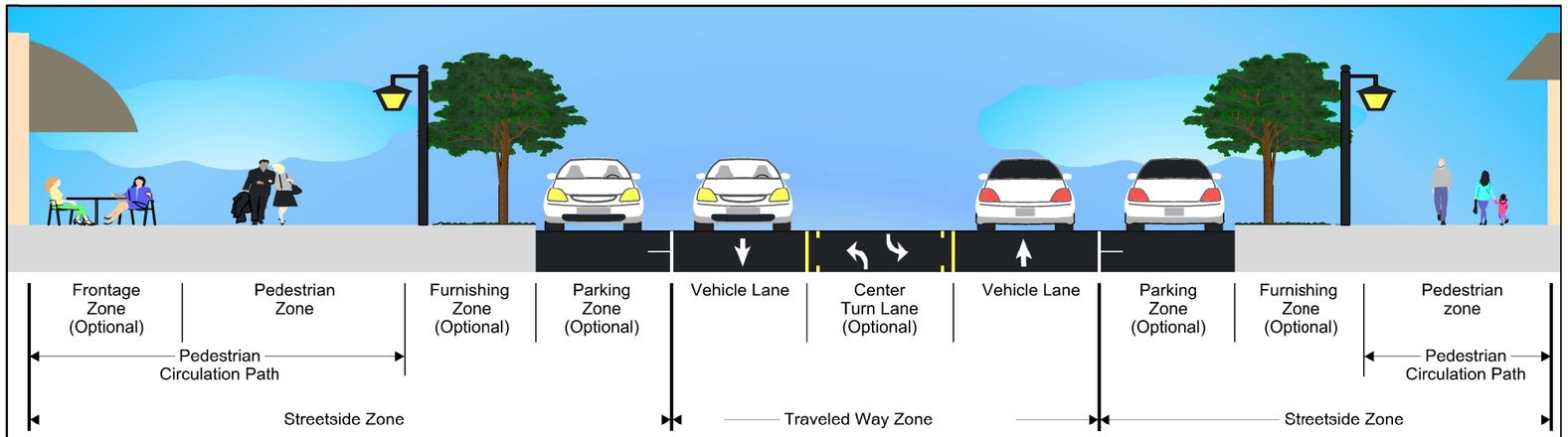
Note: For lane and shoulder widths, lane cross slopes (minimum and maximum), and other cross section design criteria, see Section 3.7, Matrix of Design Values.

ARTERIALS, COLLECTORS, AND LOCAL ROADS

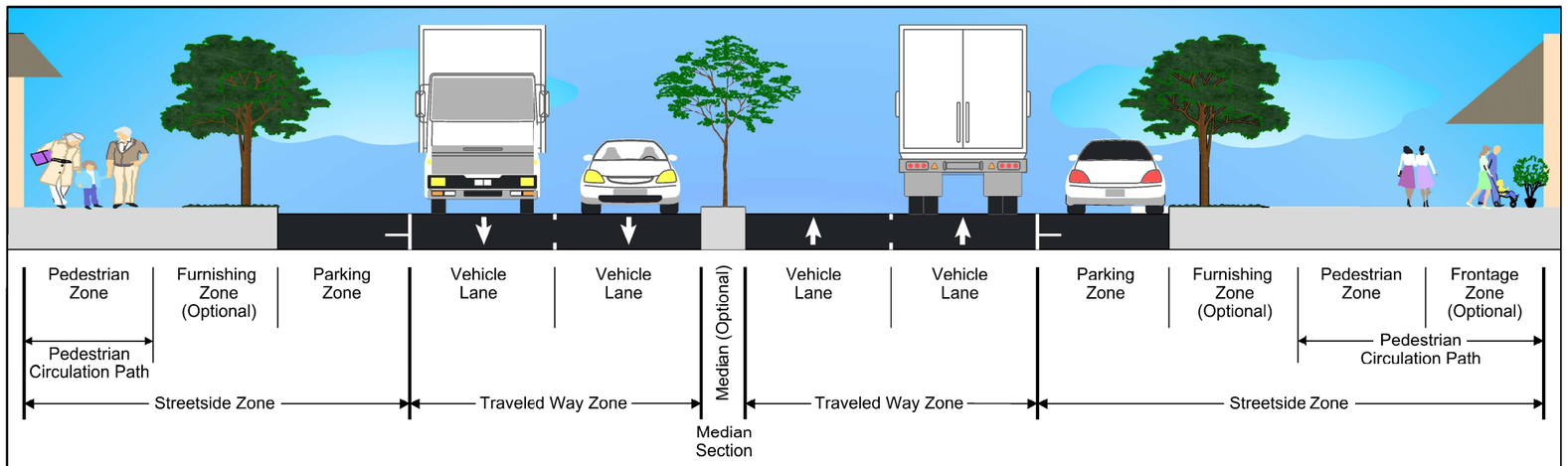
CURBED SECTIONS AND BIKEWAYS
HIGHWAY BIKEWAY CONTINUUM

(URBAN AND RURAL)

Exhibit 3.8.9



Pedestrian - Oriented Cross Section with Center Turn Lane

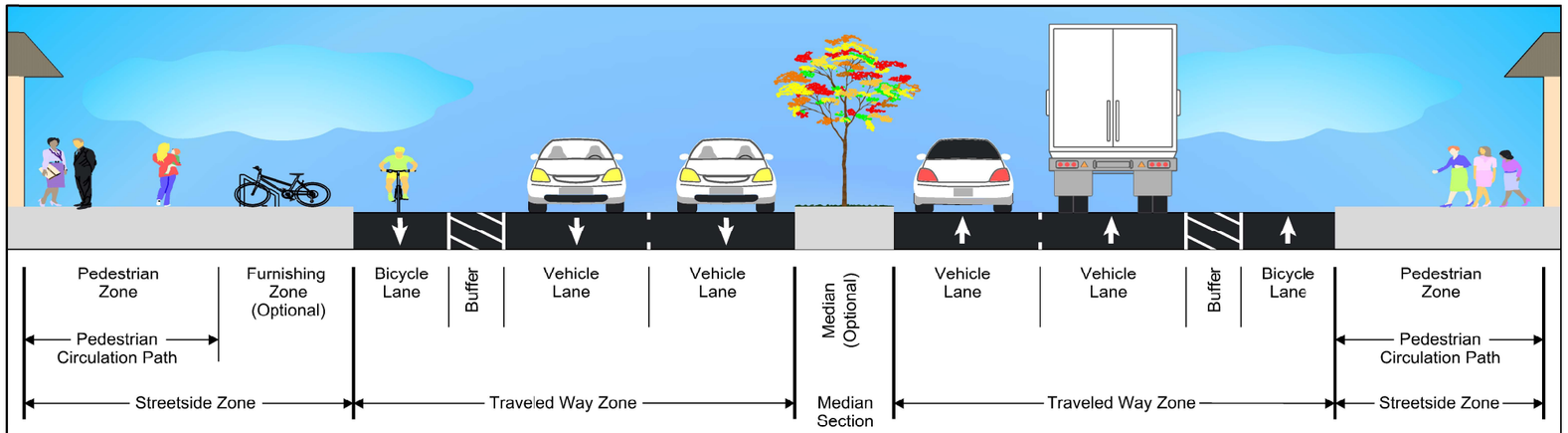


Pedestrian - Oriented Cross Section with Median

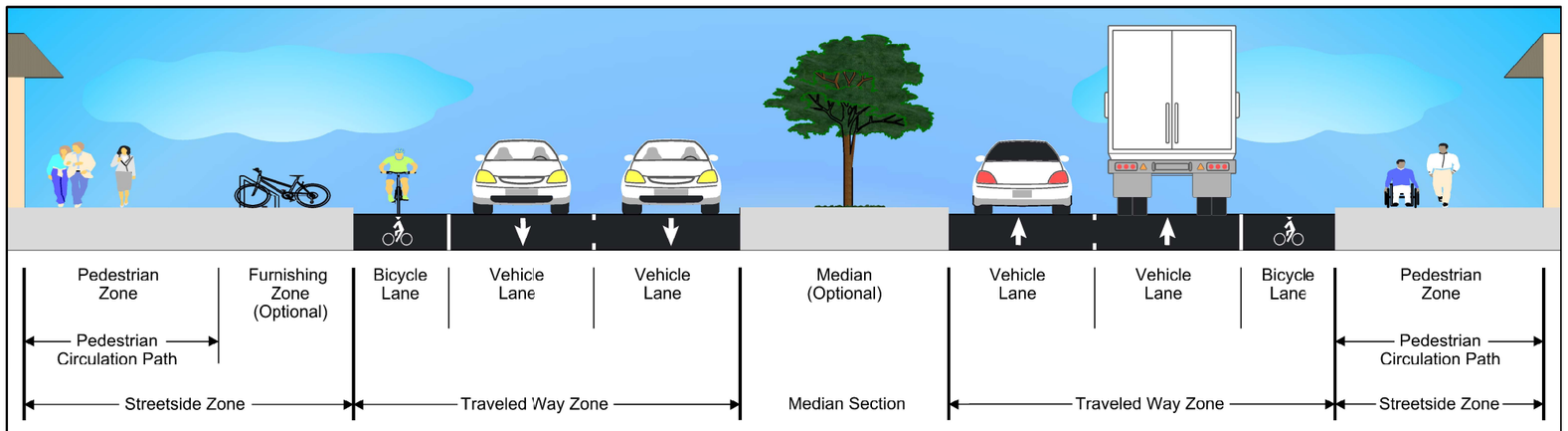
ARTERIALS AND COLLECTORS

CURBED SECTIONS AND BIKEWAYS
HIGHWAY BIKEWAY CONTINUUM

Exhibit 3.8.10



Bicycle - Oriented Cross Section with Bicycle Lane Buffers

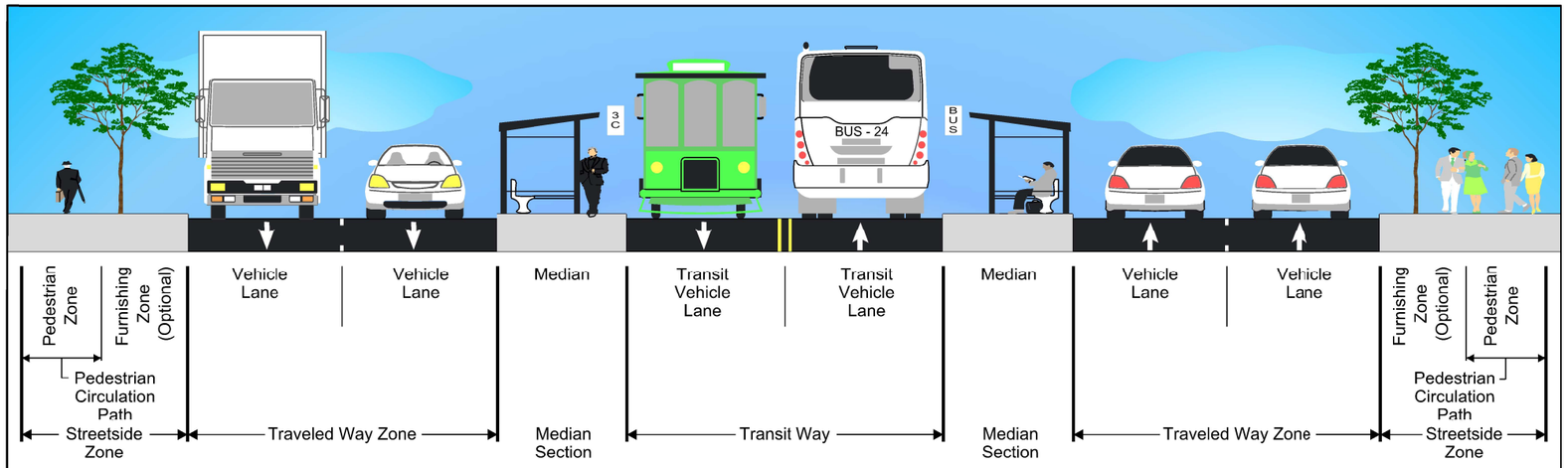


Bicycle - Oriented Cross Section without Bicycle Lane Buffers

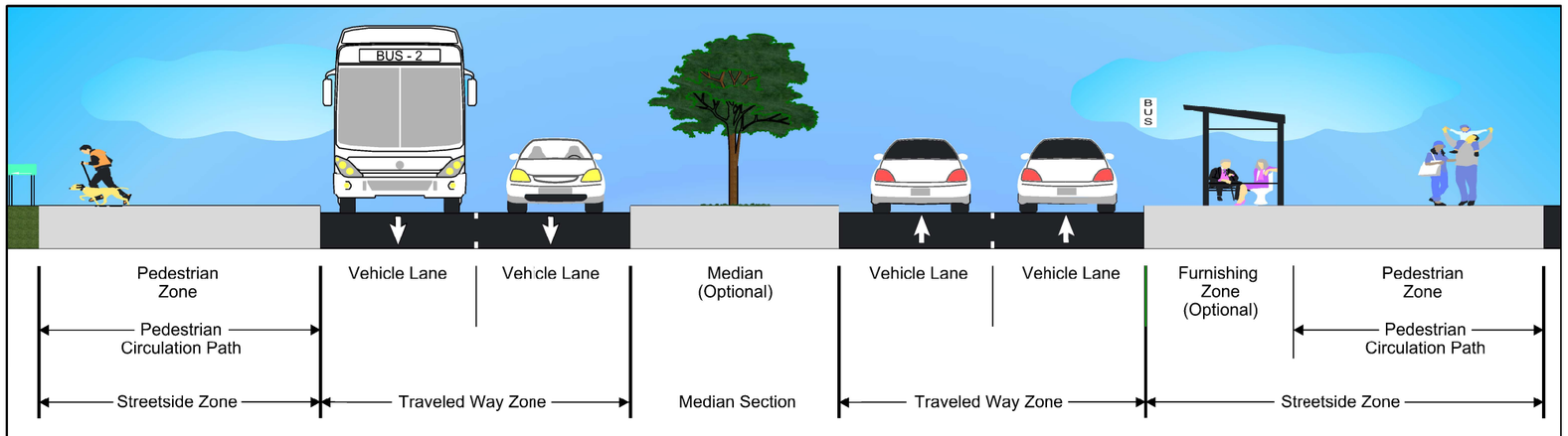
ARTERIALS AND COLLECTORS

CURBED SECTIONS AND BIKEWAYS
ARTERIAL AND COLLECTOR/
HIGHWAY BIKEWAY CONTINUUM

Exhibit 3.8.11



Transit - Oriented Cross Section Transit Boulevard



Transit - Oriented Cross Section

ARTERIALS AND COLLECTORS

CURBED SECTIONS AND BIKEWAYS
ARTERIAL AND COLLECTOR/
HIGHWAY BIKEWAY CONTINUUM

Exhibit 3.8.12

Appendix 3A: Vertical Clearance Design Exception Coordination with the Surface Deployment and Distribution Command Transportation Engineering Agency (SDDCTEA)

Information Required for Vertical Clearance

Design Exception Coordination with SDDCTEA

(For FHWA or State DOT Use)

E-mail Coordination Form (Including Vicinity Map) to:

Office of the Special Assistant for Transportation Engineering Office of the Special Assistant for Transportation Engineering (army.mil) or call (618) 220-5060

1) **Structure Location** –

   Direction – EB, WB, NB, or SB

   Overpass Route – include route name and number

2) **Structure NBI Number** – National Bridge Inventory reference number

3) **Project Description** – pavement rehabilitation, pavement preservation, etc.

   Estimated Total Project Cost – self-explanatory

4) **Location and Description of the Substandard Clearance** – single units of the existing and proposed clearance are preferred – English (feet and inches)

5) **Description of Work Required to Achieve the 16.0 ft Clearance** – self-explanatory

   Estimated Additional Cost to Obtain 16.0 ft Clearance – self-explanatory

6) **Reason Why 16.0 ft Vertical Clearance Cannot be Attained** – high cost, environmental issues, etc.

7) **Alternate Route with (16.0 ft) Vertical Clearance** – alternate route around each substandard-vertical-clearance substructure. The alternate route should have standard vertical clearances. If at least one standard vertical clearance through lane exists (in both directions), this can be considered an alternate route. A diamond interchange can provide an alternate route.

8) **Anticipated Schedule for Future Projects Which Will Correct of Improve the Substandard Vertical Clearance** – include type of project (bridge replacement, etc.) and year programmed

9) **Names of Nearby Military Installations or Ports** – self-explanatory

10) **Remarks** – self-explanatory

To: Surface Deployment and
Distribution Command (SDDCTEA)
ATTN: SDTE-SA
Contact: Mr. Douglas Briggs, P.E.
Telephone: (618) 220-5229
Fax: (618) 220 -5125
E-mail: jason.cowin@us.army.mil

From: Federal Highway Administration
_____ (State) Division or _____ DOT
Contact/Title:
Telephone
Fax:
E-mail Address:
Date to SDDCTEA:
Date response is requested by:

Above Information is to be completed by the FHWA or State DOT

Interstate Vertical Clearance Exception Coordination
1. Structure Location: State: _____ County: _____ Route I-_____ Direction _____ Milepost _____ (mark an "x" on the appropriate line) _____ Rural _____ Urban Single Routing Overpass Route: Include a map showing the general vicinity.
2. Structure NBI number:
3. Project Description: Estimated Total Project Cost: $
4. Location (e.g., driving lane, passing lane, shoulder, ramp, C-D Road, etc.) and description of the substandard clearance: Through Lane(s) Shoulder(s) Aux./Ramp (Interstate to Interstate) Existing: _____(ft) _____(ft) _____(ft) Proposed: _____(ft) _____(ft) _____(ft)
5. Description of work required to achieve the 16.0 ft clearance: Estimated additional cost to obtain 16.0 ft clearance: $
6. Reason why 16.0 ft vertical clearance cannot be attained:
7. Alternate route with 16.0 ft vertical clearance:
8. Anticipated schedule for future project(s) which will correct of improve the substandard clearance: ☐ Future Project Year: _____ Anticipated Clearance: _____(ft) ☐ Future project not programmed
9. Names of nearby military installations or ports:
Remarks:

Appendix 3B: Applicable Design Criteria for Roadway Projects

Exhibit 3B.1 – Applicable Design Criteria for Roadway Projects

Project Type	New Construction	Reconstruction Change in Road Type (CIRT)	Reconstruction No Change Road Type (NoCIRT)	Resurfacing, Restoration, and Rehabilitation (3R)	Pavement Preservation
Design Criteria	• Green Book • AASHTO, A Policy on Design Standards – Interstate System • DM-2, Chapter 3, *New Construction and Reconstruction Change In Road Type* • AASHTO Low-Volume Roads Guidelines (where appropriate -as defined by the guidance)	• Green Book • AASHTO, A Policy on Design Standards – Interstate System • DM-2, Chapter 3, *New Construction and Reconstruction Change In Road Type* • AASHTO Low-Volume Roads Guidelines (where appropriate-as defined by the guidance)	• DM-2, Chapter 4, *Reconstruction No Change In Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects, Section 4.2.1* • AASHTO Low-Volume Road Guidelines (where appropriate-as defined by the guidance)	• DM-2, Chapter 4, *Reconstruction No Change In Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects, Section 4.2.2*	• DM-2, Chapter 4, *Reconstruction No Change In Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects, Section 4.3*
Examples	• A new project on a completely new alignment, including New Highway, New Bypass, or New ramps at an existing interchange where none previously existed. • A project on an existing corridor where a majority of the project has a new horizontal and/or vertical alignment. • Note: Exclude minor sections of roadway which are part of a larger project. For example, addition of a right turn by-pass lane.	• Reconstruction with a change in Road Type. • Projects that substantially modify horizontal or vertical alignments. • Widening to add a raised or depressed median where none currently exists. • Widening to add a travel lane(s). • Widening to add new parking lanes or bike lanes. • Widening to add lanes to an existing ramp. This applies to the ramp proper, not turn lanes at ramp terminal. • Widening to add a two-way left turn lane where none previously existed. • Widening to add auxiliary lanes such as connecting freeway ramps between two interchanges. • The addition of a median greater than or equal to one lane width or changing the median to/from traversable from/to non- traversable. • Reconstruction of Interchanges and associated Acceleration /Deceleration Lanes and Ramps that add capacity. • Signalized or stop controlled intersections converted to roundabouts. • Major Realignment of interchange ramps • Major interchange reconfiguration, such as converting a diamond interchange to a DDI or SPDI. • Major intersection improvements, such as signalizing a previously un-signalized intersection or major modifications to an existing intersection • Widening to add climbing lanes.	• Reconstruction with no change in Road Type. • The number of lanes and/or the functionality of the median shall not change. However, existing lanes and shoulders may be widened. • Only minor portions of the roadway may be realigned horizontally and/or vertically. • Reconstruction of Interchanges and associated Acceleration/Deceleration Lanes, and Ramps that do not add capacity or have major realignments. • Reconstruction from curb to curb • Reconstruction and Widening existing lanes and/or shoulders • Adding turn lanes with minor realignment of thru lanes • Road Diets • Removal of travel lanes • Removal of shoulders (perhaps adding curbing instead) • Adding or removing curbing • Adding channelizing islands • Adding median curbs for access management (with no widening) • Structural pavement overlays on freeways (see Publication 242, *Pavement Policy Manual*).	• Resurfacing, Restoration or Rehabilitation. • The number of lanes shall not change; however, existing lanes and shoulders may be widened and turn lanes may be added. • Only minor portions of the roadway may be realigned horizontally and/or vertically or fully constructed. Up to 30% base repair to existing traveled way surface area. • Minor widening of a through lane (less than a full lane). • Shoulder widening. • Adding turning lanes (without modifying the through lanes or median). • Adding a new signal to an existing intersection with roadway work (If no roadway or restriping work, then non-roadway criteria may be applicable.) • Minor intersection improvements.	• Resurfacing that does not increase the pavement structure capacity for all typologies and functional classifications. • No roadway alignment modifications are permitted. • Restriping, such as striping a shoulder for extending an acceleration or deceleration lane. Appropriate criteria still needs to be applied along with necessary design exceptions if for example a shoulder width is reduced below New and Reconstruction widths. • Asphalt Pavement – Base Repair • Concrete Pavement – Concrete patching

Exhibit 3B.1 – Applicable Design Criteria for Roadway Projects

Project Type	Bridge Projects (Geometry)	Maintenance	Non-Roadway and Non-Bridge	Roadway and Bridge Components
Design Criteria	• DM-2, Chapter 5, *Bridge Projects*	• Publication 23, *Maintenance Manual* • Publication 55, *Bridge Maintenance Manual*	• DM-2, Chapter 13, *Pedestrian Facilities* • DM-2, Chapter 14, *Bicycle Facilities*	• DM-2, Chapter 4, *Reconstruction No Change In Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects* • DM-2, Chapter 10, *Drainage* • DM-2, Chapter 12, *Roadside Design*

Examples	• New and replacement bridges
	• Superstructure and deck partial and full replacements
	• Bridge Preservation
	• Minimal bridge approaches (not to exceed 500 ft for each approach) where a project ties into an existing roadway.
		• Pavement Repairs such as:
		  ○ Seal Coats
		  ○ Full Width Patching
		  ○ Crack Sealing
		  ○ Correcting Minor Irregularities
		• Making Permanent Repairs to the surface and/or base on Paved Shoulders.
		• Reapplication of existing Pavement Markings
		• Guide Rail Maintenance
		• Maintenance and/or minor Placement/Replacement of Guide Rail.
		*See DM-2, Chapter 4, *Reconstruction No Change In Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects*, for a list of Maintenance Project vs. Alteration Projects in relation to ADA requirements.
			• Pedestrian/Bicycle/Shared Use Trails
			• New Sidewalks and/or ADA Curb Ramps
			• Slope Repairs/Stabilization
				• ITS Device Implementation
				• Roadway Sign Installation
				• Sound wall Construction
				• Lighting Installation
				• Adding or replacing Guide Rail or High-Tension Cable Barrier
				• Upgrading existing Median Barrier or Single Face Barrier
				• Traffic Signal Installation
				• Equipment Replacement
				• Drainage Pipe Replacement
				* These projects may include replacement of components or new components.

Chapter 4 – Reconstruction No Change in Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects

In this chapter there are references to future chapters 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 4 – Reconstruction No Change in Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects

4.0 – Introduction

This chapter presents the Department's criteria for projects that improve existing roadways without changing the roadway type. These projects require different criteria than New Construction and Reconstruction Change In Road Type (CIRT) criteria since it is typically not practical or financially possible to design them to the most desirable criteria. "Road Type" refers to the predominate typical section of the roadway corridor, not the Functional Classification. In addition, design criteria for New Construction and Reconstruction CIRT projects are often not attainable without incurring adverse impacts. However, the Department should determine and evaluate the performance measures associated with the project, including practical safety and geometric improvements to the existing roadway. For more information on performance measures, refer to the Chapter 2, *Design Controls*, Section 2.4, *Performance Metrics*, and the Green Book, Section 1.9, *Performance Based Design*.

This chapter provides guidance on how to identify applicable projects and apply the appropriate criteria.

Criteria found in this chapter are associated with the following project types:

1) Reconstruction No Change in Road Type (NoCIRT)
2) Resurfacing, Restoration, and Rehabilitation (3R)
3) Pavement Preservation Projects

The following project types and associated design criteria are also included in this Chapter:

4) Maintenance
5) Non-Roadway and Non-Bridge
6) Roadway and Bridge Components

For design criteria on projects that involve New Construction or Reconstruction CIRT, see Chapter 3.

The criteria provided in this Chapter applies to all roadways with the exception that Reconstruction NoCIRT does not apply to Interstates or Freeways. If a project does not qualify for Reconstruction NoCIRT, 3R, or Pavement Preservation, as described in this Chapter, then design criteria for New Construction and Reconstruction CIRT in Chapter 3 applies.

Important context questions to ask:

- Should a project be limited to reconstruction or resurfacing of the existing pavement, or should it also include geometric improvements that enhance safety?
- When is it appropriate to apply Reconstruction NoCIRT or 3R versus New Construction and Reconstruction CIRT criteria?
- If geometric improvements are warranted, what design criteria should be used?
- Which of several possible design alternatives is most appropriate for the context and stated project needs?

4.0.1 – Resources and References

- AASHTO, *Guidelines for Geometric Design of Low-Volume Roads*, 2019.
- AASHTO*, A Guide to Achieving Flexibility in Highway Design*, 2018.
- AASHTO*, Highway Safety Manual, 1st Edition*, 2010.
- National Cooperative Highway Research Program (NCHRP), Research Report 876: *Guidelines for Integrating Safety and Cost-Effectiveness into Resurfacing, Restoration, and Rehabilitation (3R) Projects*, 2018.
- National Cooperative Highway Research Program (NCHRP), Research Report 839: *A Performance-Based Highway Geometric Design Process*, 2017.
- PennDOT, Publication 242, *Pavement Policy Manual*, (most recent version).
- PennDOT, Publication 23, *Maintenance Manual*, (most recent version).
- PennDOT, Publication 55, *Bridge Maintenance Manual*, (most recent version).

4.1 – Highway Safety Manual (HSM) Analysis

Projects associated with this Chapter should be evaluated for safety issues in meeting the goals presented in the Strategic Highway Safety Plan (SHSP). The purpose for this evaluation is to assist in determining the correct project type, what criteria to use, and to justify safety improvements to be considered for HSIP funds. See FHWA Systemic Safety Project Selection Tool for additional guidance.

The Districts are provided network screening lists annually showing high crash areas and their associated observed, predicted, and expected crashes. A review of these crash clusters should be done for all projects utilizing criteria in this Chapter. If there are no crash issues, HSM project specific analysis as described below is optional.

AASHTO developed the Highway Safety Manual in 2010 as a guidance document for incorporating quantitative safety analysis in the highway transportation planning and development process. Utilizing HSM methods and principles, the Department created

computational safety analysis tools to evaluate existing conditions and alternatives. See link for access to Pennsylvania HSM tools.
https://www.penndot.pa.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx

The HSM tools include the following:

- Highway Safety Screening Tool (Existing Conditions Analysis)
- PennDOT SPF Collision Type & Severity Tables
- PennDOT HSM Analysis Tools, Tool A (Existing Conditions) and Tool B (Alternatives Analysis)
- Freeway and Ramps HSM Analysis Tool
- Benefit Cost Analysis (BCA) Tool

For Reconstruction NoCIRT projects, PennDOT's HSM Analysis tools can be utilized to comparatively quantify safety performance of the existing conditions against alternatives. The HSM tools indicate how safety is improved by changing the design element values. For example: lane and shoulder width - If crash clusters exist, the HSM analysis will indicate how an increase in lane and shoulder width may improve safety and estimate a positive benefit-cost ratio on investment. If safety issues are identified, and will be addressed in the project, then Chapter 3 criteria or HSM Project Specific and Benefit Cost Analysis shall apply.

3R projects and Pavement Preservation projects provide an opportunity to utilize the HSM analysis tools to improve safety. The HSM analysis tools are available and encouraged to determine if safety will be improved with a change in geometric elements and provide the benefit-cost value.

Common possible countermeasures applicable to Reconstruction NoCIRT and 3R projects utilizing HSM analysis include rumble strips, shoulder and lane widening, increasing sight distance, removal of fixed objects, increasing clear zone, high friction surface treatment, signing and pavement markings, and signal upgrades. See Publication 638A, *Pennsylvania Safety Predictive Analysis Methods Manual* and Chapters 5, 6, and 7 of Publication 638, *Highway Safety Program Guide*, for additional guidance on HSM analysis.

4.2 – Definitions of Project Types

4.2.1 – Reconstruction No Change In Road Type (NoCIRT) Projects

Construction on existing road projects are those that keep the existing roadway alignment (except for minor changes) and do not change the basic roadway type. Such projects are classified for design purposes by the primary reason they are needed, such as, to repair or restore pavement, to improve traffic operations, or to reduce current or anticipated crash patterns. The criteria provided applies to all roadways with the exception that Reconstruction NoCIRT does not apply to Interstates or Freeways.

The Reconstruction NoCIRT project type is meant to be flexible enough to address multiple problems if present. However, unlike Reconstruction CIRT Projects defined in Chapter 3, Reconstruction NoCIRT project type does not address capacity concerns. The number of lanes and/or the functionality of the median does not change. Turn lanes at intersections may be added and lanes and shoulders may be widened. Minor adjustments to the horizontal and vertical alignments are permitted.

For more information about Reconstruction on Existing Roads Projects, see the AASHTO Green Book, Section 1.7 as well as the associated DM-2 chapters as shown in **Exhibit 4.2.1.**

Also, see **Exhibit 4.7.1** for a list of low cost safety improvement measures to consider, as applicable.

Exhibit 4.2.1 – General Roadway Project Types and the Associated Chapters

New Construction Projects	**Reconstruction Change In Roadway Type (CIRT)**	**Reconstruction No Change In Roadway Type (NoCIRT)**
No Existing Road	On an Existing Road	
Chapter 3		**Chapter 4**

For examples of project types associated with this Chapter, see **Exhibit 3B.1** in Appendix 3B of Chapter 3.

4.2.1.a – Reconstruction No Change In Road Type (NoCIRT) Criteria

If established performance measures are met, including a safety evaluation that shows no crash clusters or other multiple safety concerns related to the roadway geometry, then the design criteria for Reconstruction NoCIRT follows the criteria outlined in **Exhibit 4.2.2** and **Exhibit 4.2.4**. The outcome of the safety evaluation may indicate potential changes to the horizontal and vertical alignment, lane and shoulder widths, cross slopes, and clear zone. Projects with significant changes that result in a change in roadway type must follow design criteria in Chapter 3.

Since the roadway pavement is determined to be reconstructed (full depth, rubblized, crack and seat) down to the subgrade, most likely due to failing pavement, each component of the design criteria should be compared to New Construction criteria. Several questions should be asked, in regards to the existing and/or predicted future performance measures:

1) Is there substantial crash frequency and severity concerns pertaining to existing conditions?
2) Will improving the feature improve safety?
3) Are there any traffic operational issues?

For example, to analyze the cross section:

1) Is there substantial crash frequency and/or severity concerns pertaining to the cross section?
2) Will bike and pedestrian accommodations require widening of the lane and shoulder? Or will accommodations be accomplished by road diet?
3) Is there expected traffic growth thereby degrading the level of service and therefore potentially requiring additional lanes to maintain an acceptable Level of Service (LOS).
4) Is the existing LOS and/or delays acceptable?

The answers to these types of questions for all aspects of the roadway will assist to define what improvements should be performed.

The Reconstruction NoCIRT criteria, outlined in Exhibit 4.2.2 and Exhibit 4.2.4, may be used if a feature of the roadway does not meet Chapter 3 design criteria, and if there are no crash cluster or multiple safety concerns associated with that feature. For example, a horizontal alignment is substandard by Chapter 3 criteria in one curve, but there are no noted crash clusters associated with the curve. In that case, the curve alignment may use the criteria in this Chapter. Another design option would be the application of the HSM Analysis, as discussed in Section 4.1.

For examples of this project type, see Exhibit 3B.1 in Appendix 3B of Chapter 3.

Exhibit 4.2.2 – Reconstruction NoCIRT Design Criteria

(Applicable to all Functional Classifications except for Interstates and Freeways)

	RURAL AREA SYSTEM		URBAN AREA SYSTEM		
	Rural	**Rural Town**	**Urban**	**Urban Core**	**Suburban**
Minimum Lane Widths ①	Exhibit 4.2.4	Existing* ② Exhibits 3.7.2 Through 3.7.4 (Preferred)	Existing * ② Exhibits 3.7.2 Through 3.7.4 (Preferred)		
Minimum Shoulder Widths ①	Exhibit 4.2.4	Existing* ②④ Exhibits 3.7.2 Through 3.7.4 (Preferred)	Existing* ②④ Exhibits 3.7.2 Through 3.7.4 (Preferred)		
Minimum Median Widths ③	Existing*		Existing*		
Parking Lanes	None	See Chapter 19	See Chapter 19		
Min. Horizontal Curvature	Existing* ⑤		Existing* ⑤		
Superelevation	See Chapter 3, Section 3.3		See Chapter 3, Section 3.3		
Min. Sight Distances	Existing* ⑤		Existing* ⑤		
Roadway Tangent Cross Slopes	Exhibits 3.7.2 through 3.7.4		Exhibits 3.7.2 through 3.7.4		
Shoulder Cross Slopes	Exhibits 3.8.5 through 3.8.9		Exhibits 3.8.5 through 3.8.9		
Min Grades	Existing* ⑤		Existing* ⑤		
Max Grades	Existing* ⑤		Existing* ⑤		
Vertical Clearance	See Section 3.4.10		See Section 3.4.10		
Vertical Curvature	Existing* ⑤		Existing* ⑤		
Bridge Widths	See Chapter 5		See Chapter 5		
Guide Rail	See Chapter 12		See Chapter 12		
Clear Zone Widths	See Chapter 12		See Chapter 12		

***If the existing exceeds Chapter 3 minimum criteria, then the proposed can be reduced below existing, but may not be reduced below Chapter 3 criteria. If the existing is below Chapter 3 maximum criteria, then the proposed may be increased above existing, but should not exceed the Chapter 3 criteria.**

Note: In lieu of the above criteria, the design analysis in Section 4.1, HSM Analysis/ Benefit Cost Analysis, may be considered where it can be applied.

NOTES

① For roadways with a local classification, lanes 9 ft wide may be used on one-way streets or for divided roadways if at least a 1 ft curb offset is used or if trucks and buses are prohibited.

② Curbed sections: full shoulder widths as per Chapter 3 may be desirable

Curb, guide rail, and concrete barrier Offset: 1 ft minimum, 2 ft desirable.

③ Left shoulder width governs over median width. For urban areas, 6' minimum is needed for pedestrian refuge.

④ See Chapter 3, **Exhibit 3.8.9,** for curbed sections.

⑤ **GENERAL:** Existing horizontal curvature, vertical curvature, grades, and sight distance shall be evaluated against minimum criteria in Chapter 3. If a crash or operational problem exists, apply the standards in Chapter 3 to that geometric feature; however, consider maintaining consistency throughout the roadway corridor, where fluctuations in lane and shoulder widths is not desirable. For projects with multiple sites experiencing crash problems, Chapter 3 Design Standards shall be used for the Design Criteria. If applying these design standards are not feasible, or the design criteria is less than new construction standards, a design exception request shall be prepared if it is a controlling criteria feature. Another option would be the application of the HSM Project Specific and Benefit Cost Analysis, discussed in Section 4.1. In addition, appropriate safety and other mitigation measures shall be applied to enhance and upgrade these geometric features for extended service life and safer operations. If HSM Analysis is not used and the Chapter 3 Design Standards are not feasible, a design exception request shall be prepared.

MINIMUM HORIZONTAL RADIUS: 15 mph or less below the design speed of the proposed project.

SUPERELEVATION: To be designed, per Chapter 3, Section 3.3, to correspond to the horizontal radius.

MINIMUM /MAXIMUM VERTICAL CURVATURE AND GRADES: 20 mph or less below the AASHTO Green Book applicable value for SSD, HLSD, or Grade for the design speed of the proposed project.

SIGHT DISTANCE: When evaluating sight distance parameters, consider horizontal and vertical curvature together.

4.2.2 – Resurfacing, Restoration, and Rehabilitation (3R) Projects

Resurfacing, restoration, and rehabilitation (3R) projects are construction projects on existing roads that maintain the roadway's functional classification. They include improvements to all Functional Classifications (Interstates, Freeway and Expressways, Arterials, Collectors, and Local Roads).

3R projects are typically undertaken to extend the service life of a roadway and/or improve the pavement structural and functional capacity while maintaining the existing roadway alignment, but they may include limited geometric changes to improve safety.

Although all 3R projects are defined as construction projects on existing roads, they often include work other than resurfacing, restoration, and rehabilitation, such as upgrading roadside barrier, sidewalks, curb ramps, transit stops, and adding traffic signals. Most 3R projects, even if they are not initiated originally by pavement resurfacing needs, are scheduled for implementation in conjunction with pavement resurfacing to obtain economies of scale.

3R project design may require the designer to work within a number of constraints, including existing geometric elements, existing land uses, existing utilities, existing pavement and drainage structures, etc. and to "thread" a proposed improvement design through the constraints to achieve an optimum combination of design elements.

Unlike a New Construction project design, which must rely solely on dimensional criteria because no safety and traffic operational performance history exist, 3R project design involves existing roadways that have safety and traffic operational performance histories that can be used to identify geometric features that may need improvement; and, as discussed in Section 4.0, also determine and evaluate the performance measures associated with the project.

3R projects typically do not include capacity improvements, major realignment, or major upgrading of geometric features, but they may include limited improvements to highway geometry and other roadway features and safety appurtenances. Exhibit 3B.1 in Appendix 3B provides a list of typical 3R improvements, as appropriate to their respective Functional Classification.

The terms resurfacing, restoration, and rehabilitation are defined as follows:

1) **Resurfacing**. Application of a new or recycled layer(s) of pavement material to existing pavements, shoulders and/or bridge decks.

2) **Restoration**. Improvements to return the pavement, shoulders and/or bridges to an acceptable condition to ensure safe operations for a substantial period.

3) **Rehabilitation**. Improvements to remove and replace major structural elements of a highway or bridge to an acceptable condition. This includes pavement rehabilitation as defined in Publication 242, *Pavement Policy Manual*.

Resurfacing projects that do not add structural capacity to the pavement may be classified as Pavement Preservation projects, as defined in Publication 242, *Pavement Policy Manual*. For examples of this project type, see Exhibit 3B.1in Appendix 3B. Refer to Chapter 5 for geometric design criteria for bridge projects.

Also, see Exhibit 4.7.1 for a list of low cost safety improvement measures to consider, as applicable.

4.2.2.a – Resurfacing, Restoration, and Rehabilitation (3R) Criteria

Geometric design improvements should be considered as part of a 3R project in the following situations:

- An analysis of the crash history of the existing road identifies one or more crash patterns that are potentially correctable by a viable design improvement, or
- A design improvement would reduce sufficient crashes over its service life to be cost effective, i.e., the anticipated crash reduction benefits over the service life of the project should exceed the improvement implementation cost, or
- An analysis of the traffic operational Level of Service (LOS) indicates that the LOS is currently worse than the highway agency's target LOS for the facility or will become worse than the target LOS within the service life of the planned pavement resurfacing. Refer to Chapter 2, *Design Controls*, Section 2.4.2.a, for additional information.

If one or all of the above is applicable, Chapter 3 criteria, Reconstruction NoCIRT criteria, or the application of the HSM Analysis, (discussed in Section 4.1), should be considered for the design criteria. If Chapter 3 or Reconstruction NoCIRT criteria is determined to be not applicable, refer to the design criteria for 3R projects provided in **Exhibit 4.2.3** and Exhibit 4.2.4. See Publication 242, *Pavement Policy Manual*, for additional guidance on 3R projects.

Exhibit 4.2.3 3R Design Criteria

(Applicable to all Functional Classifications)

	RURAL AREA SYSTEM		URBAN AREA SYSTEM		
	Rural	**Rural Town**	**Urban**	**Urban Core**	**Suburban**
Minimum Lane Widths ①	**Interstates and Freeways** Existing * Exhibit 3.7.1 (Preferred) **All Other Classifications** Exhibit 4.2.4	Existing* ② Exhibits 3.7.2 Through 3.7.4 (Preferred)	**Interstates and Freeways** Existing* ② Exhibit 3.7.1 **All Other Classifications** Existing* ② Exhibits 3.7.2 through 3.7.4 (Preferred)	Existing* ② Exhibits 3.7.2 through 3.7.4 (Preferred)	
Minimum Shoulder Widths ①	**Interstates and Freeways** Existing * Exhibit 3.7.1 (Preferred) **All Other Classifications** Exhibit 4.2.4	Existing* ②④ Exhibits 3.7.2 Through 3.7.4 (Preferred)	**Interstates and Freeways** Existing* ②④ Exhibits 3.7.2 through 3.7.4 (Preferred) **All Other Classifications** Existing* ② Exhibits 3.7.2 through 3.7.4 (Preferred)	Existing* ②④ Exhibits 3.7.2 through 3.7.4 (Preferred)	
Minimum Median Widths ③	Existing*		Existing*		
Parking Lanes	None	See Chapter 19	See Chapter 19		
Min. Horizontal Curvature	Existing* ⑦		Existing* ⑦		
Superelevation ⑦	Existing*		Existing*		
Min. Sight Distances	Existing* ⑦		Existing* ⑦		
Roadway Tangent Cross Slopes ⑥	Tangent: 2.0% (Desirable) 1.0% (Minimum). For existing cross slopes between 1.5% and 2.0%, do not reduce below existing. For existing cross slopes below 1.5%, increase to 1.5%. 2.0% should be considered where practicable. For retained cross slopes less than 2.0%, confirm adequate drainage.		Tangent: 2.0% (Desirable) Match Existing* (Minimum) May increase to 3% to address drainage issues		
Shoulder Cross Slopes ⑤ ⑥	Existing*; however, the algebraic difference between the lane/shoulder cross slopes should not exceed 8.0% For shoulder rounding details when superelevation is greater than 6.0%, see Exhibit 3.8.6		Existing*; however, the algebraic difference between the lane/shoulder cross slopes should not exceed 8.0% For shoulder rounding details when superelevation is greater than 6.0%, see Exhibit 3.8.6		

Min Grades	Existing* ⑦	Existing* ⑦
Max Grades	Existing* ⑦	Existing* ⑦
Vertical Clearance	See Section 3.4.10	See Section 3.4.10
Vertical Curvature	Existing* ⑦	Existing* ⑦
Bridge Widths	See Chapter 5	See Chapter 5
Guide Rail	See Chapter 12	See Chapter 12
Clear Zone Widths	See Chapter 12	See Chapter 12

***If the existing exceeds Chapter 3 minimum criteria, then the proposed can be reduced below existing, but may not be reduced below Chapter 3 criteria. If the existing is below Chapter 3 maximum criteria, then the proposed may be increased above existing, but should not exceed the Chapter 3 criteria.**

Note: In lieu of the above criteria, the design analysis in Section 4.1, *HSM Analysis/ Benefit Cost Analysis*, may be considered where it can be applied.

NOTES

① For roadways with a local classification, lanes 9 ft wide may be used on one-way streets or for divided roadways if at least a 1 ft curb offset is used or if trucks and buses are prohibited.

② Curbed sections: full shoulder widths as per Chapter 3 may be desirable.
Curb, guide rail, and concrete barrier offset: 1 ft minimum, 2 ft desirable.

③ Left shoulder width governs over median width. For urban area, 6' minimum is needed for pedestrian refuge.

④ See Chapter 3, **Exhibit 3.8.9,** for curbed sections.

⑤ In order to increase the amount of drainage capacity or to include reconstruction of the shoulder, the shoulder cross slopes may be increased.

⑥ If the lane is widened, the widening portion of the lane should be constructed at the same slope as the existing lane. The shoulder slope should begin at the edge of the widened lane. When the pavement structure is being extended for the full width of the shoulder, the shoulder slope should begin at the edge of the design width of the lane. Typical sections should indicate the shoulder area in these cases even though the materials used may be paid for separately.

⑦ **GENERAL:** If a crash problem exists, apply the standards in Chapter 3 to that geometric feature. If the Chapter 3 Design Standards are not feasible, a design exception request shall be prepared; however, consider maintaining consistency throughout the roadway corridor, where fluctuations in lane and shoulder widths is not desirable. For projects with multiple sites experiencing crash problems, Chapter 3 Design Standards shall be used for the Design Criteria. If applying these design standards are not feasible, or the design criteria is less than new construction standards, a design exception request shall be prepared if it is a controlling criteria feature. Another option would be the application of the HSM Project Specific and Benefit Cost Analysis, discussed in Section 4.1. In addition, appropriate safety and other mitigation measures shall be applied to enhance and upgrade these geometric features for extended service life and safer operations. If HSM Analysis is not used and the Chapter 3 Design Standards are not feasible, a design exception request shall be prepared.

HORIZONTAL CURVATURE: Additionally, consider friction overlays and improved signing & pavement markings.

SUPERELEVATION: Where the superelevation of an existing curve is less than the design superelevation value in the Chapter 3 Design Standards by more than 1 percent, consider improving the superelevation as close as practicable to the Chapter 3 Design Standards.

SIGHT DISTANCE: When evaluating sight distance parameters, consider the preceding criteria on horizontal and vertical curvature together.

Exhibit 4.2.4 Minimum Lane and Shoulder Width Criteria for Reconstruction NoCIRT, and 3R Rural Projects (e)

Open to Traffic ADT (a)	Number of Heavy Vehicles (b)	Design Speed (mph)	Minimum Thru Lane Widths (ft) (c)	Minimum Shoulder Widths (ft) (f)
Under 400	40 or less	< 50	9	2
		≥ 50	10	2
400-1000	100 or less	< 50	10	2
		≥ 50	11	2
1001-2000	200 or less	< 50	10 - Collectors and Local Roads 11 - Arterials	2
		≥ 50	11	3
2001-4000	400 or less	< 50	11	3
		≥ 50	11	4
4001-10000	1000 or less	< 50	11	4
		≥ 50	11	5
10001-20000	2000 or less	ALL	11	5
> 20000	2000 or less (d)	ALL	11	5

For Reconstruction NoCIRT and 3R projects within Rural Town, Suburban, Urban and Urban Core contexts, refer to the Lane and Shoulder Widths in Exhibits in Chapter 3

(a) For Open to Traffic ADT, where the number of Heavy Vehicles falls within the range Indicated, use the corresponding minimum widths. Where the number of Heavy Vehicles exceeds the range indicated for the corresponding ADT, use the minimum width values for the appropriate range of Heavy Vehicles.

(b) Number of Heavy Vehicles = Current Traffic ADT × % of Trucks, Buses and Recreational Vehicles.

(c) Curve widening shall be applied to pavement widths as presented in Chapter 3. Consideration should be given to maintaining curve widened pavements over the entire project limits when a significant proportion of the project requires curve widening due to multiple curves.

(d) Over 10% Heavy Vehicles, increase minimum shoulder width to 6 ft each side.

(e) Refer to Chapter 3, **Exhibits 3.7.2** through **3.7.4,** for all other applicable items not covered in this Chapter.

(f) When bike usage is expected, consider shoulder width guidance provided in Chapter 14.

4.3 – Pavement Preservation Projects

The intent of pavement preservation projects is to maintain or improve the functional condition of the pavement. Pavement preservation projects are typically resurfacing projects that do not increase the pavement structural capacity for all typologies and functional classifications. Pavement Preservation projects should also consider appropriate ways to maintain or enhance the current level of safety and accessibility.

Unlike Reconstruction NoCIRT and 3R projects, Pavement Preservation projects do not allow minor alignment modifications.

See Publication 242, *Pavement Policy Manua*l, Chapter 12, for additional guidance on pavement preservation projects.

Also, See Exhibit 4.7.1 for a list of low cost safety improvement measures to consider, as applicable.

4.3.1 – Pavement Preservation Criteria

Refer to Publication 242, *Pavement Policy Manual,* for determining when Pavement Preservation criteria is applicable to a project.

Safety guidance in this Chapter and in Publication 242, *Pavement Policy Manual*, shall be met, including evaluating the crash history to identify safety concerns. All identified safety concerns are to be evaluated as applicable. For example, widening of the traveled way on horizontal curves may be necessary to address a safety concern.

The following is the geometric criteria for pavement preservation projects. The proposed geometric design elements shall be compared to the required criteria presented below, and a design exception is required if any of the 11 controlling criteria is not met (defined in Publication 10X, Design Manual Part 1X, *Appendices to Design Manuals 1, 1A, 1B, and 1C*, Appendix P, *Design Exceptions*). If non-controlling criteria is not met, some form of documentation must be provided. Documentation may include meeting minutes or Design Field View Reports, etc.

4.3.1.a – Non-Freeway Criteria:

1) Cross Slopes of Lanes in Tangent Sections.
    i) Rural Classification. Desirable = 2.0%. Minimum = 1.0%. For existing cross slopes between 1.0% and 2.0%, do not reduce below existing.
    ii) Urban Classification.
        a) Curbed Roadways. Desirable = 2.0% to 3.0%. Minimum = match existing. Address drainage issues.
        b) Non-Curbed Roadways. Same as rural criteria.
2) Vertical Clearance Criteria. Refer to Chapter 3, Section 3.4.10.

3) All Other Controlling Criteria.

   i) Existing geometric elements not meeting New and Reconstruction Criteria, as outlined in Chapter 3, are not to be adversely affected.

   ii) Existing geometric elements that meet or exceed New and Reconstruction Criteria as outlined in Chapter 3 are not to be affected to the extent of not meeting New and Reconstruction Criteria.

4.3.1.b – Freeway and Expressways Criteria:

1) Cross Slopes in Tangent Sections.

   i) Lanes. Desirable = 2.0%. Minimum = 1.5%. Maximum = 3.0%. For existing cross slopes between 1.5% and 2.0%, do not reduce below existing.

   ii) Shoulders. Maximum = 8.0%.

2) Cross Slope in Superelevated Sections.

   i) Maximum. 8.0% algebraic cross slope difference in lane/shoulder cross slope. If the algebraic difference in cross slope is greater than 8.0%, then provide rounding as per DM-2, Exhibit 3.8.6, typical section detail.

   ii) Required superelevation and superelevation transition rate is to meet the statements provided below under 4) All Other Controlling Criteria.

3) Vertical Clearance Criteria. Refer to Chapter 3, Section 3.4.10.

4) All Other Controlling Criteria.

   i) Existing geometric elements not meeting New and Reconstruction Criteria, as outlined in Chapter 3, are not to be adversely affected.

   ii) Existing geometric elements that meet or exceed New and Reconstruction Criteria as outlined in Chapter 3 are not to be affected to the extent of not meeting New and Reconstruction Criteria.

4.4 – Maintenance

Maintenance is defined as maintaining the existing roadway, bridge and related appurtenances. Geometric design improvements are typically not the intent of maintenance operations. Maintenance projects typically do not require right-of-way acquisition and need minimal coordination with permitting agencies and/or utilities. Pavement repairs such as seal coats, full width patching, crack sealing, correcting minor irregularities, etc. are generally considered maintenance activities. Refer to Publication 23, *Maintenance Manual*, and Publication 55, *Bridge Maintenance Manual*, for guidance on maintenance work.

Work performed by Department Force Maintenance crews which does not qualify as maintenance type work, such as bridge and culvert replacements or pavement preservation

projects must use applicable criteria in this manual. This includes minimum lane and shoulder widths on bridges and roadways over culverts. See Chapter 5, *Bridges and Tunnels*, for more information.

Maintenance type work which adversely affects the existing geometry of the roadway or if the roadway and shoulder widths do not meet the requirements of Publication 23, *Maintenance Manual*, Chapter 7, Appendix A, *Minimum Width Criteria for Maintenance Projects*, may require a design exception. The District may contact the Highway Design Technology Division for determining if a design exception is required.

4.5 – Non-Roadway and Non-Bridge Projects

For non-roadway and non-bridge projects, the criteria applied should be project specific. For example, for pedestrian and bicycle facilities, see Chapters 13, *Pedestrian Facilities*, and 14 *Bicycle Facilities*, respectively. A design exception as outlined in Publication 10X, Design Manual Part 1X, *Appendices to Design Manuals 1, 1A, 1B, and 1C*, Appendix P, *Design Exceptions*, may be required if the project adversely affects the roadway geometric criteria. Typically, other requirements may be applicable. For example, if ADA criteria cannot be met, a Technically Infeasible Form (TIF) should be submitted. In all cases, some form of documentation must be provided if criteria cannot be met. Documentation may include meeting minutes or Design Field View Reports, etc. The District may contact the Highway Design Technology Division for determining if a design exception is required.

4.6 – Roadway and Bridge Components

These are standalone projects for specific components of a roadway or bridge. Examples of these types of projects include, but are not limited to, ITS devices, signing, lighting, guiderail, drainage, signalization or reapplication of pavement markings. These projects may include replacement of components or new components.

Requirements for these projects should reference applicable publications or other DM-2 chapters; for example, guiderail projects should follow requirements in Chapter 12, *Roadside Design*. In all cases, documentation should be provided if requirements cannot be met. Documentation may include meeting minutes or Design Field View Reports, etc.

Roadway and Bridge Component projects which adversely affects the existing geometry of the roadway or bridge may require a design exception. The District may contact the Highway Design and Technology Division for determining if a design exception is required.

4.7 – Low Cost Safety Measures

Low Cost Safety Improvement Measures are found in Exhibit 4.7.1. These are examples of geometric features and associated safety measures that can be considered for adoption and incorporation into various types of projects and/or a design exception request justification when current design criteria is not practical.

Exhibit 4.7.1 Low Cost Safety Improvement Measures

GEOMETRIC FEATURES	SAFETY MEASURES
Narrow Lanes and Shoulders	Pavement edge lines Raised pavement markers Post delineators
Steep Side slopes and Roadside Obstructions	Object markings Slope flattening Ditch rounding Obstruction removal Breakaway safety hardware Guide rail
Narrow Bridges	Traffic control devices Approach guide rail Object markers Pavement markings Structure delineation Warning signs Speed control Direction control
Limited Sight Distance at Crest or Sag Vertical Curves	Traffic control devices Fixed object removal Driveway relocation
Sharp Horizontal Curves	Traffic control devices Shoulder widening Appropriate superelevation Slope flattening Pavement antiskid treatment Obstruction removal or relocation Obstruction shielding Warning signs
Intersections with Point of Conflict	Traffic control devices Traffic signalization Fixed lighting Pavement antiskid treatment Speed controls

Chapter 5 – Bridges and Tunnels

In this chapter there are references to future chapters 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 5 – Bridges and Tunnels

5.0 – Introduction

This chapter addresses the geometric design factors and the basic issues the roadway designer must consider when designing projects that include bridges and tunnels. A bridge is defined as a structure with a span length of 8 ft or greater that provides safe passage of traffic over a roadway, a waterway, a railroad, or other obstructions. A tunnel is defined as an enclosed roadway for motor vehicle traffic with vehicle access limited to portals.

For bridge design policies, procedures and specifications refer to Publication 15M, Design Manual Part 4, *Structures,* (DM-4) and the referenced edition of AASHTO's LRFD *Bridge Design Specifications*.

Important context questions:

- Is the transition from the roadway to the bridge "seamless" from the traveling public's perspective?
- Have all factors been taken into consideration when determining the proposed bridge width, for example: construction phases, future re-decking, parking, all modes of transportation, environmental impacts, right-of-way impacts, minimum lane and shoulder widths, and are the bridge's lanes and shoulders widths the same or greater than the approaching roadways?
- Is the proposed structure wide enough for future preservation/rehabilitation work while maintaining traffic if needed?
- Are non-motorized modes of transportation (pedestrian, bicycle) accommodated?

Key design considerations include:

- **Unobtrusive Transition**. The transition between the roadway and the bridge from a geometrics perspective should be the same. This means the roadway lane and shoulder widths of the bridge should match the roadways. The exception to this would be where the bridge shoulder widths are greater for sight distance, constructability, or other reasons.
- **Accommodation of Non-Motorized Modes**. Sidewalks, bicycle lanes or multi-use paths on bridges should be considered and continued with the same width as on the approaches. Refer to Chapter 13, *Pedestrian Facilities*, and Chapter 14, *Bicycle Facilities*, for additional information.

5.0.1 – References

- AASHTO, *LRFD Bridge Design Specifications*, (refer to DM-4 for current accepted version to use).

5.1 – Types of Bridge Projects

The following are definitions and design years for different types of bridge projects. Note that the geometric design year is typically different than the bridge structural design year.

5.1.1 – New Bridge

Definition. Construction of a bridge on an alignment that does not qualify as a Replacement Bridge as defined in Section 5.1.2 and is therefore on a new alignment.

Design Year. The Design Year is typically 20 years or more from when the project is open to traffic for these types of projects.

5.1.2 – Replacement Bridge

Definition. Reconstruction of a bridge in its approximate current location. Shift in alignment may be necessary for traffic control purposes. However, if the location of the replacement bridge is more than approximately 100 ft from the existing bridge (clear out-to-out) or shifted double the width of the existing bridge, whichever is greater, then the constructed bridge is considered a New Bridge and must use New Bridge geometric criteria.

Design Year. The Design Year is typically 20 years or more from when the project is open to traffic for these types of projects.

5.1.3 – Superstructure Replacement

Definition. The superstructure is the part of the bridge which supports traffic and connects one substructure element to another. A full superstructure replacement includes the entire superstructure. A partial superstructure replacement is a replacement of a portion of the superstructure where some of the existing superstructure remains. The superstructure replacement project would include the deck, barriers, girders, and other such elements.

Design Year. The Design Year is typically the year the bridge is fully open to traffic for these types of projects.

5.1.4 – Deck Replacement

Definition. The deck is the portion of the bridge that directly carries traffic. A full deck replacement includes the entire deck. A partial deck replacement is replacement of a portion of the deck where some of the existing deck remains.

Design Year. The Design Year is typically the year the bridge is fully open to traffic for these types of projects.

5.1.5 – Bridge Preservation

Definition. See DM-4, Part A, Chapter 5.6.1, to determine which projects qualify as Bridge Preservation projects. Typically repairs "less than" a partial deck replacement qualifies as a Bridge Preservation project. When Bridge Preservation projects add safety items such as repair and replacement of parapet and barrier, as well as approach guide rail and connections, Bridge Preservation highway geometric criteria still apply.

Design Year. The Design Year is typically the year the bridge is fully open to traffic for these types of projects.

5.1.6 – Temporary Bridges

Definition. Temporary Bridge is defined as a temporary crossing of a stream or other topographic feature consisting of a bridge superstructure with an appropriate substructure and may only remain during construction.

Temporary bridges shall be designed using current Department bridge design methodology found in DM-4, Volume 1, Part A, Chapter 5, including consideration of geometric constraints (including truck turning patterns, pedestrian accommodations, etc.) as per Chapter 6, *Intersections and Driveways*, of this manual.



Temporary Bridge During Construction

5.2 – Geometric Criteria for Bridge Projects

5.2.1 – Introduction

Ideally the geometrics on a bridge should be no different than roadway geometrics. However, many bridge projects are modifying existing structures or replacing existing structures with only minimal approach work to tie into the existing roadway. The criteria presented in this section is for the structure itself and not for the approaches.

The bridge scope of work determines which design criteria is applied to a bridge project. For each set of bridge design criteria discussed below, there is a set of geometric requirements. If a bridge is part of a larger roadway project, then the proposed bridge geometrics will typically follow the larger roadway project's overall design criteria. If only minimal roadway approach work (not to exceed approximately 500 ft for each approach) is included for the purpose of transitioning to the adjacent roadway, then the approach shoulder width transitions and other roadway geometrics should be improved as practicable.

Refer to DM-4 for other criteria not provided in this Section (e.g., shoulder cross slope, etc.)

A design exception is required if the controlling criteria on or affected by the structure is not met. The 11 controlling criteria are provided in Publication 10X, Design Manual Part 1X, *Appendices to Design Manuals 1, 1A, 1B, and 1C* (DM-1X), Appendix P, *Design Exceptions*.

5.2.2 – Freeways and Expressways (NHS and Non-NHS)

New Bridges, Replacement Bridges, Full and Partial Superstructure and Deck Replacements must meet New Construction and Reconstruction roadway criteria as per Section 5.2.5 and Chapter 3, *New Construction and Reconstruction Change in Road Type*.

5.2.3 – Non-Freeways / Non-Expressways

5.2.3.a – New Bridges on New Locations (NHS and Non-NHS)

Must meet New Construction and Reconstruction Change In Road Type (CIRT) roadway criteria as per Chapter 3. Minimum lane and shoulder widths are discussed in Section 5.2.5.

5.2.3.b – Replacement Bridges (NHS and Non-NHS); Full Superstructure Replacements (NHS)

Geometric design criteria for the 11 controlling criteria are as follows:

- Minimum lane and shoulder widths as provided in Section 5.2.5.
- Vertical Clearance Criteria as provided in Chapter 3, Exhibit 3.4.6.
- Lane cross slopes in tangent sections are 2% desirable, 1.5% minimum.

For the remaining 7 controlling criteria, meet Chapter 3, *New Construction and Reconstruction CIRT*, criteria as close as practical, but at a minimum meet Reconstruction NoCIRT roadway criteria as per Chapter 4.

If a bridge replacement is part of a larger roadway reconstruction project, then the proposed bridge geometrics will follow the larger roadway project's overall design criteria.

5.2.3.c – Partial Superstructure Replacements (NHS); Full and Partial Deck Replacements (NHS).

Geometric design criteria for the 11 controlling criteria are as follows:

- Minimum lane and shoulder widths as discussed in Section 5.2.5.
- Vertical Clearance Criteria as provided in Chapter 3, Exhibit 3.4.6.

For the remaining 8 controlling criteria, meet Chapter 3 New and Reconstruction CIRT criteria as close as practical, but at a minimum, meet Reconstruction NoCIRT roadway criteria as per Chapter 4.

5.2.3.d – Full and Partial Superstructure Replacement (non-NHS); Full and Partial Deck Replacements (non-NHS).

Geometric design criteria for the 11 controlling criteria are as follows:

- Minimum lane and shoulder widths as discussed in Section 5.2.5.
- Vertical Clearance Criteria as provided in Chapter 3, Exhibit 3.4.6.
- Lane cross slopes in tangent section are 2% desirable; 1.5% minimum for full superstructure replacements. Other projects use cross slope criteria as per the 7 remaining controlling criteria described below.

For the remaining 7 controlling criteria, follow:

- Existing geometric elements not meeting Chapter 3 Reconstruction CIRT roadway criteria are not to be adversely affected.
- Existing geometric elements that meet or exceed Chapter 3 Reconstruction CIRT roadway criteria are not to be reduced beyond Chapter 3 Reconstruction CIRT minimum criteria.

5.2.4 – Bridge Preservation on All Routes

Geometric design criteria for the 11 controlling criteria are as follows:

- Minimum lane and shoulder widths as discussed in Section 5.2.5.
- Vertical Clearance Criteria as provided in Chapter 3, Exhibit 3.4.6.

For the remaining 8 controlling criteria, follow:

- Existing geometric elements not meeting the Chapter 3 Reconstruction CIRT roadway criteria are not to be adversely affected.
- Existing geometric elements that meet or exceed the applicable roadway criteria are not to be reduced beyond Chapter 3, Reconstruction CIRT minimum criteria.

5.2.5 – Width of Lanes and Shoulders on Bridges

The width of lanes and shoulders on bridges are determined as described in this Section. It should be noted that "minimum" is not always synonymous with "appropriate".

Refer to Section 5.4 for additional information on Pedestrian and Bicycle provisions.

5.2.5.a – Bridges on New Location on All Routes; Bridge Replacements on NHS Routes; and Full Superstructure Replacements on NHS Routes

- The lane and shoulder widths on the bridge are the same as for roadways as provided in Chapter 3, Exhibits 3.7.1 through 3.7.4.
- The lane and shoulder widths on a bridge are not to be less than the approach roadway lane and shoulder widths (excluding one-lane bridges) and must also meet or exceed other applicable lane and shoulder width criteria in Chapters 3. However, on curbed approaches, the curb-to-curb width may be carried across the bridge.
- Where parking lanes are provided on the approaches, and in limited circumstances, consideration should be given to extending the parking lanes across the bridge. For example, if a bridge is very short in an urban core setting, it may be appropriate to have the parking continue on the structure.
- Where Plain People modes of travel (e.g., horse and buggy) are anticipated, see Chapter 17, *Plain People Community Considerations*.
- When special conditions warrant, such as two-way traffic operations during future rehabilitation (repair, overlay, or deck/superstructure replacement), consideration should be given to increased widths which may require additional girders.

Width of Lanes & Shoulders on Bridges:

- Bridge lanes and shoulder widths are not to be less than roadway lane or shoulder widths.
- Parking lanes can be extended onto the bridge.
- Provide sidewalks for pedestrian traffic where anticipated.
- Consider adding bicycle lanes on bicycle routes or for anticipated bicycle traffic.

5.2.5.b – Bridge Replacements on Non-NHS Routes

Criteria in Section 5.2.5.a is applicable, in addition to the following:

For Rural Context Non-NHS Arterials, Collectors and Local Roads, the minimum lane and shoulder widths may use Chapter 4, Exhibit 4.2.4 (rural context only), in lieu of the Chapter 3 width criteria if the following conditions are met:

- The roadway within the vicinity of the subject bridge is not anticipated to be reconstructed to meet Chapter 3 criteria within the next 20 years.
- There is no approved planning at the local, county, regional, or state level to suggest future development pressures will make the proposed bridge width incompatible with future land use in the project corridor.
- An analysis of crash data has been conducted and the subject location has no history of crashes related to the existing bridge width.
- The subject roadway does not service a sufficient percentage of heavy trucks, buses, large farm equipment, or emergency vehicles such that these vehicles should govern design.

5.2.5.c – Full Superstructure Replacements on non-NHS Routes; Partial Superstructure, Full and Partial Deck Replacements and Bridge Preservation on All Routes

If the existing lane and shoulder widths are below or match the minimum width for New and Replacement bridges per Section 5.2.5.b then the lane and shoulder widths are not to be reduced below existing widths.

If the existing lane and shoulder widths exceed the minimum widths for New and Replacement bridges, then the lane and shoulder widths are not to be reduced below the minimum width for New and Replacement bridges per Section 5.2.5.b.

5.2.5.d – One Lane Bridges

A one lane bridge may be provided if the following requirements are met:



One-Lane Bridge

- The facility is functionally classified as a Local Road.
- The minimum width of a one-lane bridge is 15 ft, and the maximum width is 16 ft.
- Alignment and sight distance are carefully studied so that they are not compromised.
- There is no significant area growth anticipated which could lead to traffic growth potential.
- Local large vehicles, such as farm equipment, are adequately accommodated if anticipated.

Bridges on New Locations

May be provided on single-lane roads and on two-lane roads with Design Year ADT less than 100 vehicles per day where a one-lane bridge can operate effectively.

Replacement Bridges or Deck/Superstructure Replacements of Existing Bridges

May be provided when all the following conditions are met:

- The Design Year ADT is less than or equal to 400.
- There is no evidence of a site-specific safety problem.

5.2.6 – Median Width and Gore Areas on Bridges

The median width on a bridge should typically match the median width on the approach roadway. However, the median widths on bridges may be wider than median widths on approach roadways because bridge barriers are typically wider than roadway barriers. Therefore, a barrier transition is required between the bridge median barrier and the roadway barrier.

Median widths under a bridge may need to be increased to accommodate the placement of bridge piers and associated protection. When the barrier or pier width varies, the minimum shoulder width is not to be reduced.

Gore areas on bridges should be avoided unless there is adequate space for installation of an impact attenuator. Refer to Chapter 12, *Roadside Design*, for additional information.

5.2.7 – Horizontal Alignment on Bridges / Skew Angle

The horizontal alignment of the bridge should be consistent with the approach roadway. However, the project may require an alignment shift or a realignment to meet the project needs. Where practical avoid alignments that place curves, especially spiral curves on structures. Design of bridges on horizontal curves should consider curve widening beyond minimum width criteria and follow guidance provided in Chapter 3, Section 3.2.8.

PennDOT defines the bridge skew angle as the smaller angle between the highway centerline (or tangent thereto) and a line parallel to the support (abutment, pier, etc.). AASHTO defines the skew angle as the angle between the centerline of the support and a line normal to the roadway centerline. The sum of PennDOT's and AASHTO's skew angle is 90 degrees. Refer to DM-4 for additional skew angle information.

Structures are typically skewed so the centerlines of the substructure units (abutments, piers, etc.) are parallel to the feature intersected by the roadway alignment.

5.2.8 – Vertical Alignment on Bridges

Where practical avoid alignments that place the low point of a sag vertical curve on a bridge.

5.2.9 – Bridge Lateral Clearance

5.2.9.a – New and Replacement Bridge Projects

On a bridge deck, the lateral clearance is from edge of travel lane to the bridge barrier, face of guide rail or curb, and is to meet or exceed the applicable minimum shoulder width criteria as indicated in Chapter 3 and Chapter 4.

Under a bridge, the lateral clearance is from the edge of the travel lane to the face of the protective barrier/guide rail in front of retaining walls and bridge substructures including piers, columns, and abutments or the substructure itself if there is no barrier/guide rail and is to meet or exceed the applicable minimum criteria as follows:

Interstates, Freeways and Expressways: Minimum Lateral Offset shall equal 14 ft wide on the outside right shoulder, and 10 ft wide on the inside left shoulder.

All Other Roadway Classifications: Minimum Lateral Offset shall be as follows:

- If there is no curb or sidewalk under the bridge, the minimum lateral offset is equal to the required shoulder width and should not be less than 4 ft.
- If there is curb and sidewalk under the bridge, a full shoulder width is not required. However, the minimum lateral offset should equal the minimum shoulder width, which

would be required if the roadway was not curbed, and should not be less than 4 ft. Additional width would be needed to accommodate ADA requirements for the sidewalk/pedestrian accommodations.

- The curb/sidewalk width is included in the lateral offset width measured from the edge of the travel lane to the barrier, or the abutment/pier if there is no barrier.
- Refer to Chapter 13, *Pedestrian Facilities*, for additional information on sidewalk width requirements.

For lateral clearance requirements adjacent to railroads refer to Pub 371, *Grade Crossing Manual*, Appendix H.

Sight distance requirements as designated in Chapter 3 are to be applied when setting substructure locations. Widened shoulders may be required to meet the minimum Stopping Sight Distance for bridges on curves. Curve flattening, which may increase the structure length, may also be considered. If adequate vertical Stopping Sight Distance cannot be achieved, a longer vertical curve may be required which could also increase the span length.

5.2.9.b – All Remaining (Non-New and Replacement) Bridge Projects

Do not reduce the Lateral Clearance below existing dimensions. However, if the existing exceeds the criteria in this Section, as directly stated above, then the proposed can be reduced below existing, but may not be reduced below these same criteria.

5.2.10 – Bridge Vertical Clearance

Refer to Chapter 3, Section 3.4.10, for the vertical clearance requirements.

The vertical clearance for bridges over waterways is to meet the hydraulic requirements, Coast Guard requirements, and any other clearance requirements that may apply. See Section 5.9.

5.3 – Bridge Approaches and Grading

For bridge projects with minimal approach work, the transition area (not to exceed approximately 500 ft for each approach) must not be adversely affected by the bridge project, unless it still meets or exceeds the Chapter 3 New and Reconstruction CIRT roadway criteria.

For lane width taper rates between the structure and the existing road tie-in location, refer to Chapter 3, Section 3.7.1.a, for L (taper length).

When the approach roadway lane and shoulder cross slopes are different than the bridge lane and shoulder cross slopes, transition the existing lane cross slopes, per Chapter 3, Section 3.3.5, to meet the cross section of the proposed bridge, and transition the shoulder cross slopes (25 ft minimum) approaching the bridge to meet the cross slope of the bridge water table.

5.4 – Pedestrian and Bicycle Provisions

For all bridge projects, including New, Replacement, Deck and Superstructure partial and full Replacements, and Bridge Preservation projects, pedestrians and bicyclists should be accommodated where usage is anticipated.

For new and reconstructed bridges:



Pedestrian Facility on a Bridge

- Where pedestrian traffic is anticipated, provisions for a sidewalk should be provided. However, this may be dependent on the municipality agreeing to maintain the sidewalk.
- Sidewalks should be provided where there are sidewalks on the existing approaches.
- Sidewalks must be separated from vehicular travel lanes and parking lanes by curbs or barriers which shall be continuous across the structure. Refer to DM-4, Part B, Section 2, Article 2.3, for when a sidewalk is to be separated from the vehicular lane with a barrier.
- Where a bicycle route crosses a bridge and/or where bicycles are anticipated, consider adding a bike lane or providing a shoulder wide enough to accommodate bicycles.
- Bicycle lanes or paths on bridges are to be at least as wide as the bicycles lanes or paths on the approaches.

Refer to Chapter 13, *Pedestrian Facilities*, and Chapter 14, *Bicycle Facilities*, for additional information.

5.5 – Bridge Barriers and Roadside Safety

Provide bridge barriers in accordance with the requirements of Chapter 12, *Roadside Design*, and Publication 218M, *Standards for Bridge Design*. Refer to DM-4 for Temporary Structure Mounted Barrier. For dual bridges, provide median "drop-off" protection between the bridges. If the terrain cannot provide adequate drop-off protection, provide earth mounds as per the details in Publication 72M, *Standards for Roadway Construction*, RC-54M.



Median Drop-Off Protectoin Between Bridges

5.6 – Fences and Railings on Bridges

Refer to DM-4, Part B, Sections 13.7, and Appendix B.2(d).

5.7 – Bridges over Railroads

Refer to DM-4, Part B, Section 2.3.3.4, and Publication 371, *Grade Crossing Manual*, Appendix H, and Publication 10C, DM-1C, *Transportation Engineering Procedures*, Section 4.11.D for clearance requirements.

5.8 – Utilities on Bridges

Refer to Publication 16, Design Manual Part 5, *Utility Relocation*, (DM-5) Chapter 1.3.B.6, for Utility Occupancy of Structures, for policy for accommodation of utilities on structures.

5.9 – Hydraulic and Permitting Considerations

Hydraulic and permit considerations should be taken into account early in the preliminary engineering phase. Refer to DM-1C, DM-2, Chapter 10, Publication 584, *Drainage Manual*, and Publication 783, *Environmental Permitting Handbook*.

5.10 – Design Loading Structural Capacity

The design of bridges, culverts, walls, tunnels, and other structures are to be in accordance with the AASHTO, *LRFD Bridge Design Specifications*, edition referenced in the current version of

DM-4. **Exhibit 5.10.1** provides the minimum design loading structural capacity based on the type of work and the roadway classification.

Exhibit 5.10.1 Minimum Design Loading Structural Capacity for Bridges

Work Type	Freeways, Expressways and Arterials	Collectors and Local Roads	
New Bridges, Replacement Bridges and Full Superstructure Replacements	PHL-93	PHL-93	
All Other Work	HS-20 (minimum) PHL-93 (desirable)	Truck ADT < 500	HS-15 (minimum) HS-20 (desirable)
		Truck ADT ≥ 500	HS-20 (minimum) PHL-93 (desirable)

5.11 – Tunnels

Tunnels have the same geometric criteria as bridges described in this chapter, except the minimum shoulder widths for new and reconstructed tunnels on the Interstate are as follows: The tunnel width should match the full paved width of the approach roadway, including shoulders. However, due to the high cost associated with tunnels, reduced shoulder widths may be provided. The minimum reduced right and left shoulder width is 4 ft each side. For these reduced shoulder widths, consideration must be given to traffic impacts because reduced shoulder widths may cause traffic to slow upon entering the tunnel. Refer to AASHTO's *A Policy on Design Standards - Interstate System*, and the Green Book for more information on tunnels.

Chapter 6 – Intersections and Driveways

In this chapter there are references to future chapters 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 6 – Intersections and Driveways

6.0 – Introduction

There are three general types of roadway crossings: at-grade intersections, grade separations without ramps and interchanges. This chapter deals primarily with the design elements, capacity analysis and traffic control concepts for at-grade intersections. The latter two crossing types are discussed in Chapter 7, *Interchanges*.

Driveways are regulated access points between the roadway and an abutting property. They are included in this chapter because in effect, driveway terminals are intersections. Whether public or private, driveways function similar to public intersections.

An intersection is among the most complicated roadway elements, as it is the place where multiple users share the same travel space. Since each intersection involves some combination of motorized and non-motorized users, these movements may be facilitated by various geometric designs and traffic control depending on the type of intersection.

Per the PA Vehicle Code (Title 75), an intersection has two definitions, which are as follows:

1) The area embraced within the prolongation or connection of the lateral curb lines, or, if none, then the lateral boundary lines of the roadways of two highways which join one another at, or approximately at, right angles, or the area within which vehicles traveling upon different highways joining at any other angle may come in conflict.

2) Where a highway includes two roadways 30 ft or more apart, then every crossing of each roadway of the divided highway by an intersecting highway shall be regarded as a separate intersection. In the event the intersecting highway also includes two roadways 30 ft or more apart, then every crossing of two roadways of the highways shall be regarded as a separate intersection.

This chapter provides guidance on intersection design including:

- Design objectives.
- Users.
- Intersection characteristics.
- Types of Intersections.
- Alignment and profile.
- Sight distance.
- Turning roadways and channelization.
- Auxiliary lanes.

- Median openings.
- Indirect left turns and U-turns.
- Roundabouts.
- Other innovative intersections.

There are many different types of intersection control other than traditional stop sign and signal controlled intersections. These intersections may be referred to as “innovative,” “non-traditional,” “non-standard” or “alternative intersections”. These designs offer a means to address safety, mobility, and congestion issues that may not be adequately addressed with a traditional intersection design. The selection of an alternative intersection design may also have the added benefits of reduced cost and reduction in required right-of-way as compared to a more traditional design. These types of intersection control may be used where warranted by traffic volumes, roadway typology, and functional classification. While not all of these intersections are common to Pennsylvania, they have been successfully implemented elsewhere in the United States and North America. Examples include, but are not limited to, the following:

- Jughandles or Loop Roadways.
- Quadrant Roadways.
- Displaced Left Turn Intersections.
- Median U-Turn Intersections.
- Restricted Crossing U-Turn Intersections.
- Roundabouts.
- Continuous Green Tee.
- Bowtie.
- Protected Intersection.

This chapter, in conjunction with Green Book, Chapter 9, *Intersections*, provides guidance on designing the physical elements of an intersection and its pertinent features to provide for the effective movement of each intersection user.

The designer should ask these important context questions:

- Is the intersection in an urban, suburban, or rural setting?
- Which motorized and non-motorized users frequently use the intersection?
- Are there business and community activities focused at or adjacent to the intersection?
- Will navigation through the intersection be safe and intuitive for its users?

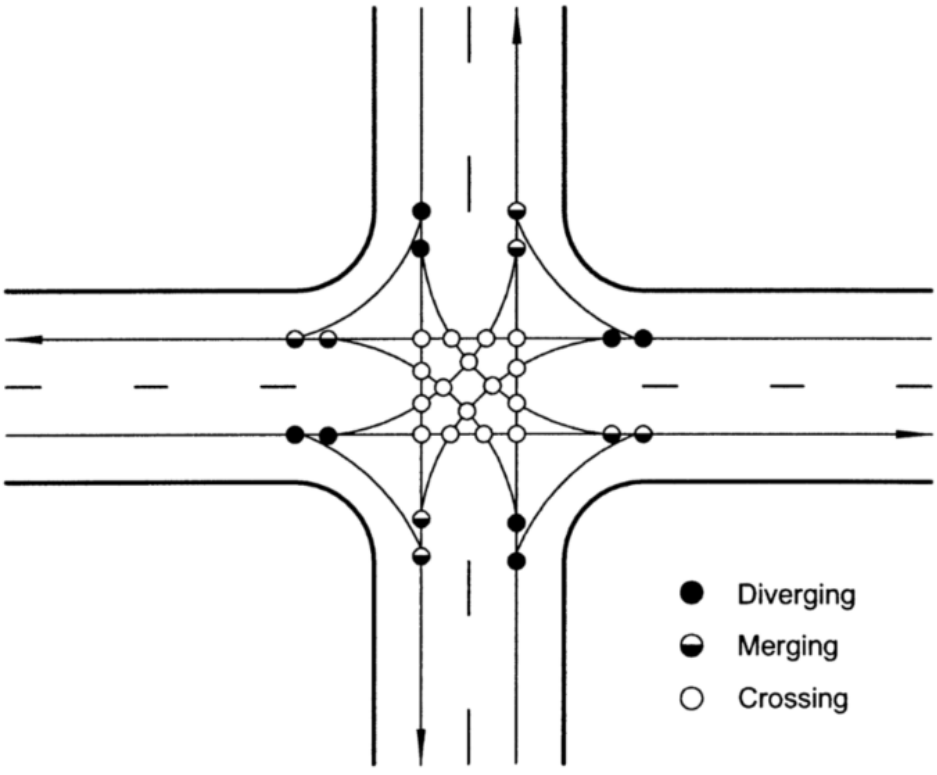
Key design components include:

- **Minimizing Conflict Points.** Intersection users often cross paths at intersections where through and turning movements conflict. These crossings are identified as “conflict

points." A traditional four-leg intersection, as illustrated in **Exhibit 6.0.1**, has 32 conflict points, consisting of eight merge, eight diverge, and 16 crossing points. By comparison, a three-leg intersection, as illustrated in **Exhibit 6.0.2**, has 9 conflict points; and a four-leg roundabout, as illustrated in **Exhibit 6.0.3**, has 8 conflict points. Conflict points should also be considered for driveway locations; increasing the distance between driveways reduces the potential for collisions.

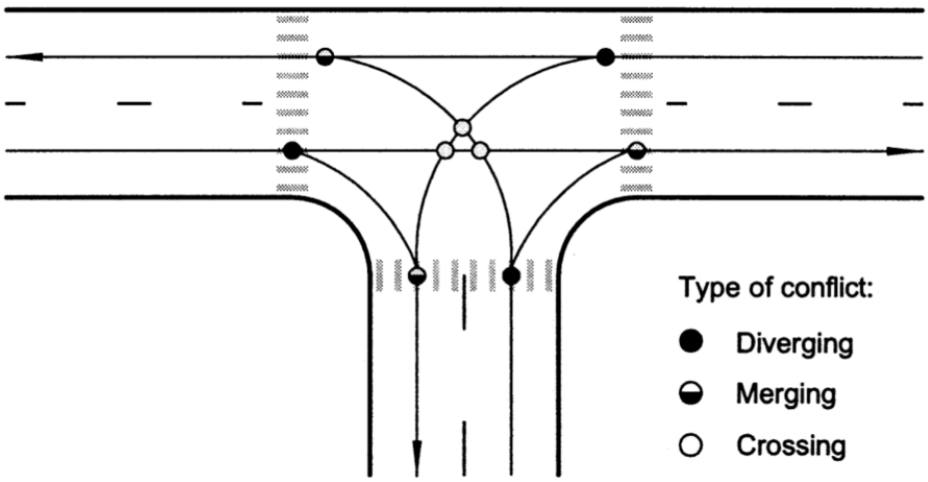
- **Designing to the Intersection Users.** Knowledge of the typical users of the intersection will result in a safer design for its users. For example, reference to Section 2.3.2 can provide guidance for an appropriate vehicular design vehicle, but an intersection with heavy pedestrian movements may warrant consideration of a non-traditional design to better accommodate pedestrians at the intersection corners. The designer needs to consider the accommodations of all expected users and modes of transportation (motor vehicles, pedestrians, bicyclists, micro-mobility devices, and transit).

Exhibit 6.0.1 Conflict Points at a 4-Leg Intersection



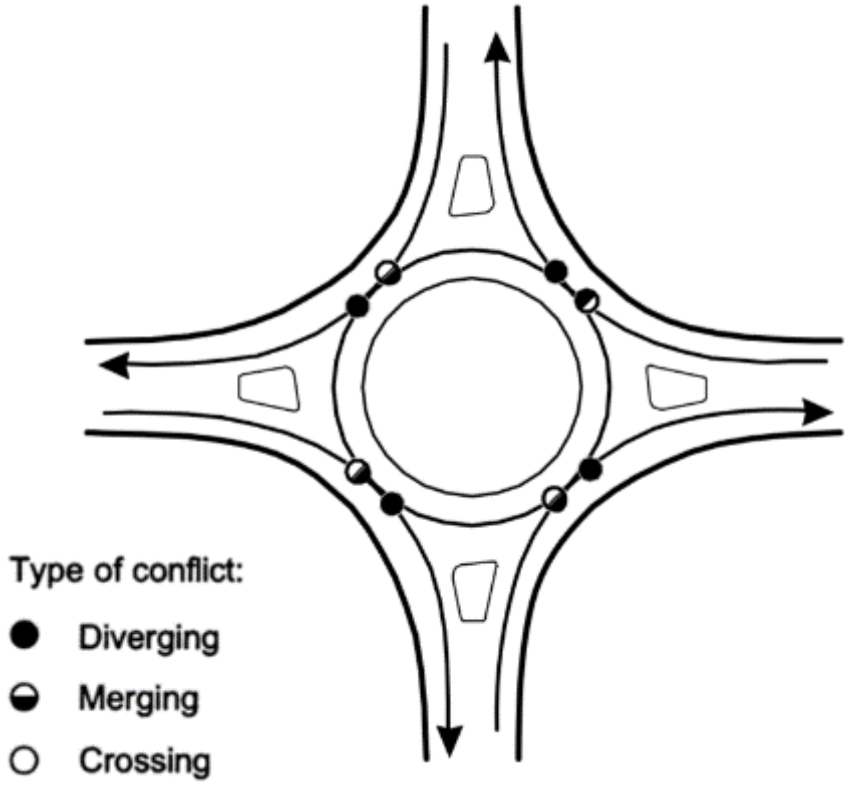
Source: FHWA Signalized Intersections: Informational Guide

Exhibit 6.0.2 Conflict Points at a 3-Leg Intersection



Source: FHWA Signalized Intersections: Informational Guide

Exhibit 6.0.3 Conflict Points at a Roundabout Intersection



Source: NCHRP Report 1043: Roundabouts: An Informational Guide

- **Consideration of Traffic Control.** Movement of users is assigned by traffic control devices such as yield signs, stop signs, and traffic signals. Traffic control often results in delay to users traveling along the intersecting roadways, but it helps to organize traffic and decrease the potential for crashes.
- **Evaluating Capacity.** Intersection types and their traffic control features can affect traffic capacity greatly. Consideration of the type of intersection and traffic control is important to consider at the beginning of the design process.

6.0.1 – Resources and Reference Documents

Additional sources of information and criteria to supplement the concepts presented in this Chapter are contained in the following resources:

- FHWA, *Advancing Turbo Roundabouts in the United States: Synthesis Report*, Pub. No. FHWA-SA-19-027, 2019.
- FHWA, *Alternative Intersections/Interchanges: Informational Report*, Pub. No. FHWA-HRT-09-060, 2010.
- FHWA, *Displaced Left Turn Intersection Informational Guide*, 2014.
- FHWA, *Median U-Turn Intersection Informational Guide*, 2014.
- NCHRP, Research Report 948: *Making Intersections Safer for People Who Walk, Bike and Roll.*
- NCHRP, Report 1043: *Guide for Roundabouts*.
- FHWA, *Restricted Crossing U-Turn Intersection Informational Guide*, 2014.
- FHWA, *Safety Evaluation of Continuous Green T Intersections, Pub. No. FHWA-HRT-16-036*, 2016.
- TRB, *Access Management Manual, Second Edition*, 2014.
- Publication 930, *Outdoor Advertising Control Reference Guide*, (most recent version).

6.1 – Design Objectives

The key to intersection design is achieving a set of fundamental design principles that include speed management, lane configuration, and human factor needs. The design must also consider the competing needs of all users (pedestrians, bicyclists, motor vehicles, micro-mobility devices, and transit) with respect to safety, operational efficiency, convenience, ease of use and comfort.

The designer should strive for these goals in intersection design:

- Provide the appropriate number of lanes and lane assignment (for adequate capacity, lane volume, and lane continuity).
- Provide channelization which is intuitive to drivers and results in motorists naturally using the intended lanes.
- Provide adequate accommodation for design vehicles.
- Meet bicyclist and pedestrian needs.
- Provide appropriate sight distance and visibility.

Human Factors

An example where human factors warrant additional consideration would be the inclusion of an alternative intersection design for left turns (e.g., jughandle or displaced left turn lanes) along a roadway in which upstream and downstream intersections have left turn lanes directly at the intersection. A driver approaching this alternative intersection may require additional advanced guidance because of deviation from the expected.

Intersection design should account for four basic elements:

- Human factors (driving habits, user expectancy, decision/reaction time, pedestrian/bicyclist behavior).
- Traffic considerations (existing/future crash frequency and severity, vehicular and mode characteristics, potential conflicts between modes, transit usage and stops, railroad accommodations).
- Physical elements (use of abutting property, available right-of-way, transit facilities, sight distance, intersection skew, auxiliary lanes, traffic control devices, access management).
- Economic factors (initial capital costs, ongoing maintenance and operations costs, energy consumption).

6.2 – Intersection Users

Intersection design should achieve an appropriate balance among the needs of all roadway users and modes of transportation using the intersection.

Key users and modes of transportation affecting design elements and intersection performance include:

- **Automobiles and other motor vehicles other than trucks –** Elements affecting intersection performance include traffic control type, intersection capacity, turning movement ability/restriction, pedestrian/bicyclist visibility, and vehicle speed.
- **Trucks –** Similar to automobiles, but of a larger size, they need larger radii and may be slower.
- **Transit –** Share some characteristics of automobiles and trucks but may also involve transit stops in the intersection's functional and/or physical area that create potential conflicts with bicyclists, pedestrians, and motor vehicles.
- **Pedestrians –** Elements affecting intersection performance include available right-of-way, crossing distance, conflicting traffic volume, speed/visibility of traffic, permissive turning movements, lighting, and accessibility.
- **Bicyclists –** Elements affecting intersection performance include the presence of bike lanes, turning movements of vehicular traffic, bicycle specific traffic control, conflicts with pedestrians, and speed differential with motor vehicles.
- **Other unique modes of transportation –** Such as horse & buggies, electric scooters, autonomous delivery vehicles, etc.

Intersection Users

The design of intersection elements for one user may have consequences for other users.

For example, an intersection designed primarily for trucks may result in large corner radii and subsequently, greater crosswalk lengths.

6.3 – Intersection Characteristics

Intersection design must consider the needs of its many motorized and non-motorized users. A successful design facilitates the comfort, convenience, and safety of these users traversing the intersection while enhancing the efficient movement of motor vehicles, buses, trucks, bicycles, and pedestrians, all at a point where motorist, bicycle, and pedestrian movements converge.

Therefore, intersection design not only addresses the roadway pavement, but also sidewalks, pedestrian ramps, bicycle facilities, and access. Consider the following in intersection design:

- Land use near intersections.
- Conflict points for motor vehicles, pedestrians, and bicyclists.
- Traffic control devices.

- Performance metrics (quality of service, level of service (LOS), service measure metrics, and intersection capacity). Refer to Section 2.4.3, *Operational Characteristics*.

In addition to the users of the street and intersections, owners and users of adjacent land often have a direct interest in the intersection design. This interest can be particularly sensitive where the intersection is surrounded by retail, commercial, historic, or institutional land uses. The primary concerns include vehicular access to private property, on-street parking, loading zones, acquisition of private property for right-of-way, turn restrictions, and provision for convenient pedestrian access.

The appropriate design vehicle for an intersection will account for the largest vehicle to frequently use the facility and may vary by intersection approach and presence of other users. The designer should refer to Section 2.3 for more information on design vehicles.

This section discusses intersection design considerations including:

- Functional and physical areas.
- Intersection capacity and operational characteristics.
- Intersection layout.

6.3.1 – Functional and Physical Areas

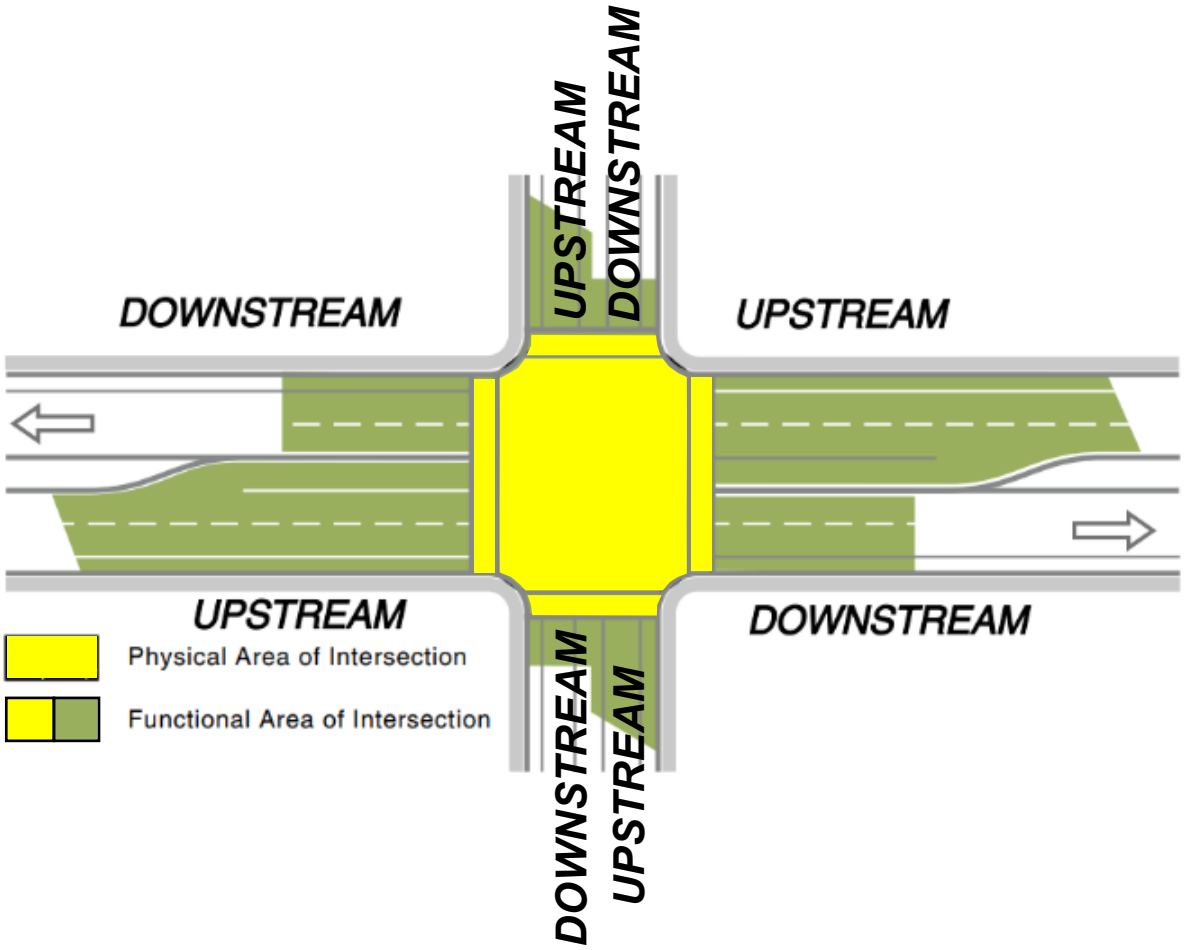
An intersection is defined by both its functional and physical areas. The functional area of an intersection extends both upstream and downstream from the physical intersection area and includes any auxiliary lanes and their associated channelization.

The functional area of an intersection, as illustrated in **Exhibit 6.3.1**, includes the physical area, and extends beyond the physical intersection of two roadways (or roadway and path) to include decision and maneuvering distance, plus any required vehicle storage length. Driveways and other mid-block crossings should be outside of the intersection's functional area. The physical area of an intersection, as illustrated in Exhibit 6.3.1, is a fixed area that represents the space confined within the corners of the intersection and includes bike/pedestrian crossings.

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 vehicular speeds and driver focus within the functional area of an intersection, bike/pedestrian crossings should be limited to the physical area of the intersection.

Exhibit 6.3.1 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 6.3.2**, an intersection's functional area accounts for perception-reaction time, deceleration, and queue storage, which all relate to design speed.

Exhibit 6.3.2 Diagram of the Upstream Functional Area of an Intersection

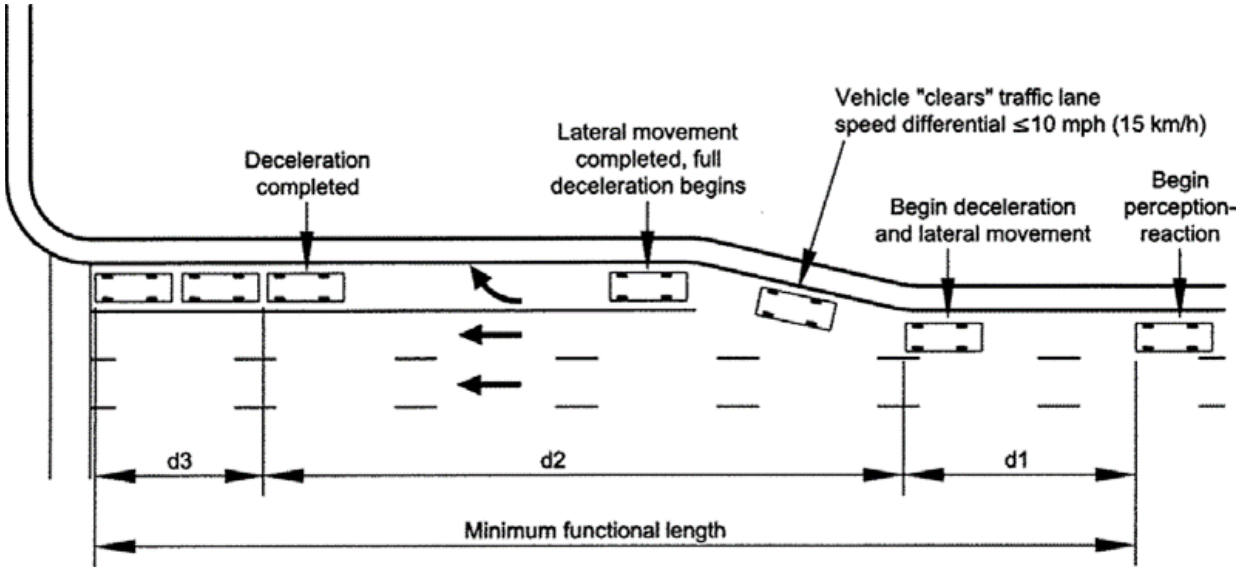


Exhibit 6.3.2 illustrates:

- **Distance d1** – Distance traveled during perception-reaction time as a driver approaches the intersection, assume 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 (perception-reaction time) and d2 (braking distance) are provided 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 allowing the driver to completely clear the intersection before needing to react to something downstream, stopping sight distance is typically applied.

6.3.2 – Intersection Capacity and Operational Characteristics

As discussed in Section 2.4.3, there are many ways to measure the operation and performance of an intersection.

Intersection capacity, which is defined as the maximum hourly rate at which vehicles can reasonably be expected to pass through the intersection under prevailing traffic, roadway, and signalization conditions, is one such measure. It is expressed in units of vehicles per hour and is influenced by traffic and roadway conditions such as volume, turning vehicles, type of control, bus stops, pedestrians, parking, geometry, and available green time (at signalized

intersections).

Highway Capacity Manual (HCM) analysis techniques are to be used to compare user operations amongst different intersection conditions. For vehicles, control delay, which is essentially the delay attributable to a control device, is the primary measure of effectiveness for operational quality of service. An intersection LOS ranging from A (little to no delay) to F (unacceptable delay) is used to characterize these conditions. **Exhibit 6.3.3** indicates the different LOS thresholds for vehicles at signalized intersections. The designer should refer to the HCM, Chapter 19, for additional detail regarding control delay, LOS, LOS for lane groups and volume-to-capacity ratios greater than 1.0.

Exhibit 6.3.3 LOS Criteria: Motorized Vehicle Mode for Signalized Intersections

Control Delay (seconds/vehicle)	LOS
≤10	A
>10-20	B
>20-35	C
>35-55	D
>55-80	E
>80	F

For unsignalized intersections, LOS criteria differs slightly from signalized intersections because of different user perceptions at unsignalized intersections. LOS is not defined for the entire intersection for two-way stop-controlled (TWSC) intersections but by minor street movements and the major street left turns. All-way stop-controlled (AWSC) and roundabout intersections define LOS by movement and by intersection. **Exhibit 6.3.4** indicates the different LOS thresholds for vehicles at unsignalized intersections. Control delay values and volume-to-capacity ratios are considered. This table applies to all unsignalized intersections, including roundabouts. The designer should refer to Chapters 20 through 22 in the HCM for additional detail regarding LOS for unsignalized intersections.

Exhibit 6.3.4 LOS Criteria: Motorized Vehicle Mode for Unsignalized Intersections

Control Delay (seconds/vehicle)	LOS by Volume-to-Capacity Ratio	
	v/c ≤ 1.0	v/c > 1.0*
0-10	A	F
>10-15	B	F
>15-25	C	F
>25-35	D	F
>35-50	E	F
>50	F	F

* LOS F is assigned to a movement (TWSC) or lane (AWSC/roundabout) if it has a v/c ratio greater than 1.0, regardless of its control delay.

The HCM only provides pedestrian and bicycle LOS for signalized intersections and pedestrian LOS for TWSC intersections. LOS are not provided for other intersections. The designer should reference Chapter 5 in the HCM for additional detail than provided here:

- Pedestrian LOS at signalized intersections is based on a score model incorporating volumes, speeds, crosswalk lengths, pedestrian delay, and channelizing islands. Pedestrian LOS at TWSC intersections is based on average control delay crossing the major street.
- Bicycle LOS at signalized intersections is based on a score model incorporating perceived separation from motorized vehicle traffic, motorized vehicle volumes, cross-street width, and on-street parking.

Exhibit 6.3.5 indicates the different LOS thresholds for pedestrians and bicyclists at signalized intersections. The designer should reference Chapter 19 in the HCM for additional detail regarding the LOS score.

Exhibit 6.3.5 LOS Criteria: Pedestrian and Bicycle Modes at Signalized Intersection

LOS	LOS Score
A	≤ 1.50
B	> 1.50 – 2.50
C	> 2.50 – 3.50
D	> 3.50 – 4.50
E	> 4.50 – 5.50
F	> 5.50

Exhibit 6.3.6 indicates the different LOS thresholds for pedestrians at TWSC intersections. Control delay values are based on Exhibit 20-3 in the HCM. The designer should reference Chapter 20 for additional detail regarding the LOS score.

Exhibit 6.3.6 LOS Criteria: Pedestrian Mode for TWSC Intersections

Control Delay (seconds/pedestrian)	LOS
0-5	A
5-10	B
10-20	C
20-30	D
30-45	E
>45	F

The designer is encouraged to refer to Section 2.4.3 for mobility, safety, and economic vitality

performance metrics to consider during intersection design. The designer is also encouraged to refer to the Green Book, Chapter 9, section titled *General Design Considerations and Objectives / Intersection Capacity*, for additional detail.

The criteria, procedures and guidance for highway capacity analysis used on all Department projects shall comply with capacity concepts presented in the HCM. Acceptable software is provided in Publication 46, *Traffic Engineering Manual*. Where traffic signal controls may be required for intersections, the warrants for their installation are governed by Publication 46 and FHWA's Manual on Uniform Traffic Control Devices (MUTCD).

6.3.3 – Intersection Layout

The intersection layout should be based on the applicable design vehicle as per Chapter 2, *Design Controls*. However, refer to Chapter 16, *Freight*, to determine if a freight network is present which could affect the layout, primarily turn movements. Additionally, access for trucks is important for delivery purposes as well as emergency response. Some local entities may prefer smaller or larger truck types.

Intersection Sight Distance (ISD) is another key design element at intersections. Although it is typically calculated based on automobiles, consideration should be given to trucks which have different eye-heights and object visibility characteristics not just from automobiles, but between truck types. Refer to Section 3.1.8 for more information on ISD. At intersections with any of the following, freight movement should be incorporated into determining the geometric elements:

- Intersection serves as access point to an industrial or retail land use where freight traffic will be present.
- Intersection is part of access route to a freeway or expressway, as defined in the Preface.
- Freight deliveries are common adjacent to or along the intersecting routes.

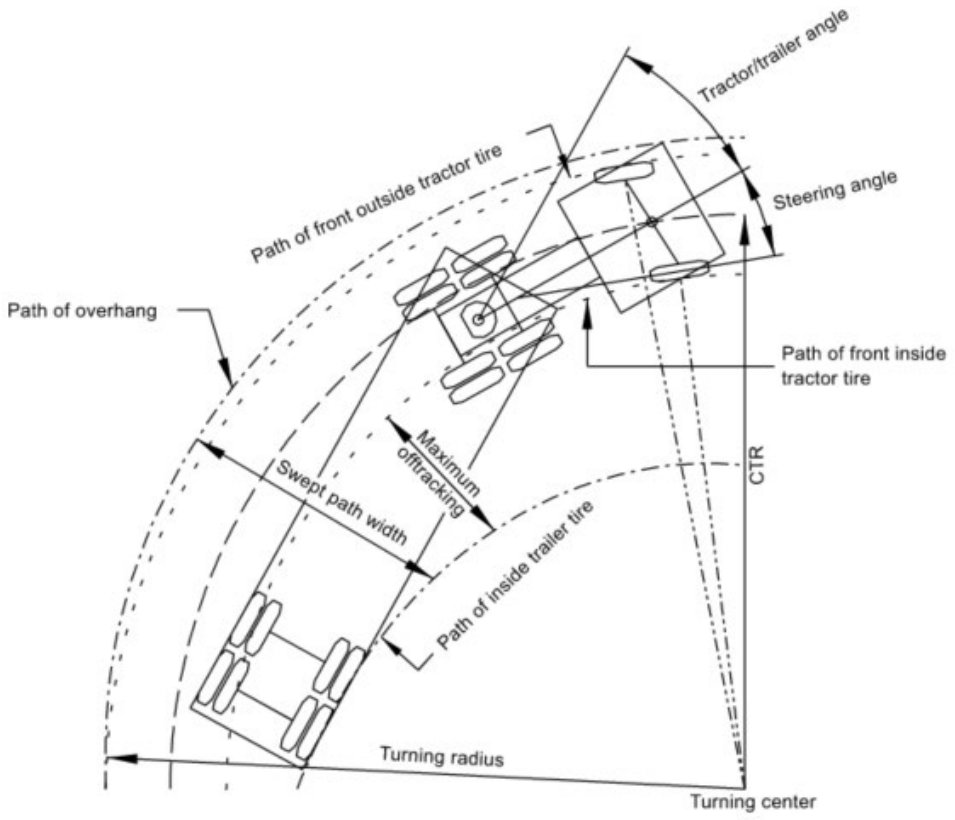
The goal is to balance all modes of travel to keep streets accessible for freight, transit, and bicycles where designated, and to create positive environments for pedestrians. The type of intersection also needs to be considered and the Intersection Control Evaluation Policy in Pub 10X, DM-1X, Appendix AI, applied as necessary. Refer to Chapter 16 for further discussion on Freight.

6.3.3.a – Vehicle Offtracking

Most corner designs for trucks will need to be analyzed for vehicle swept path, which is the width of the tractor unit plus offtracking. Offtracking is the difference in the paths of front and rear wheels as a truck makes left or right turns at intersections, and it does not follow the same path made by an automobile. Swept path and offtracking are illustrated in **Exhibit 6.3.7**. Green Book turning templates may be used for simple designs, but they provide limited flexibility for complex design scenarios. Another approach is to use specialized computer software to complete the offtracking analysis.

A consideration of the evaluation of vehicle offtracking is the determination of whether the turning envelope modeled should be “designed for” or “accommodated.” Inputs into this decision include the frequency of the modeled vehicle in using the intersection and the likelihood of interaction with a conflicting vehicle (i.e., two larger trucks attempting to make the turn at the same time or opposing trucks turning that could overlap envelopes). The potential interaction with other modes (pedestrians adjacent to mountable curb, presence of bike lanes, etc.) should also factor into the design development. A “designed for” turning envelope will provide adequate roadway space to avoid interaction, while an “accommodated” turning envelope will allow some overlap, based on a probability of interaction and conflict being very low. The designer should refer to Section 2.3 for additional discussion on “designed for” versus “accommodated” for trucks at intersections.

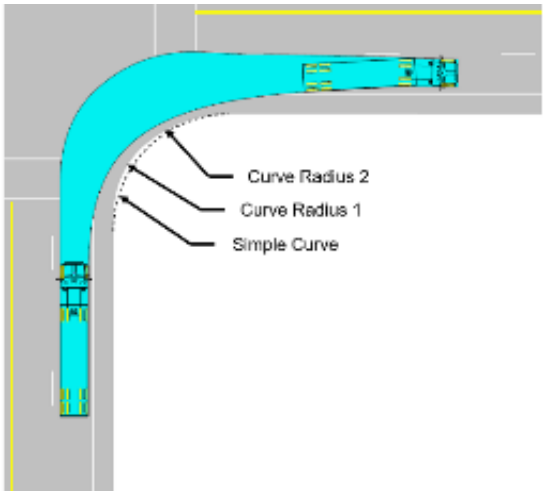
Exhibit 6.3.7 Swept Path and Offtracking for Trucks



When trucks turn, particularly tractor-trailers, they sweep a path that can best be simulated by a series of curves. A simplified approach as seen in **Exhibit 6.3.8** would use two or three

compound curves to best match the pathway of the truck. By using this approach, the full swept path for the design vehicle is met, and the sweep path for larger vehicles can be checked for accommodation, if appropriate, while still minimizing the amount of roadway surface. Minimizing roadway surface also manages crossing distances, signal pole arm lengths, etc., and provides both safety and cost benefits to the project. These designs also allow for a tighter radius corner, which will help promote speed reduction for smaller vehicles making the turn. For dual left turns, wider receiving lanes may need to be provided to minimize sideswipe interactions on movements with higher heavy truck volumes. The Green Book, Chapter 3, contains additional details on the design of compound curves.

Exhibit 6.3.8 Compound Curve Corner Layout



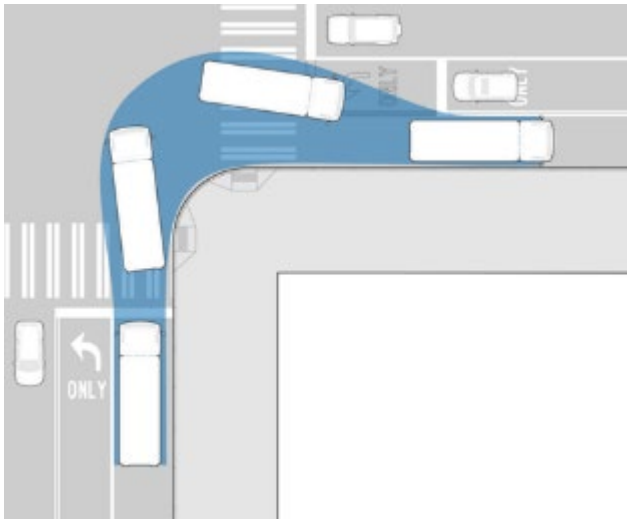
Vehicle Turn Tracking

- Typically, designers will complete an analysis using a two- or three-centered curve design with a vehicle swept path software package or turning templates. When using such software, the following guidance is recommended:
- Start and end the vehicle in the center of the exiting and receiving lanes.
- Set the vehicle speed as follows:
  - 10 mph or greater for signalized intersections.
  - 5 mph for stop sign controlled or uncontrolled intersections.
- In these analyses, designers seek to provide at least 1 ft (2 ft preferred) of clearance from vehicle body to the curb face at any portion of the corner.
- Use 2 ft of vehicle clearance envelope in most situations so that vehicle path is unlikely to run onto the gutter pans at the curb and gutter, as well as provide a buffer for path variability to the curb face. Over shorter distances, 1 ft of clearance may be acceptable. A strengthening of the gutter may be required in these situations.

6.3.3.b – Stop Bar Placement

Stop bar location on both the street a truck is turning from, as well as the cross-street approach the truck is turning onto, can have a dramatic effect on the accommodation of truck turning movements. Stop bars can be set back from the intersection and crosswalk to provide room for the swept path of the turning vehicles. Additionally, not all lanes need to have the stop bar setback. On cross street approaches, this treatment is typically limited to the left-turn lane when such a lane is present as illustrated in **Exhibit 6.3.9**. For cross street approaches without a left-turn lane, the stop bar for the inside through lane can be set back.

Exhibit 6.3.9 Stop Bar Placement



Stop Bar Placement

- Check the stop bar placement for both left- and right-turning movements on both the street a truck is turning from as well as the cross-street approaches (if accommodating and not designing for) for the specified design vehicle.
- Verify that the stop bar location does not exceed the maximum stop bar to traffic signal head distance.
- Include supplemental lane markings so that cars have clear indication of the lane locations through the intersection.
- Take into consideration signal detection equipment and make adjustments as needed.

6.3.3.c – Traffic Signal Timing Adjustment

Because of their size, length, and decreased power-to-weight ratio, heavy vehicles can have a tremendous impact on the operations of a signalized intersection. Not only do they take up more space and have slower acceleration rates, but they affect the operations of vehicles around them. Each heavy vehicle at an intersection impacts the operation of the lane queue at an intersection. When developing traffic signal timings, be sure to account for heavy vehicles when necessary, at the lane queue level so that appropriate start up lost times are accounted for in appropriate signal phases.

6.4 – Types of Intersections

The basic types of intersections are characterized primarily by the number of intersecting legs, the geometrics of the intersecting roadways, the needs of all users, the traffic volumes, patterns and speeds, and the desired type of operation. These intersections include:

- Three-leg (T-intersection).
- Four-leg.
- Multileg (five or more intersection legs).
- Roundabouts (See Section 6.12).

The characteristics of an intersection are also related to the type of traffic control, which includes the following:

- Cautionary, uncontrolled, or non-stop controlled.
- Stop control for minor approaches.
- Four-way stop control.
- Fixed time signal control.
- Traffic (motorized or non-motorized) actuated signal control.

Tying together intersection type and traffic control, the HCM provides analysis techniques for the following:

- Signalized Intersections.
- Two-Way Stop-Controlled (TWSC) Intersections, which includes three-leg intersections in which the stem of the T is controlled by a stop sign.
- All-Way Stop-Controlled (AWSC) Intersections.
- Roundabouts.
- Ramp Terminals and Alternative Intersections.

Channelized Right Turns

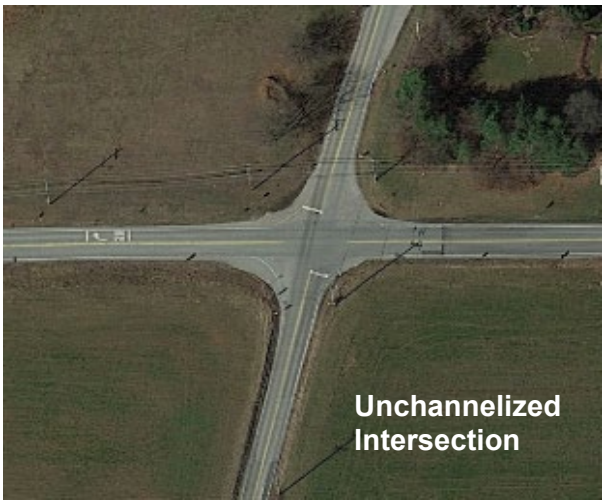
Right turn lanes without stop or yield control are sometimes provided at channelized intersections. The designer should consider the following with their use:

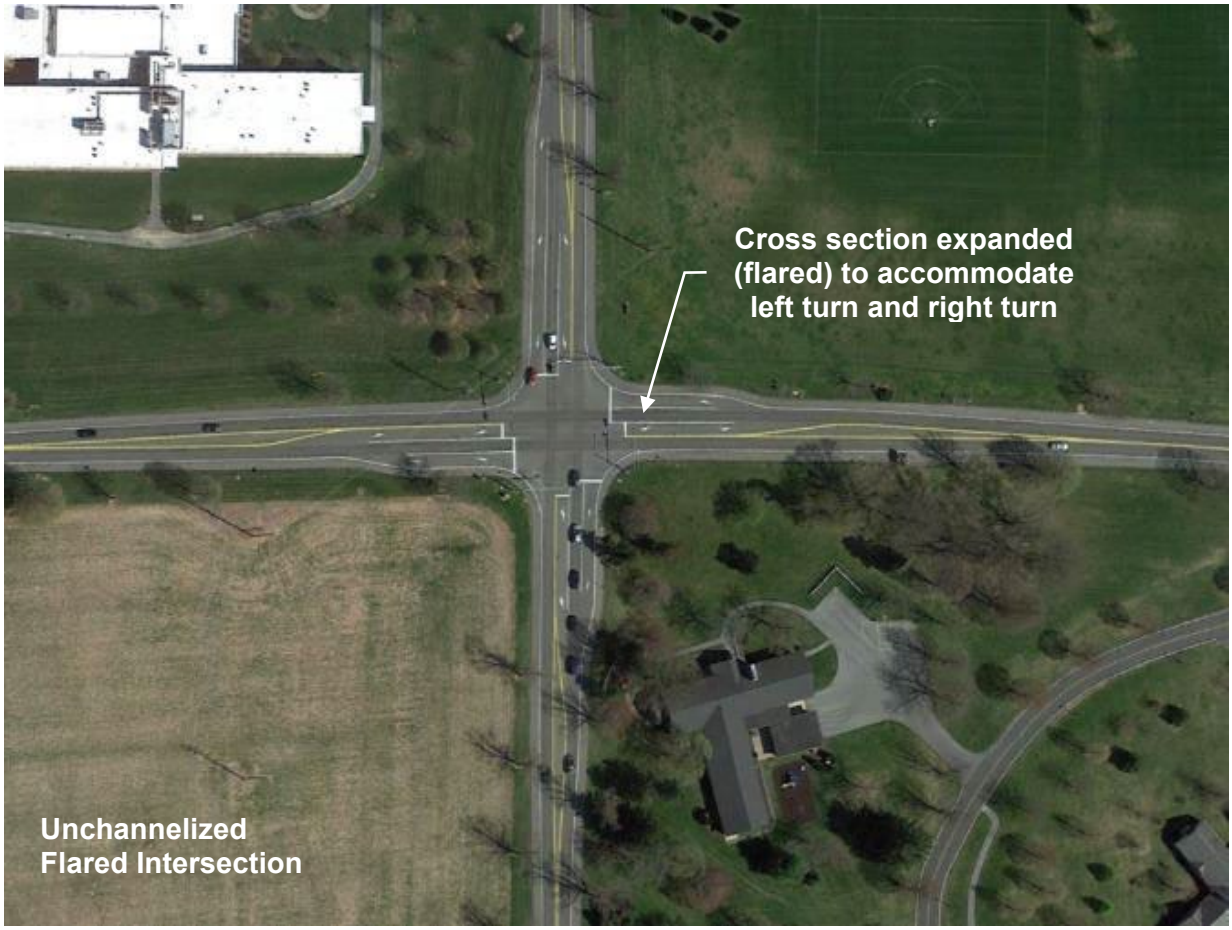
- Use only if an adequate merge is provided.
- Consider provisions for bicyclist and pedestrian movements.
- Pedestrians with vision disabilities may have difficulty perceiving the intended pedestrian crossing route.
- Locations with high pedestrian or bicyclist volumes should only consider them when crash patterns may occur without them and if appropriate pedestrian crossings are provided.

These intersections can be further classified as channelized and unchannelized. Examples of these intersections are illustrated in **Exhibit 6.4.1.** Channelized intersections separate or regulate conflicting traffic movements into definite paths of travel by traffic island or pavement markings. This aids in orderly movements of motor vehicles, bicyclists, and pedestrians. Unchannelized intersections do not separate paths by islands or pavement markings. Channelized and unchannelized intersections can also be flared. Flared intersections expand the cross-section of a street to accommodate turn lanes at an intersection.

Exhibit 6.4.1 Examples of Flared, Channelized, and Unchannelized Intersections







Two variations to this list are an indirect intersection and an offset intersection.

- Indirect intersections provide one or more of the intersection movements at a location away from the primary intersection. Indirect intersections are discussed in further detail in Section 6.11.

- An offset intersection consists of two adjacent T-intersections that function similar to a four-leg intersection. While the close proximity of offset intersections can be seen as a negative, offset intersections can be useful when 1) both major and minor through volumes are low or 2) it is a retrofit of a skewed intersection with heavy turn volumes and limited through volumes.

Whether the intersection is located in an urban area or a rural area, the principles are the same. A balanced approach to intersection design accommodates the anticipated various transportation modes and considers the context and community in which the project is located.

Figures 9-4 through 9-14 in Chapter 9 of the Green Book illustrate the general application of basic types of intersection design.

Once the type of intersection and the intersection control is established, the design controls, criteria and the geometric elements of intersection design can be applied to arrive at a suitable geometric plan. A basic intersection type can vary greatly in scope and shape depending on the need for auxiliary lanes and the degree of channelization. The modern roundabout is discussed in more detail in Section 6.12. Other variations beyond basic intersections are discussed in Sections 6.11.2 through 6.11.6. For additional information on variations of the basic types of intersections, their treatments, and applications, refer to Green Book, Chapter 9, section titled *Types and Examples of Intersections*.

6.5 – Intersection Control Evaluation Policy

An Intersection Control Evaluation (ICE) policy has been developed to consistently consider and screen from among many proven combinations of geometry and traffic control when a new intersection or existing intersection modification is being considered.

The goal of ICE is to better inform the decision-making authority in identifying and selecting an alternative that meets the project purpose and reflects the overall best value in terms of specific performance-based criteria within available resources. As with most transportation studies, ICE is scalable, meaning the corresponding level of effort for screening and analysis should be commensurate with the magnitude and nature of the project, i.e., there is less effort for simple, more effort for complex. The premise of an ICE is the same whether it involves new intersections or modification to existing intersections. The users should use their judgment to apply the ICE framework in the way that meets project needs and the objectives of the ICE policy. Ultimately, the ICE policy is intended to foster thoughtful consideration of intersection types and ensure a holistic, quantitative analysis is completed when selecting an intersection control type.

ICE Policy

PennDOT's ICE Policy includes consideration of many factors and data including, but not limited to, the following:

- 24-hour intersection approach counts.
- Peak hour turning movement counts.
- Pedestrian and bicycle volumes by approach.
- Future projected volumes.
- Last five full calendar years of crash data.
- Existing geometrics on an aerial photo or CADD layout.
- Posted speed limit.
- Traffic control.
- Adjacent utilities and structures.
- Community need and/or preferences for parking, sidewalks, bicycle lanes, etc.
- Adjacent land uses requiring treatment for pedestrians or vehicles.
- Environmental factors.
- Transit routes and frequency.
- Stakeholder/public input considerations.

The designer should refer to Publication 10, Design Manual 1C, *Transportation Engineering Procedures* (DM-1C), for the proper application of ICE policy for intersections during the pre-TIP conceptual alternatives analysis and preliminary engineering alternative analysis phases of a project. Refer to Publication 10X, Design Manual 1X, *Appendices to Design Manuals* (DM-1X), Appendix AI, *Intersection Control Evaluation (ICE) Policy*, for details on how to apply the ICE. Spreadsheets for the ICE Stage Forms and ICE Evaluation Tool, as well as a PowerPoint presentation and Case Studies, can be found on the PennDOT Traffic Signal Portal.

6.6 – Horizontal Alignment and Profile

Since intersections contain points of conflict between vehicles, pedestrians and bicycles, the alignment and profile of the intersecting roads should permit users to easily recognize the intersection and vehicles using it, and readily perform the maneuvers needed to pass through the intersection with minimum interference. The gradients should be as flat as practical. In most cases the alignment should also be as straight as practical unless approach chicanes are used to calm traffic prior to the intersection. The sight distance should be equal to or greater than the minimum values for specific intersection conditions. If design objectives are not met, users may have difficulty in discerning the actions of other users, in reading and discerning the intent of traffic control devices, and in controlling their operations.

Combination of Horizontal and Vertical Alignments

The combination of horizontal and vertical alignment at or near intersections should provide traffic lanes that are:

- Clearly visible to drivers and other users.
- Clearly visible for any direction of travel.
- Free from potential for conflicts to suddenly appear.
- Consistent in design with portions of the roadway just traveled.

6.6.1 – Horizontal Alignment

The designer should consider the following design elements for horizontal alignments at intersections. These design elements are discussed in additional detail in Green Book, Chapter 9, under Alignment:

- Intersect roads as close to 90 degrees as practical. Realigning an intersection to at least 75 degrees provides most benefits provided by a 90-degree intersection, but 90 degrees is preferred.
- Realign skewed crossings with curves to intersect at right angles but avoid short-radius horizontal curves on side road approaches due to traffic control and lane encroachment issues.
- Consider offset intersections to realign roads intersecting at acute angles.
- Avoid intersections on sharp curves because of possible complications from superelevation, widening of pavements, and reduced sight distance.

6.6.2 – Profile

The following design elements should be considered for profiles at intersections.

- The major roadway cross slope should typically be carried through the intersection. However, at a signalized intersection with two roadways with high ADT, it may be desirable to warp the crowns of both roads to avoid a pronounced hump or dip in either direction.

- Preferences for a transition from a minor road vertical grade to a major road cross slope are as follows:
    - Vertical curves:
        - Stop condition (or T-intersection leg that does not go straight): Although design speeds are not applicable to a stop condition, use a minimum 20 mph design speed for this geometric element.
        - Signalized intersections: Use the design speed, as full design speed can be attained by vehicles.
    - Angle breaks with no curve:
        - Stop condition: max 3% preferred, but up to 8% allowed in constrained areas. Design vehicles must be evaluated for bottoming out.
        - Signalized intersections:
            - 20 mph: crest 7%, sag 5%.
            - 25 mph: crest 5%, sag 3%.
            - 30 mph: crest 3%, sag 2%.
            - 35 mph: crest 2%, sag 1%.
- Minor street grades at all intersections should be as flat as possible, but preferably no greater than 5% or flatter when intersecting the major route cross slope.
- Minor road stop approach “storage platforms” should be at least 30 ft long.

Refer to the Green Book, Chapter 9, section titled *Alignment and Profile / Profile* for additional discussion:

- Avoid combinations of grade lines that make vehicle control difficult.
- Avoid substantial grade changes at intersections.
- Avoid intersecting crossover grades that could cause “lowboy” trucks to bottom out.
- Provide adequate sight distance along both intersecting roads and across their included corners.
- Provide gradients as flat as practical on those sections that are to be used for storage of stopped vehicles.
- Limit the cross slope of crosswalks through the intersection. Crosswalk cross slopes exceeding 2.1% are not desirable, refer to Chapter 13 for ADA guidance.
- Avoid grades steeper than 3% for intersecting roadways where practical.
- Adjust profile gradelines and cross sections on legs of an intersection a distance back from the intersection proper to provide a smooth junction and proper drainage.

- Avoid sharp horizontal curves following a crest vertical curve.

6.7 – Intersection Sight Distance

The potential for crashes at intersections can be greatly reduced by providing adequate intersection sight distance (ISD). Chapter 3, *New Construction and Reconstruction – Change In Road Type*, Section 3.1.8, Exhibit 3.1.5, provides a good graphical representation of the relationship between typical ISD and SSD at an intersection.

For additional intersection sight distance considerations, refer to Chapter 3, Sections 3.1.8 and 3.1.9, as well as the Green Book, Section 9.5, *Intersection Sight Distance*.

6.7.1 – Sight Triangles

Specified areas along intersection approach legs and across their included corners should be clear of obstructions that might block a driver's view of potentially conflicting vehicles. These specified areas are known as clear sight triangles as depicted in **Exhibit 6.7.1.** The dimensions of the legs of the sight triangles depend on the design speeds of the intersecting roadways and the type of traffic control used at the intersection.

There are two types of clear site triangles to be considered in intersection design:

- Approach sight triangles
- Departure sight triangles

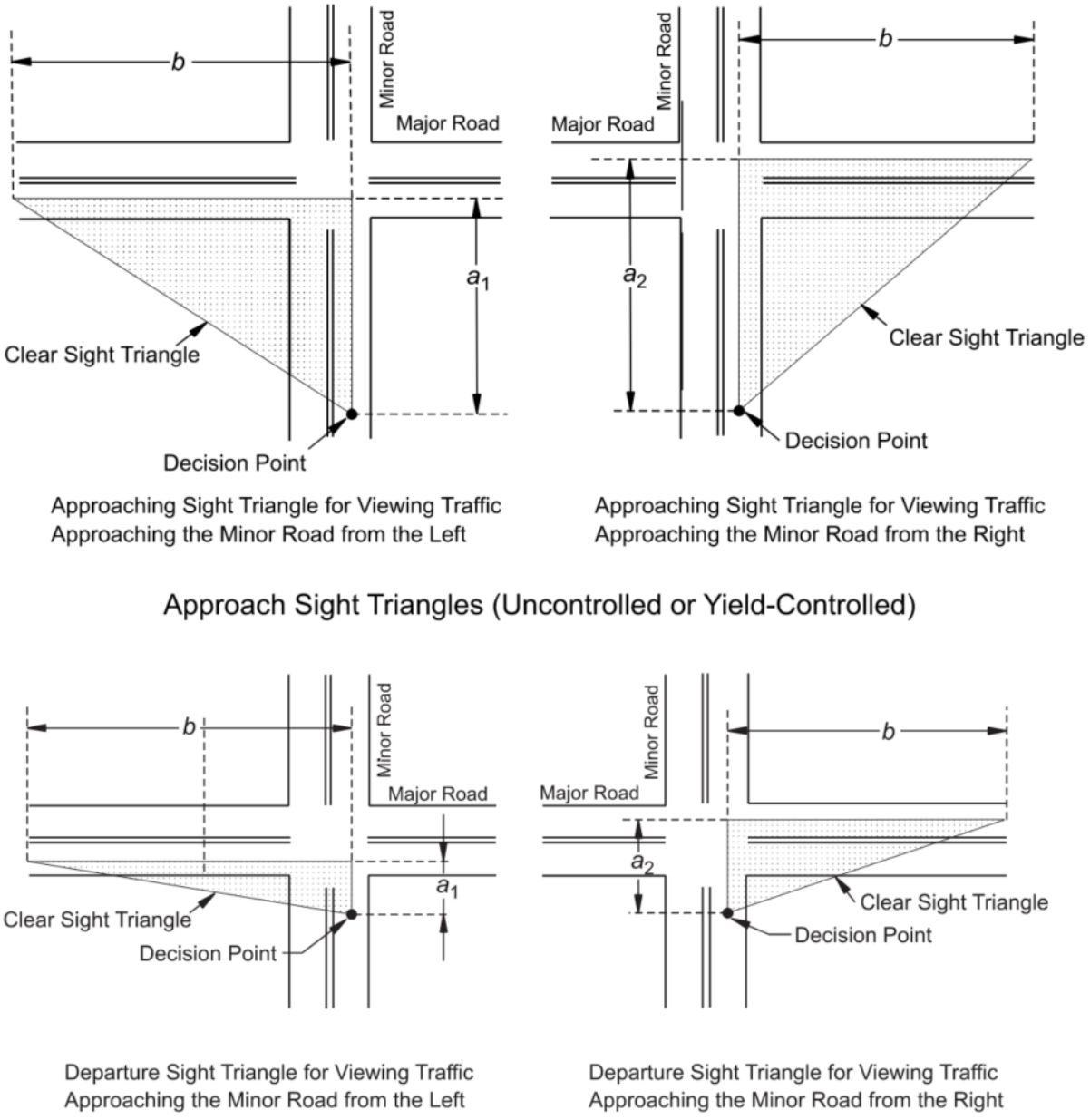
Approach sight triangles are for drivers approaching an intersection. Approach sight triangles allow a driver to see potentially conflicting vehicles in sufficient time to slow or stop before colliding within the intersection. Departure sight triangles are for a driver on a minor road approach departing from the intersection to enter or cross the major road on which traffic is not required to stop.

Sight Triangle Obstructions

Examples of obstructions within an intersection sight triangle include the following:

- Crops.
- Hedges.
- Trees.
- Parked vehicles.
- Utility poles.
- Buildings.
- Guiderail and barriers.
- Embankments.
- Signs.

Exhibit 6.7.1 Approach and Departure Sight Triangles



Source: AASHTO Green Book

For more information about sight triangles at intersections and the methodology for identifying sight obstructions within sight triangles, refer to the Green Book, Chapter 9, section titled *Intersection Sight Distance / Sight Triangles*.

6.7.2 – Intersection Control

Dimensions of the intersection sight triangles vary with the type of intersection traffic control. Different traffic control types impose different legal constraints on drivers, and therefore, different driver behaviors. Refer to the Green Book, Chapter 9, section titled *Intersection Sight Distance / Intersection Control* for details on procedures to determine intersection sight distances for the following different types of traffic control.

- Case A – Intersections with no control.
- Case B – Intersections with stop control on the minor road.
    - Case B1 – Left turn from the minor road.
    - Case B2 – Right turn from the minor road.
    - Case B3 – Crossing maneuver from the minor road.
- Case C – Intersections with yield control on the minor road.
    - Case C1 – Crossing maneuver from the minor road.
    - Case C2 – Left or right turn from the minor road.
- Case D – Intersections with traffic signal control.
- Case E – Intersections with all-way stop control.
- Case F – Left turns from the major road.
- Case G – Roundabouts.

Roundabout ISD

NCHRP Report 1043 indicates that it is advantageous to provide only the minimum intersection sight distance (ISD) needed at a roundabout:

- Providing minimum ISD should result in lower vehicle speeds and therefore decrease conflicts between motor vehicles, bicyclists, and pedestrians.
- Landscaping within the central island can be effective in restricting ISD to the minimum and create a “terminal vista” on approaches to improve visibility of the central island.

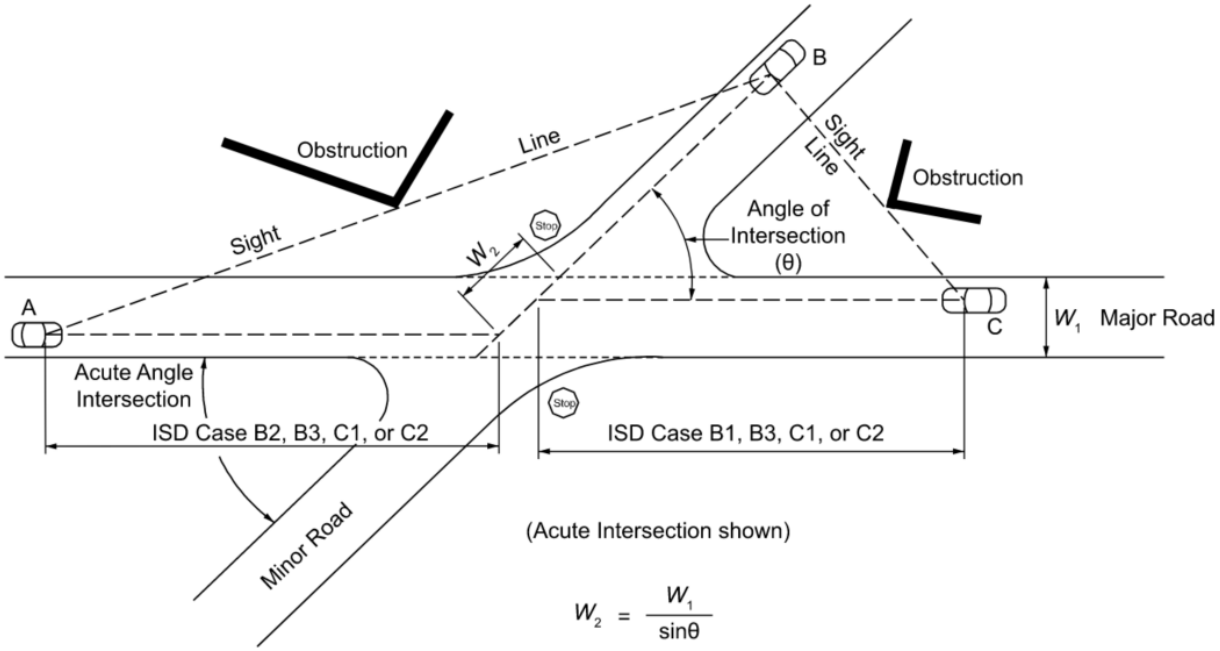
6.7.3 – Effect of Skew

In cases where two roadways intersect at an angle less than 75 degrees or greater than 105 degrees, and realignment or roundabout conversions are not justified to increase the intersection angle, some adjustments should still be made to provide adequate intersection sight distance, especially as the length of the travel paths for some crossing and turning maneuvers increase.

As seen in **Exhibit 6.7.2**, the sight triangles are either smaller (acute angle) or larger (oblique angle) than a sight triangle for a right-angle intersection. Note that at oblique-angle

intersections, sight distances at least equal to Case B should be provided, when practical.

Exhibit 6.7.2 Sight Triangles at Skewed Intersections



Source: AASHTO Green Book

Refer to the Green Book, Chapter 9, section titled *Intersection Sight Distance / Effect of Skew* for discussion on these factors.

6.8 – Turning Roadways and Channelization

Turning roadways and channelization are key aspects of intersection design and aid in separating or regulating conflicting traffic movements into definite paths of travel. This aids in orderly movements of motor vehicles, bicyclists, and pedestrians through the intersection.

6.8.1 – Turning Roadways

The widths of turning roadways for intersections are governed by the volumes of turning traffic and the types of vehicles to be accommodated. In most cases, turning roadways are designed for use by right-turning traffic. Widths for right-turning roadways may also be applied to other roadways within an intersection, such as between channelizing islands.

6.8.1.1 – Design Considerations

Where vehicles make right turns from the approach traveled way to the receiving traveled way the corner radius should be based on the minimum turning path of the design vehicle.

In the design of the edge of the traveled way based on the path of a given design vehicle, the vehicle is assumed to be properly positioned within the traffic lane at the beginning and end of the turn.

In most cases, the largest design vehicle likely to use the turning roadway with considerable frequency will be used to determine the design of critical features such as intersection radii and turning roadways. On occasion, a design vehicle with special characteristics will control design. The designer should refer to the Intersection Layout Section earlier in this chapter as well as Chapter 2 and the Green Book, Chapter 9, section titled *Design Considerations* for additional detail regarding design vehicles.

Minimum radii values for intersection curves in consideration of design superelevation rates and design speed for different design vehicles shall conform to the values derived in the Green Book, Chapter 3, Tables 3-8, 3-9, and 3-10.

Design Vehicle Selection

The designer should not only consider the design vehicle for an appropriate turning movement, but also other users such as pedestrians, bicyclists, transit, and freight.

For example, if pedestrians are present, the designer should consider keeping the intersection area to a minimum and allow for an occasional large truck to swing wide and encroach on other lanes.

The design widths of the traveled way for turning roadways are presented in the Green Book, Chapter 3, Tables 3-27 through 3-30 and consider three different traffic conditions:

- Traffic Condition A – consists of primarily P vehicles and an occasional SU-30 vehicle.
- Traffic Condition B – consists of sufficient SU-30 vehicles to govern design and some tractor-semitrailer combination trucks.
- Traffic Condition C – consists of sufficient tractor-semitrailer combination trucks; WB-40 or larger governs design.

6.8.1.2 – Curb Radius

Because of space limitations, pedestrians, and lower operating speeds, curve radii used for turning movements may be smaller in urban areas than in rural areas. Curb radii should be based on the number and types of turning vehicles and pedestrian volumes. In urban areas, parking lanes may influence curb radii.

The Green Book, Chapter 9, sections titled *Turning Roadways and Channelization / Turning Roadways / Design Considerations* and *Turning Roadways and Channelization / Turning Roadways / Curb Radius* provide guidelines for corner radii.

6.8.1.3 – Channelized Right Turn Lanes

A well-designed channelized right-turn lane will improve motor vehicle operations and reduce the potential for crashes at intersections. The designer should consider each of these elements in providing channelized right turn lanes:

- **Crosswalk location**. Placement at the center of the channelized right-turn lane is preferred for yield control or no control; otherwise, it shall be immediately downstream of the stop bar. This promotes consistency for pedestrians with vision disabilities.
- **Island type**. Islands typically serve two or all of these functions: channelization, division of traffic streams, and pedestrian refuge. In urban areas, most islands are raised vertical face or mountable curbs. If a cut-through pedestrian path is provided, it must be ADA compliant as provided in Chapter 13, *Pedestrian Facilities*.
- **Turning roadway radius**. Channelized right turn lanes can accommodate larger turning radii without widening the major street pedestrian crossings and increasing the intersection pavement area. Smaller turning radii are appropriate with higher pedestrian activity in order to promote lower speed right turns.
- **Angle of intersection with cross street**. A flat-angle (typically an equilateral triangle with one curved side) entry design is typically appropriate with limited pedestrian use and higher turning speeds. A nearly right-angle entry design can be used for a stop control or traffic signal control, as it encourages lower turning speeds and promotes greater pedestrian visibility.
- **Deceleration lanes**. Deceleration lanes separate decelerating right-turning from high-speed through lanes. They also can assist in optimization of traffic signal phasing.
- **Acceleration lanes**. These provide an opportunity for vehicles to make a right turn unimpeded by conflicting vehicles and accelerate parallel to cross-street traffic prior to merging. Typically, these should be at a location with no sidewalks or pedestrian crossings as they are difficult for pedestrians to cross, especially those with impaired vision.
- **Pedestrian signals**. Pedestrian signals allow an exclusive right-of-way for pedestrians, especially those with vision impairment. The designer should consider a pedestrian-actuated signal at these locations as well as if accessible pedestrian signals (APS) are warranted.
- **Bicycle lanes**. Bicycle lanes designate an exclusive space for bicyclists using pavement markings and signage. Refer to Chapter 14, *Bicycle Facilities*, for information on bicycle lanes at channelized right turn lanes.

Refer to the Green Book, Chapter 9, section titled *Turning Roadways and Channelization / Turning Roadways / Channelized Right Turn Lanes* for additional design guidance for each of these elements.

6.8.2 – Channelization

Channelization is the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement markings to facilitate the orderly movements of both vehicles and pedestrians. A simple channelization improvement can sometimes result in dramatic operational efficiencies and reduction in crash frequencies. Separation of left-turn movements from through movements, such as left-turn lanes at intersections, reduces the potential for rear-end crashes and provides a comfortable means for making a left turn.

The Green Book, Chapter 9, section titled *Turning Roadways and Channelization / Channelization* identifies the factors and principles that should be considered for channelization of intersections.

Design controls for a channelized intersection include the type of design vehicle, cross sections on the crossroads, projected traffic volumes, pedestrian traffic, bicycle traffic, vehicle speed, bus stop locations and the type and location of traffic control devices. The physical controls such as right-of-way and terrain have an effect on the extent of channelization that is economically practical.

6.8.3 – Islands

An island is a defined area between traffic lanes used to control vehicle movements. Islands generally are either elongated or triangular in shape whose dimensions are dependent on the particular intersection conditions. Islands can be delineated by a raised curb (common in suburban/urban settings) or by delineation such as paint or pavement markings. If curbed, vertical face curb is recommended if the island contains a pedestrian refuge area and mountable curb is recommended if offtracking of trucks is expected. Islands serve three primary functions:

1. Channelization (control and direct traffic movements, usually turning).
2. Division (divide opposing or same-direction traffic streams, usually through movements).
3. Refuge (provide refuge for pedestrians and/or bicyclists).



Division and Refuge Island

For additional information concerning island sizes and designations, delineation, approach-end treatments, and island designs based on turning roadways, refer to the Green Book, Chapter 9, section titled *Turning Roadways and Channelization / Islands*.

6.8.4 – Superelevation for Turning Roadways at Intersections

Superelevation

The designer should consider the effects of superelevated pavements on pedestrian grades and access in urban and suburban areas where pedestrian use is anticipated.

The general factors that control the maximum rates of superelevation, as discussed in Chapter 3, also apply to turning roadways at intersections. When entering or leaving a superelevated curve, the issue of how fast to introduce or remove the superelevation rate arises. In general, the rate of change in cross slope in the runoff section should be based on the maximum relative gradients used in the equation in the Green Book, Chapter 3, section titled *Minimum Length of Superelevation Runoff*. Adjustment factors shown in the table in this same chapter allow for slight increases in the effective gradient for wider rotated widths.

Additional information and figures illustrating the method of developing superelevation at turning roadway terminals are located in the Green Book, Chapter 9, section titled *Turning Roadways and Channelization / Superelevation for Turning Roadways at Intersections / Superelevation Runoff*.

6.8.5 – Stopping Sight Distance at Intersections for Turning Roadways

The Green Book, Chapter 9, section titled *Turning Roadways and Channelization / Stopping Sight Distance at Intersections for Turning Roadways* provides minimum stopping sight distances for both horizontal and vertical alignments for turning roadways with design speeds ranging from 10 mph to 45 mph.

The horizontal and vertical alignments through the intersection should be designed to provide these minimum stopping sight distances at all points along the turning roadway. Refer to the Green Book, Chapter 9, section titled *Turning Roadways and Channelization / Stopping Sight Distance at Intersections for Turning Roadways / Vertical & Horizontal Control* for further discussion.

6.9 – Auxiliary Lanes

An auxiliary lane refers to a lane adjoining the through travel lanes that is provided for turning movements, acceleration, deceleration, weaving and to supplement through-traffic movements.

6.9.1 – Design Considerations

In general, auxiliary lanes are used preceding median openings and are also used at intersections preceding right- and left-turning movements. Auxiliary lanes may also be added to increase capacity and reduce potential for crashes at an intersection. In many cases, an

auxiliary lane may be desirable after completing a right-turn movement to provide for acceleration, maneuvering, and weaving.

To preclude or minimize undue acceleration and deceleration that may arise from conflicts between high speeds on the through roadway and stopped or near-stopped conditions for traffic entering or leaving the through roadway at intersections, auxiliary lanes are provided on highways having expressway characteristics and are frequently used at other intersections on main highways and streets. An auxiliary lane, including the tapered area, serves as a speed-change lane primarily for the acceleration or deceleration of vehicles entering or leaving the through-traffic lanes.

General conclusions and considerations for the use of auxiliary lanes are contained in Publication 46. Refer also to the "Publication 46 Turn Lane Guidelines" Guidance box in Section 6.9.2. For additional information and design guidance relative to auxiliary lanes, including taper rates for lane drops, refer to the Green Book, Chapter 9, section titled *Auxiliary Lanes / General Design Considerations*.

The designer should consult Chapter 14, *Bicycle Facilities*, for bicycle lane considerations at intersections within auxiliary lanes.

Publication 46 Turn Lane Guidelines

The designer should consult Publication 46, *Traffic Engineering Manual*, Chapter 11, for auxiliary lane guidance. Guidelines within Section 11.16, *Turn Lane Guidelines*, includes the following:

- Left turn lane warrants.
- Right turn lane warrants.
- Turn lane storage length.

In addition to the stated warrants, other factors to consider for auxiliary lane use include, but are not limited to, the following:

- Crash history.
- Sight distance.
- Deceleration requirements.
- Type and volume of turning traffic.
- Grades.
- Locations on high-speed multilane highways.
- 85th percentile and safe running speeds.

6.9.2 – Deceleration Lanes

Auxiliary lanes (left turn and right turn lanes) within the upstream functional area of an intersection are treated as deceleration lanes. Deceleration lane length is dependent on the individual lengths of three components: (1) entering taper, (2) deceleration length and (3) storage length. Desirably, the total length of the auxiliary lane should be the sum of the length for these components. General practice is to accept some deceleration in the through lane and to consider the taper length as part of the deceleration within the through lanes.

Refer to the Green Book, Chapter 9, section titled *Auxiliary Lanes / Deceleration Lanes* for discussion on the following components of deceleration lane length:

- Perception-reaction distance.
- Storage length. Publication 46, Section 11.16, *Turn Lane Guidelines*, also provides guidance.

- Taper length.

For deceleration lanes on freeways and expressways, refer to Chapter 7 as well as Green Book, Chapter 10.

6.9.3 – Design Treatments for Left-Turn Maneuvers

Left-turning traffic should be removed from through lanes where practical. Left turn lanes are generally recommended at driveways and at street intersections along major collector roads and arterials wherever left turns are permitted.

Refer to Publication 46, *Traffic Engineering Manual*, Section 11.16, to determine warrants for left turn lanes. These warrants consider the opposing volume, advancing volume, and the percentage of left turns in the advancing volume.

Refer to the Green Book, Chapter 9, section titled *Auxiliary Lanes / Design Treatments for Left-Turn Maneuvers* for discussion on the following elements for left-turn maneuvers:

- Median left-turn lanes.
- Median end treatment.
- Offset left-turn lanes.
- Simultaneous left turns.
- Double and triple left-turn lanes.

Indirect left turn treatments are discussed in Section 6.11.

6.9.4 – Acceleration Lanes

Auxiliary lanes within the downstream functional area of an intersection can provide sufficient distance for vehicles leaving an intersection from a stop to accelerate to normal roadway speed. The total acceleration lane length, including the taper distance, is the required downstream functional distance. Driveway access should not be allowed in the acceleration-based ideal downstream intersection distance.

Refer to the TRB, *Access Management Manual*, Section 14.3.1, for recommended distances based on speed, as well as additional discussion on auxiliary lanes as acceleration lanes.

6.10 – Median Openings

Intersections include median openings to accommodate crossing and turning traffic movements. Median openings should also be provided for U-turns by cars unless restricted.

The designer shall also consider providing openings in medians on Interstates and other freeways or expressways to provide crossovers for use by emergency and other authorized

vehicles.

Median openings are also intended to be used where snow and ice removal equipment to clear interchange ramps would be expedited.

Their use shall conform to the guidelines presented below. Median barrier and end treatments, if required at these locations, shall be constructed as indicated in Publication 72M, *Roadway Construction Standards* (RC's), and Chapter 12. Crossovers on freeways require adequate justification.

6.10.1 – Design Considerations

Factors to consider in median opening design include the following:

- Median width (refer to Chapter 3).
- Location and length of the opening.
- Design of the median ends.
- Character and volume of through and turning traffic.
- Street or block spacing.
- Access classification of the roadway.
- Consistency with traffic signal spacing criteria.

For any three-leg or four-leg intersections, the length of median opening is determined by the widths of the intersecting highways. The minimum opening should be as long as the width of the crossroad traveled way pavement plus shoulders including the width of the median, if provided. In general, median openings longer than 80 ft should be avoided.

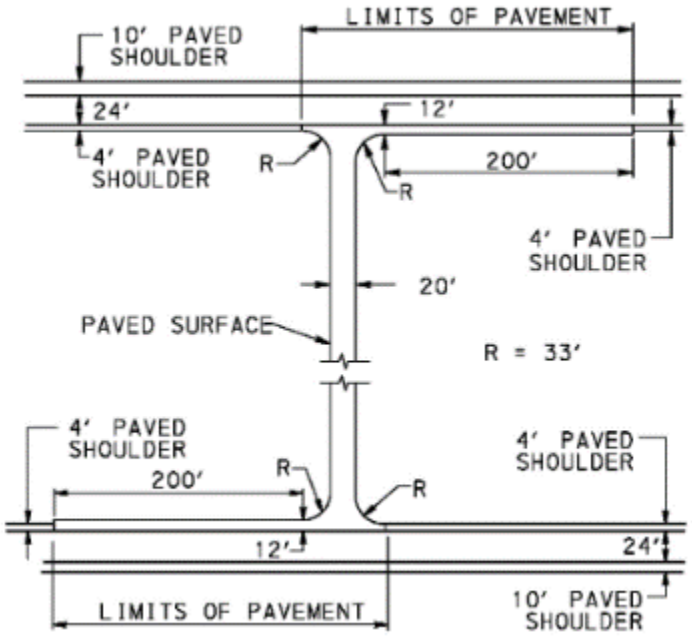
Median crossovers can be used on Interstate and non-Interstate freeways and expressways when the median width is greater than 33 ft. Median crossovers can be located as follows:

- Where the distance between the ends of speed-change tapers for adjacent interchanges is less than 4 miles, one median crossover may be provided. This crossover should be constructed at a suitable location midway between the interchanges, but not closer than 1,500 ft from the end of any speed-change taper or structure. Crossovers should be located only where above-minimum stopping sight distance is provided and preferably should not be located on superelevated curves.
- Where the distance between the ends of speed-change tapers for adjacent interchanges is greater than 4 miles, two or more median crossovers may be provided. These crossovers shall be provided at no less than 3-mile intervals and shall not be constructed closer than 1,500 ft from the end of any speed-change taper or structure.
- One set of dual crossovers may be located at or near a state or county line if the proximity of the nearest interchange or median crossover is greater than 1 mi. The intent of the dual crossovers is to allow for the safe operation of winter maintenance activities,

eliminating the need for winter maintenance vehicles to back up to a crossover after plowing or spreading materials beyond the crossover. If an acceptable location for dual crossovers cannot be established at the state or county line, the pair may be shifted to the nearest acceptable location that has adequate sight distance.

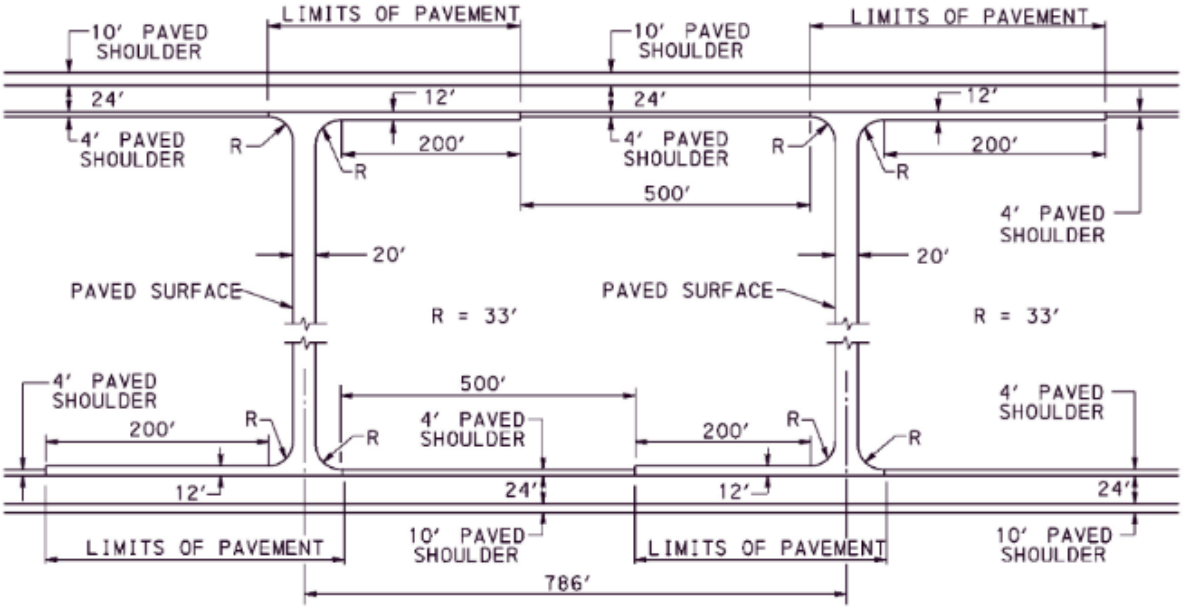
All median crossovers should conform to the typical detail shown in **Exhibit 6.10.1**. They should be constructed with a paved surface, paved shoulders, and deceleration lanes as shown. A typical detail for dual crossovers at or near a state or county line is shown in **Exhibit 6.10.2**.

Exhibit 6.10.1 Typical Median Permanent Crossover



1) The transverse slopes should be 1V:10H or flatter with respect to the crossover pavement. Refer to Chapter 12 for the definition of transverse slopes and when shielding is required.
2) The cross slopes along the mainline should match the minimum and maximum cross slopes shown in Chapter 3, Exhibit 3.8.2.
3) Paved surface shall consist of: the minimum thicknesses for an MFC E roadway as shown in Table 9.4 of Publication 242, or 1.5 in Asphalt Wearing Course on 4 in Roller Compacted Concrete Base Course on 6 in Subbase or 5 in Roller Compacted Concrete Pavement on 6 in Subbase.
4) When concrete shoulders are provided on the mainline, the 4 ft concrete shoulder shall be continued through the deceleration lane and crossover area. The additional 8 ft widening for the deceleration lane and the crossover pavement shall be a paved surface consisting of: the minimum thicknesses for an MFC E roadway as shown in Table 9.4 of Publication 242, or 1.5 in Asphalt Wearing Course on 4 in Roller Compacted Concrete Base Course on 6 in Subbase or 5 in Roller Compacted Concrete Pavement on 6 in Subbase.
5) The dimensions shown in the exhibit are minimum dimensions.

Exhibit 6.10.2 Typical Dual Median Crossovers at State or County Lines



1) The transverse slopes should be 1V:10H or flatter with respect to the crossover pavement. Refer to Chapter 12 for the definition of transverse slopes and when shielding is required.
2) The cross slopes along the mainline should match the minimum and maximum cross slopes shown in Chapter 3, Exhibit 3.8.2.
3) Paved surface shall consist of: the minimum thicknesses for an MFC E roadway as shown in Table 9.4 of Publication 242, or 1.5 in Asphalt Wearing Course on 4 in Roller Compacted Concrete Base Course on 6 in Subbase or 5 in Roller Compacted Concrete Pavement on 6 in Subbase.
4) When concrete shoulders are provided on the mainline, the 4 ft concrete shoulder shall be continued through the deceleration lane and crossover area. The additional 8 ft widening for the deceleration lane and the crossover pavement shall be a paved surface consisting of: the minimum thicknesses for an MFC E roadway as shown in Table 9.4 of Publication 242, or 1.5 in Asphalt Wearing Course on 4 in Roller Compacted Concrete Base Course on 6 in Subbase or 5 in Roller Compacted Concrete Pavement on 6 in Subbase.
5) The dimensions shown in the exhibit are minimum dimensions.

The location of median crossovers should be coordinated with proposed or existing median drainage systems to eliminate exposed pipe end sections that could present an obstacle to errant vehicles. Where cross pipes are deemed necessary, careful thought should be given to providing a safe, hydraulically-efficient drainage system that uses proper drainage appurtenances to eliminate undesirable conditions. The kind, size, and location of the drainage system required is dependent on actual field conditions.

All exposed culvert end sections shall be designed to ensure they can be safely negotiated by

errant vehicles. The ends of the pipe should be sloped to match the side slopes of the crossover. All pipe openings greater than 18 in in diameter should be designed to provide safe traversability by using a grate, longitudinal or transverse bars or a combination thereof. Embankment slopes in the crossover area should be 1V:6H minimum, longitudinally and 1V:12H minimum, transversely (1V:20H desirable), with respect to the crossover pavement. In order to limit usage to emergency and other authorized vehicles, appropriate signing and delineation shall be used (see Traffic Standard TC-8604). When eliminating existing crossovers, proper coordination should be conducted with local emergency management officials to ensure their operations are not significantly impacted.

Refer to the Green Book, Chapter 9, section titled *Median Openings / General Design Considerations* for additional discussion.

6.10.2 – Control Radii for Minimum Turning Paths

An important factor in designing median openings is the path of each design vehicle making a minimum turn at 10 to 15 mph. The Green Book, Chapter 9, section titled *Median Openings / Control Radii for Minimum Turning Paths* discusses the minimum turning paths of various design vehicles and the minimum practical radii for the design of median ends.

The ends of medians at openings may be either a semicircular shape or a bullet nose shape. The appropriate selection of the shape of median end depends on several factors such as median width, driver path, pedestrian refuge, and length of median opening.

General Considerations

The designer should consider the following when evaluating skew:

- An asymmetrical bullet nose has the most positive control and less paved area than other median end types.
- Avoid median openings larger than 80 ft, regardless of the skew.
- Utilize turning path software in choosing the preferred layout.

6.10.3 – Effect of Skew

The designer should study each skewed crossing with turning templates or turning path software in choosing a preferred layout. Considerations in this design should include the skew angle, median width, control radius, pedestrian refuge, sight distance, and shape of median end.

6.10.4 – Higher Speed Left Turns

Above-minimum designs for direct left turns are often appropriate for intersections where through-traffic volumes and speeds are high and left-turn movements are important. At such intersections median openings should be long enough to permit turns without encroachment on adjacent lanes. Longer median openings enable higher speed turns and provide space for vehicle protection while turning or stopping.

The designer should consider median-opening arrangements that depend on the control dimensions (median width, width of crossroad), design vehicle size, and the need for pedestrian refuge.

6.11 – Indirect Left Turns and U-Turns

The various design methods and arrangements to accommodate indirect left-turn and U-turn movements are predicated on the design control dimensions (width of median and width of crossroad or street) and the size of vehicle used for design control.

6.11.1 – Design Considerations

The necessity to turn left or to make a U-turn in urban or heavily developed residential or commercial sectors may create inefficient traffic operations.

Non-traditional intersection design attempts to address design objectives that conventional design cannot achieve. Intersection designs such as jughandle or loop roadways, displaced left-turn intersections, and wide medians with U-turn crossovers, attempt to accomplish the following objectives:

- Design and operations emphasis on arterial corridor through-movements.
- A reduction in the number of traffic signal phases at major intersections and increased green time for the arterial through movements.
- A reduction in the number of vehicular conflict points at intersections.
- Accommodation of pedestrians and bicyclists as appropriate for the project context.

Refer to the Green Book, Chapter 9, section titled *Indirect Left Turns and U-Turns / General Design Considerations* for additional discussion.

6.11.2 – Intersections with Jughandle or Loop Roadways

Jughandles are one-way roadways typically in two quadrants of the intersection that eliminate left-turning traffic from the major roadway. All turns (left, right, U-turn) are made from the right side of the roadway. Jughandles may be appropriate under the following conditions:

- High major-street through movements with low-to-medium left turns from the minor street.
- Intersections too small to allow large vehicles to turn left.
- Intersections with medians too narrow to provide a left turn lane.

Some advantages include the following:

- Less right-of-way may be needed along the roadway in advance of the intersection because left turn lanes are not needed.

- Reduces potential for left-turn collisions.
- Eliminates a traffic signal phase and provides more green time for major street through movements.

Some disadvantages include the following:

- More right-of-way may be needed at the intersection to accommodate the jughandles.
- Longer travel distance for left-turning vehicles.
- Accommodating pedestrians can be challenging.

An alternate to a jughandle roadway in advance of an intersection is to provide a loop roadway beyond the intersection. Some advantages include the following:

- A loop roadway offers an alternative for a scenario where the right-of-way for the far side quadrant is less expensive than the near side quadrant.
- The major street left turn movement becomes a right-turn movement at the far side loop roadway, which results in fewer vehicular conflicts and higher capacity for the left turn movement.

In addition to the disadvantages listed above for a jughandle, this intersection increases the through volume for the intersection and requires vehicles to traverse the intersection twice.

Exhibit 6.11.1 depicts an intersection with both a jughandle and loop roadway.

Exhibit 6.11.1 Example of a Jughandle and Loop Roadway, SR 0309 and SR 2036/SR 2044, Saucon Valley, PA



6.11.3 – Quadrant Roadways

A quadrant roadway intersection is intended to eliminate all direct left-turn movements from the main intersection by rerouting them to turns to and from a connector roadway located in one quadrant. All left turns at the main intersection are prohibited, allowing for a two-phase signal operation at the main intersection.

Quadrant roadway intersections are most applicable under the following conditions:

- A roadway in the road network can be used as a connection roadway.

- Heavy left turns and through volumes exist on both the major and minor roadways.
- The minor road total volume to total intersection volume ratio is less than or equal to 0.35.

A quadrant roadway differs from the loop roadway discussed in Section 6.11.2 as the quadrant roadway accommodates two-way traffic and allows left turns from and to the major street. Left and right turns from the minor street are also allowed onto the quadrant roadway.

The two secondary intersections will require signalization and will usually require three phases. Ideally, the spacing of the secondary intersections are 500 ft or more from the main intersection.

Intersection designs with connecting roadways in two or more quadrants are also possible. Refer to Chapter 5, *Quadrant Roadway Intersection*, in FHWA Publication FHWA-HRT-09-060, *Alternative Intersections/Interchanges: Informational Report (AIIR)* for additional information on quadrant roadways.

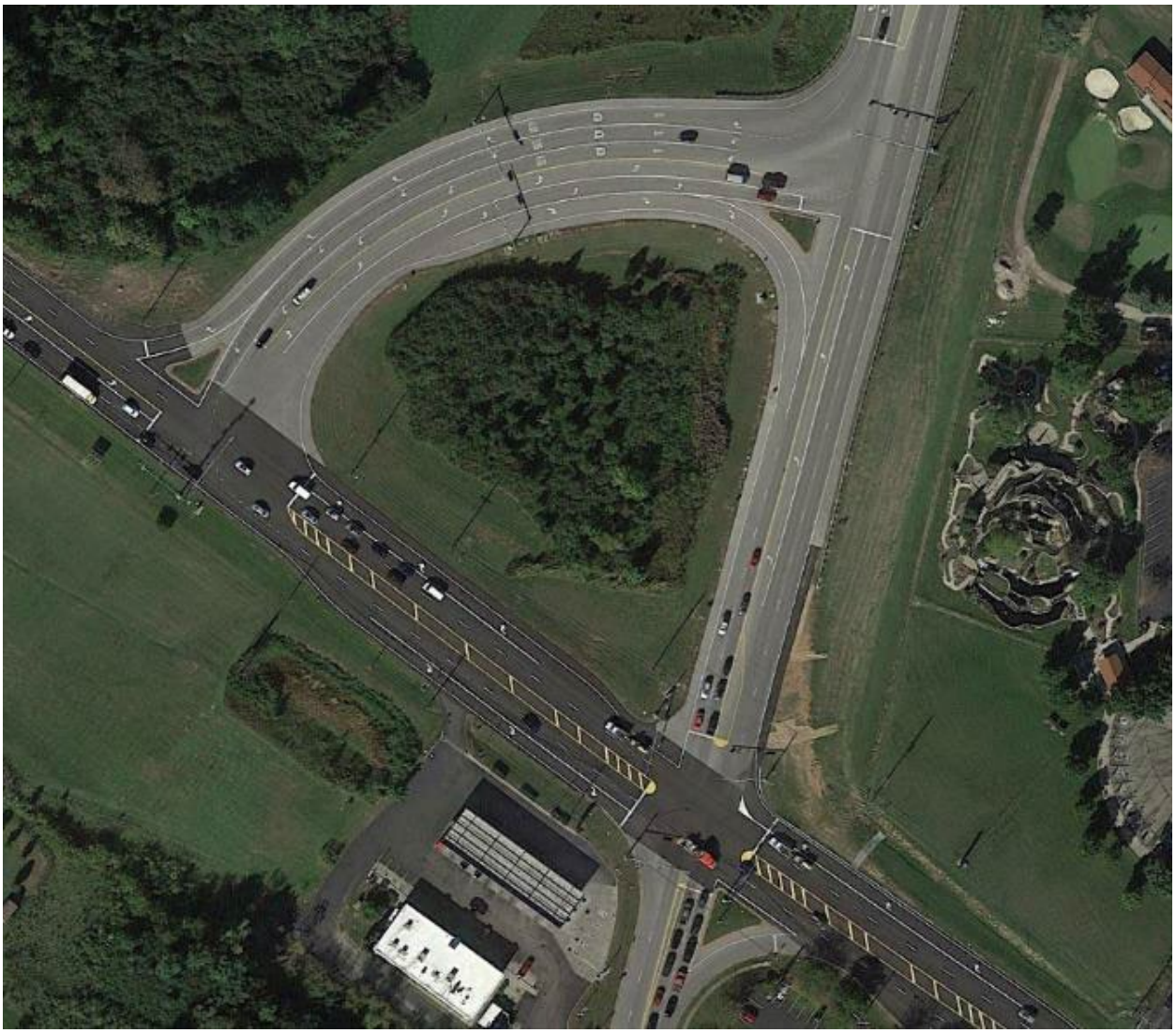
Exhibit 6.11.2 depicts a quadrant roadway intersection.

Quadrant Roadway Pedestrian Considerations

The designer should consider the following for pedestrians at Quadrant Roadway intersections:

- Some pedestrians cross an extra street as compared to a conventional intersection.
- A conflict exists between pedestrians and vehicles within the crosswalk to the left of a quadrant roadway approach unless an exclusive pedestrian phase is provided.

Exhibit 6.11.2 Example of Quadrant Roadway, Route 4 and Route 4 Bypass, Fairfield, Ohio



6.11.4 – Displaced Left Turn Intersections

A Displaced Left Turn (DLT) intersection, also known as a continuous-flow intersection (CFI), relocates the left-turn movement on an approach to the other side of the opposing roadway. A complete DLT intersection operates as a set of two-phase signals and eliminates a left-turn signal phase for each approach at the intersection. **Exhibit 6.11.3** is an example of a DLT intersection.

Traffic that would normally turn left at the main intersection first crosses the opposing through lanes several hundred feet upstream of the main intersection. Left-turning vehicles then travel on a new roadway parallel to the opposing lanes and execute the left-turn maneuver simultaneously with the opposing through traffic at the main intersection. Traffic signals are present at the main intersection and typically at the locations of the left-turn crossovers. The traffic signals are operated in a coordinated manner.

Ideal locations for a DLT intersection have high left-turn and through volumes with low U-turn demand, as they are prohibited with this design. Right-of-way will be required adjacent to the intersection for the left turn roadways.

Pedestrian crossings at DLT intersections are different from conventional intersections because of the position of left-turn lanes between right turn lanes and opposing through lanes. Crosswalk distances at these intersections are similar to those of large conventional intersections with channelized right turns. Providing pedestrian refuge islands, as seen in Exhibit 6.11.3, is desirable. The designer can refer to Chapter 13 for guidance on pedestrian refuge islands. Pedestrian crossings can either be one or two stages depending on the placement of refuge locations and signal operations.

Exhibit 6.11.3 Example of a Displaced Left Turn Intersection, SR 741 and Austin Pike, Dayton, OH



FHWA, *Displaced Left Turn Intersection Information Guide*, August 2014, should be used for vehicle, pedestrian, and bicyclist guidance. Refer also to the Green Book, Chapter 9, section titled *Indirect left Turns and U-Turns / Displaced Left-Turn Intersections*.

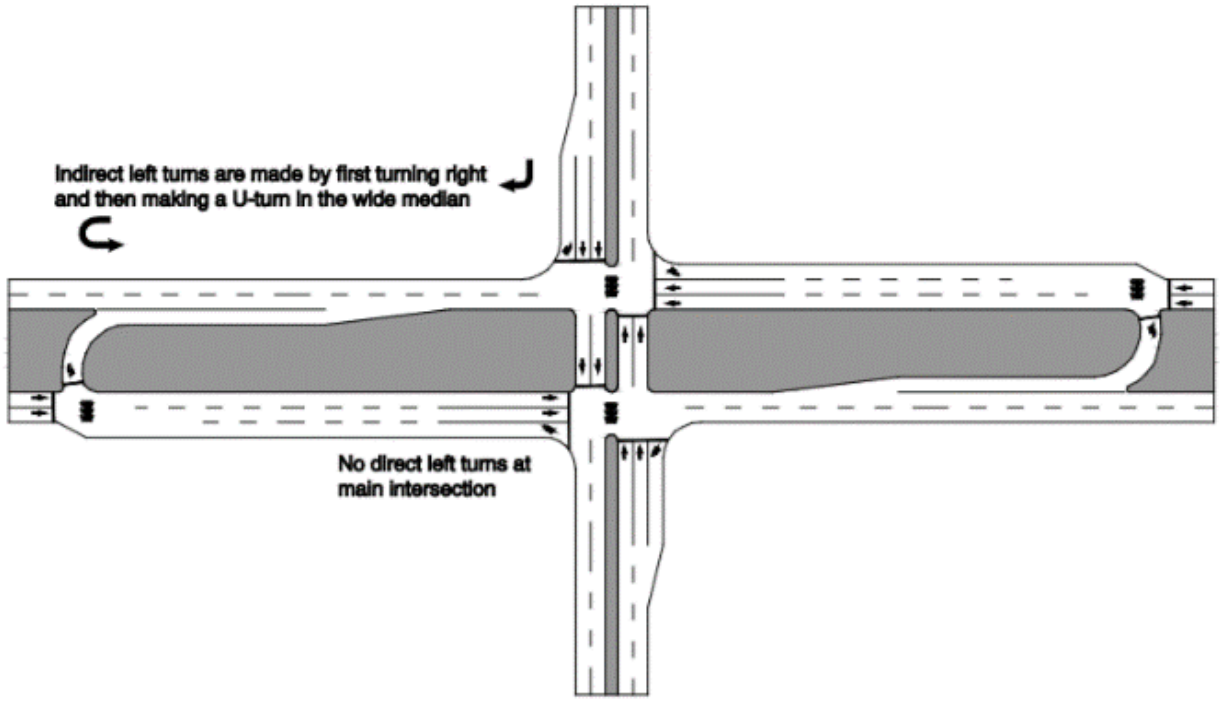
6.11.5 – U-Turn Crossover Roadways

A Median U-turn (MUT) intersection can be used to improve operations and achieve fewer conflict points at a major intersection. At a MUT intersection, left turns are not allowed from the major street approaches. Major street motorists turning left must first proceed through the intersection and make a U-turn at a location several hundred feet downstream of the major intersection. These motorists then head back toward the intersection and execute a right turn onto the side road to complete the "left turn." This type of treatment is most effective on boulevard type streets with wide medians.

The MUT intersection can be classified as either a partial MUT intersection or a full MUT intersection. At a partial MUT intersection, the side road approaches operate in a manner similar to the side road approaches at conventional intersections. Specifically, left-turn movements can be made directly from left-turn lanes on the side road approaches. For partial MUT intersections, left turns from the major road at the intersection with the crossing side road are prohibited. A partial MUT intersection requires three phases at the major intersection. At a full MUT intersection, no left turns are permitted from either the major road or the intersecting side road and a two-phase signal operation is achieved at the major intersection.

There are many variations on the MUT intersection. **Exhibit 6.11.4** provides a depiction of a full MUT intersection:

Exhibit 6.11.4 Typical Full Median U-Turn (MUT) Intersection

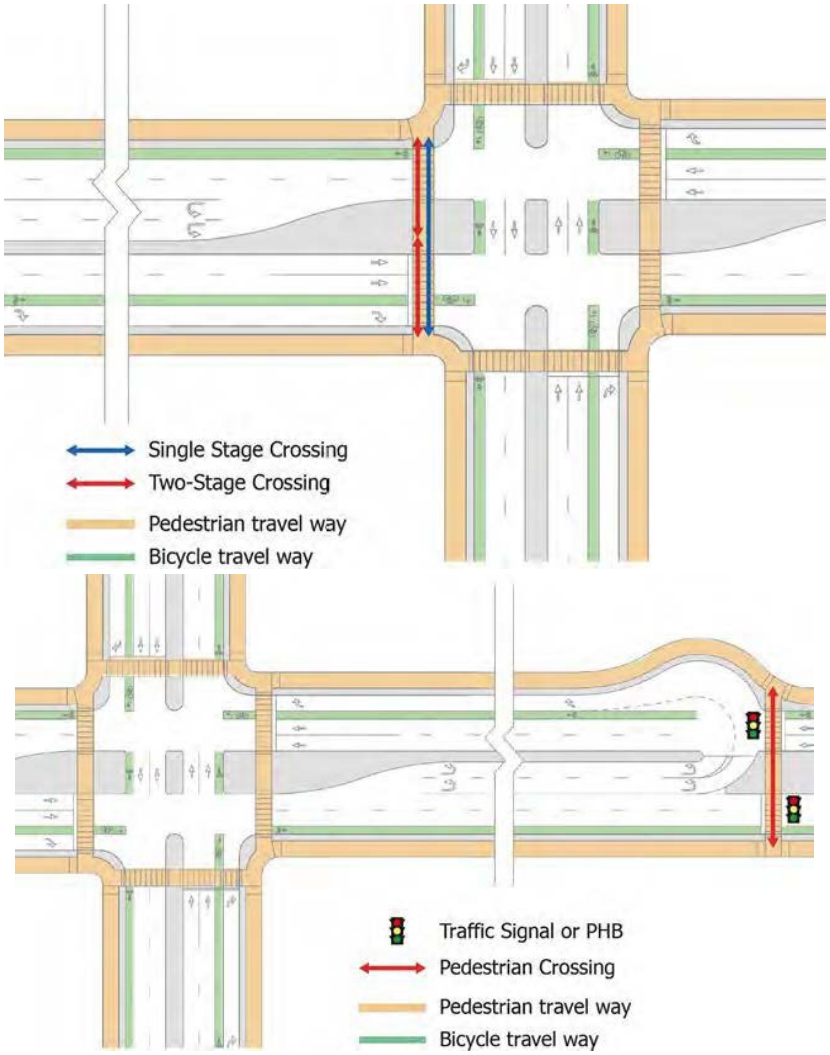


Source: FHWA Median U-Turn Intersection Informational Guide

Pedestrians can cross at the main MUT intersection and potentially at each of the U-turn

crossover locations, as shown in **Exhibit 6.11.5.** The location of pedestrian crossings at the main MUT intersection is essentially the same as a conventional intersection. These crossings can either be a one or two-stage operation.

Exhibit 6.11.5 Pedestrian Crossing at a MUT Intersection and U-Turn Crossover Location



Source: NCHRP Research Report 948

Note that right turning traffic volumes are higher at an MUT intersection than at an equivalent conventional intersection. This can create operational or safety challenges for pedestrians, bicyclists, and motor vehicles. The designer should consider reviewing Chapter 6 in NCHRP Research Report 948 for additional guidance regarding bicyclists and pedestrians at an MUT intersection.

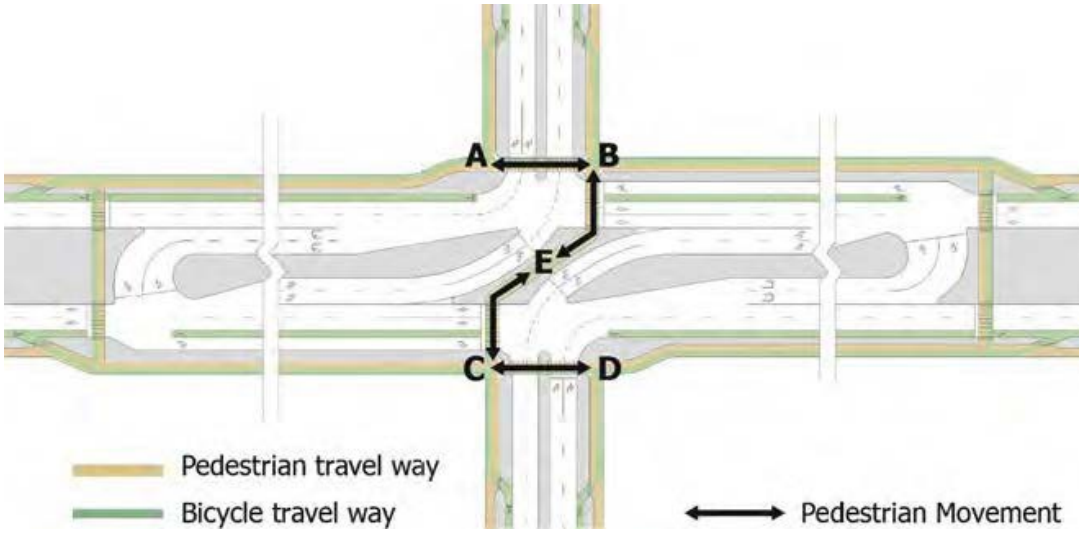
FHWA's *Median U-Turn Intersection Information Guide*, August 2014 should be used for guidance as well as the Green Book, Chapter 9, section titled *Indirect Left Turns and U-Turns / Wide Medians with U-Turn Crossover Roadways* for additional discussion and examples.

The Restricted Crossing U-turn (RCUT) intersection, also known as a Superstreet or a J-turn intersection, is similar to the full MUT intersection treatment in that left-turning traffic from the minor-road approach must first turn right and then execute a U-turn maneuver downstream. The distinguishing characteristic is that the through and left-turn maneuvers are not allowed from the side road. Rather, all of this traffic approaching the major road on the side road must first turn right onto the major road, travel a short distance downstream on the major road, and then make a U-turn on the major road. Drivers on the side street who want to go through on the side road can then make a right turn from the major roadway onto the side road. While conventional intersections can be converted to RCUT intersections at individual spot locations, the RCUT intersection treatment is more applicable as a treatment applied to arterial segments.

With the RCUT intersection, left turns from the major arterial are still permitted at the crossroad similar to a conventional intersection. This treatment is typically implemented where left-turn volumes and side road volumes are relatively low. The benefit of the RCUT intersection is that it allows the major arterial through traffic to proceed without stopping for traffic signal control.

Pedestrians can cross at the main RCUT intersection and potentially at each of the U-turn crossover locations. **Exhibit 6.11.6** focuses on the pedestrian crossing at the main RCUT intersection. The pedestrian crossing at the main RCUT intersection differs substantially from a conventional intersection. While its wide geometric footprint can be a challenge for accommodating pedestrians, the typical short cycle lengths associated within RCUT intersections can help make these pedestrian crossing times more comparable to those at a conventional intersection. The pedestrian crossing path shown in Exhibit 6.11.6 is one example of crossing the RCUT intersection. The designer is encouraged to refer to Section 7.4 of NCHRP Research Report 948 for additional pedestrian crossing configurations.

Exhibit 6.11.6 Pedestrian Crossing at an RCUT Intersection



Source: NCHRP Research Report 948

Note that right turning traffic volumes are higher at a RCUT intersection than at an equivalent conventional intersection. This can create operational or safety challenges for pedestrians,

bicyclists, and motor vehicles. The designer should consider reviewing Chapter 6 in NCHRP Research Report 948 for additional guidance regarding bicyclists and pedestrians at an RCUT intersection.

FHWA published the *Restricted Crossing U-Turn Intersection Information Guide* in August 2014 which should be used for guidance as well as the Green Book, Chapter 9, section titled *Indirect Left-Turns and U-Turns / Wide Medians with U-Turn Crossover Roadways* for additional discussion and examples. **Exhibit 6.11.7** is an example of a RCUT intersection.

Exhibit 6.11.7 Example of an RCUT Intersection, Highway 9 and Liberty Church Road, South Carolina



6.11.6 – Location and Design of U-Turn Median Openings

On some divided roadways, additional median openings are needed to separate vehicles solely making U-turns from other openings which accommodate cross and left-turning movements. The Green Book, Chapter 9, section titled *Indirect Left Turns and U-Turns / Location and Design of U-Turn Median Openings* provides discussion on the following topics:

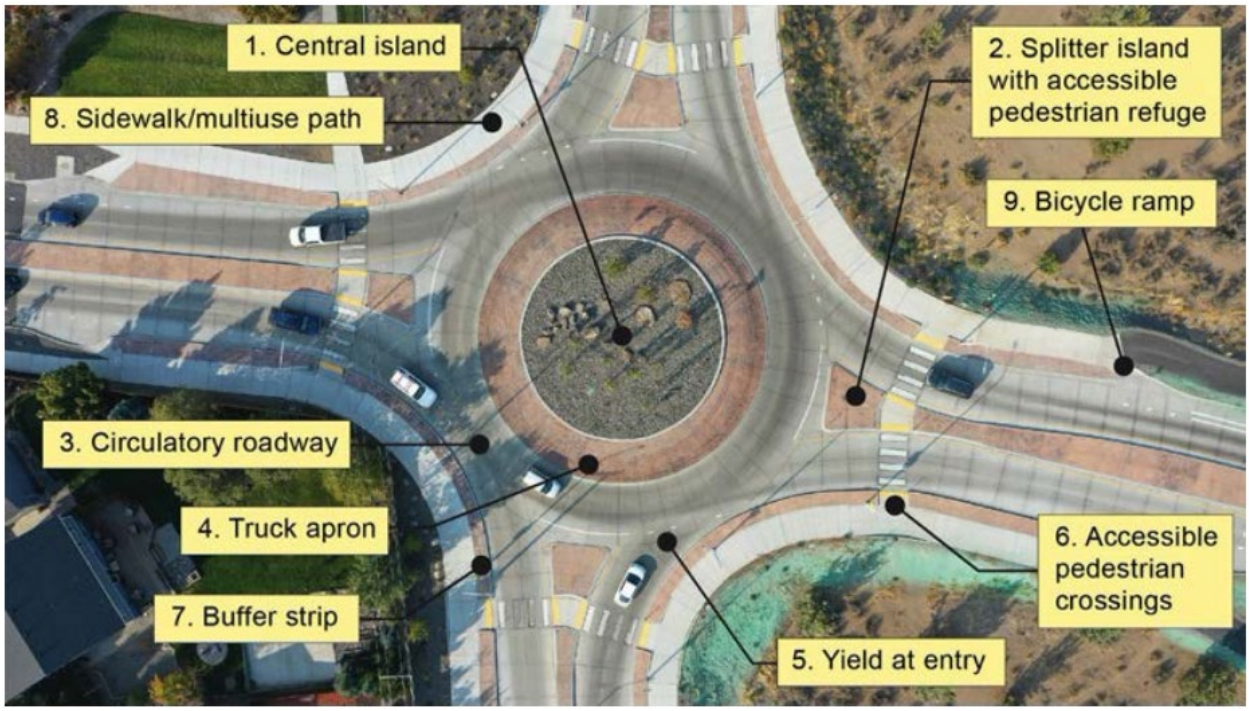
- Locations to consider U-turn median openings.
- Spacing between U-turn openings.

- Minimum median widths to permit U-turns by design vehicle.
- Use of loons where right-of-way is restricted.
- Special U-turn designs for narrow medians.

6.12 – Roundabouts

A roundabout is a form of circular intersection in which traffic travels counterclockwise around a central island and in which entering traffic must yield to circulating traffic. Modern roundabouts "roundabouts" are distinctly different from other forms of circular intersections (rotaries, signalized traffic circles, etc.). **Exhibit 6.12.1** illustrates the common characteristics of a modern roundabout.

Exhibit 6.12.1 Common Roundabout Characteristics



Modern roundabouts have demonstrated safety and operational benefits and they commonly offer several advantages over signalized and stop controlled alternatives, including better overall safety performance, shorter delays, shorter queues (particularly during off-peak periods), better management of speeds, and opportunities for community enhancement.

This section is not intended to comprehensively cover the design of roundabouts, but it is intended to cover many of the key principles related to roundabout design. For detailed guidance, refer to the National Cooperative Highway Research Program (NCHRP) Research Report 1043, *Guide for Roundabouts*. However, any non-geometric guidance in NCHRP 1043

that conflicts with PennDOT policies are not to be applied including but not limited to the following:

- Planning and public involvement guidance that conflicts with PennDOT's guidance.
- Project development process guidance that conflicts with PennDOT's guidance.
- Applicability and use of the Intersection Control Evaluation (ICE) process that conflicts with Publication 10X, DM-1X, Appendix AI.
- Use of analysis software that does not comply with Publication 46, Chapter 12.
- Use of Pedestrian Hybrid Beacons as PennDOT does not allow their use.
- Tactile Walking Surface Indicators (TWSI's) other than Detectable Warning Surface (DWS), should not be used until the U.S. Access Board has provided guidance regarding their use.

Other roundabout guidance includes the *Highway Capacity Manual* and the MUTCD.

6.12.1 – Types of Roundabouts

Roundabouts are classified by the common types listed below; however, they do not always fit neatly into these categories. They may combine features from various types.

- **Mini-Roundabouts.** Mini-roundabouts may be appropriate at physically constrained intersections to help improve safety and reduce delays. They are typically characterized by a small diameter and traversable central island and are best suited to environments where speeds are already low and constraints would preclude the use of a larger roundabout with a raised central island.

  Since mini-roundabouts are rarely constructed on state roadways, they are not elaborated on in this Chapter. Refer to NCHRP 1043 for more information. **Exhibit 6.12.2** illustrates a photo of a mini-roundabout.

Exhibit 6.12.2 Mini-Roundabout in Chadds Ford Township, PA



- **Compact Roundabouts.** Compact roundabouts combine features of mini- and single-lane roundabouts. They are typically used in low-speed contexts as entry and exit flaring is usually less than required for typical single-lane roundabouts and the central island may be traversable or partially traversable.

- **Single-Lane Roundabouts.** Single-lane roundabouts are by far the most common type of roundabout constructed in Pennsylvania and across the country. **Exhibit 6.12.3** illustrates a photo of a modern single-lane roundabout.

Exhibit 6.12.3 Single-Lane Roundabout in Swarthmore, PA



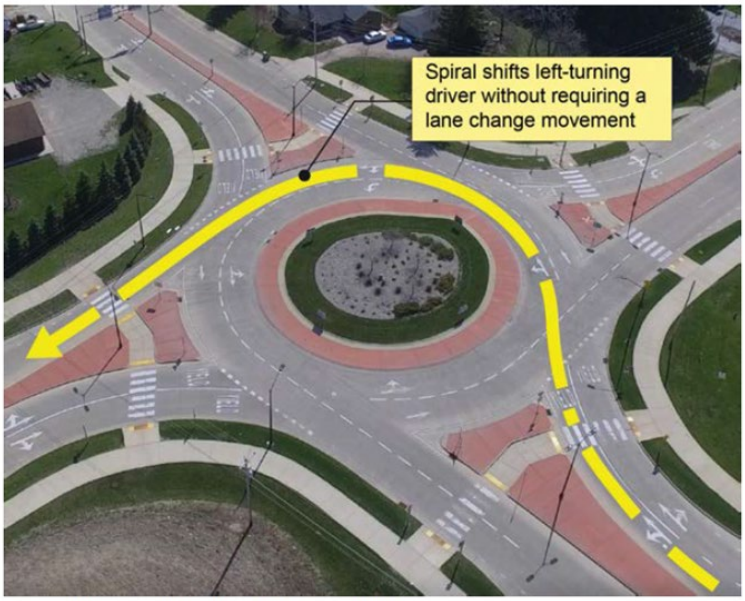
- **Multilane Roundabouts.** Multilane roundabouts consist of two or more circulating lanes in at least a portion of the circulatory roadway. Full multilane roundabouts have 2 or more lanes on the entire circulating roadway and require a high level of design scrutiny primarily because of the potential for crossover crashes within the circulating roadway.
    - **Multilane Hybrid Roundabouts**. Roundabouts which have a mix between one lane and multilane circulating lanes are considered a type of multilane hybrid roundabout. Hybrid roundabouts with 2 lanes on the major through movement and 1 lane on the minor side roads are commonly referred to as 2x1 hybrid roundabouts. **Exhibit 6.12.4** illustrates a photo of a 2x1 hybrid roundabout.

Exhibit 6.12.4 2x1 Hybrid Multilane Roundabout in Richmond Township, PA



    - **Spiraling Multilane Roundabouts**. A spiral is a circulating lane alignment for some multilane roundabout configurations. It can effectively shift vehicles from the inside circulating lane to the outside circulating lane without the vehicles needing to change lanes. In certain situations, this may prevent vehicles from becoming trapped in the inside circulatory lane or needing to change lanes in the circulatory roadway. **Exhibit 6.12.5** illustrates a spiral multilane roundabout. Refer to NCHRP 1043, Section 2.3.4 and NCHRP 1043, Exhibit 2.21.

Exhibit 6.12.5 Example of Multilane Roundabout with Spiraling



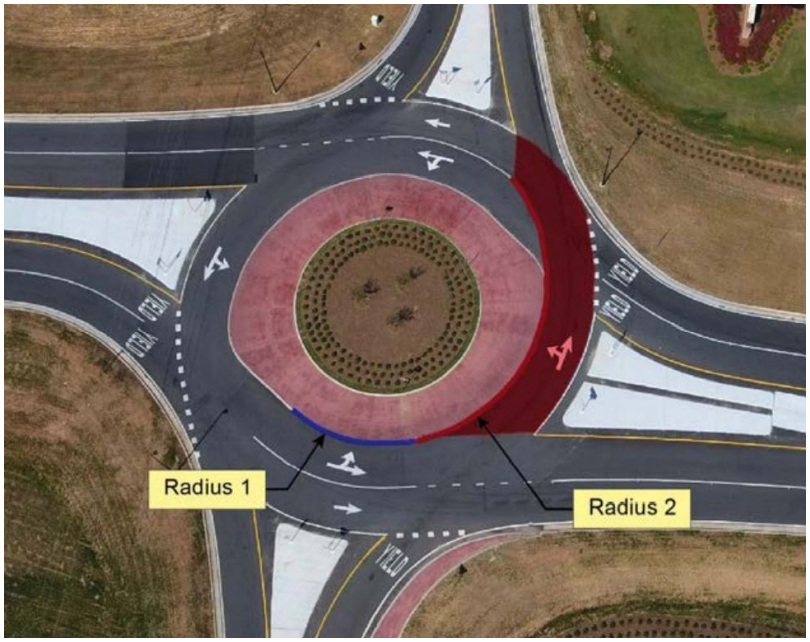
SOURCE: Wisconsin Department of Transportation.

Spirals are commonly used in the following situations:

- One or more entries require exclusive left-turn lanes.
- A combination of entering and exiting lanes requires a spiral to maintain lane continuity.
- A circulating driver must shift to the outside lane when transitioning from single-lane to multilane portions of the circulatory roadway.
- A 2x1 multilane design and similar configurations to improve the likelihood of entering drivers in the outside lane yielding at entry.

Exhibit 6.12.6 (see also NCHRP 1043, Exhibit 10.73) shows a 2x1 spiraling multilane roundabout. Radius 1 is the original circle radius, and Radius 2 provides the spiral. The combination of Radius 1 and Radius 2 is a compound curve, not a true spiral with a continuously variable radius. However, when Radius 1 and Radius 2 are sufficiently similar, the net effect is to create a smooth path to help circulating drivers shift to the outside circulating lane and to reduce the likelihood of entering drivers in the outside lane from entering next to a circulating vehicle. Refer to NCHRP 1043, Section 10.7.7.

Exhibit 6.12.6 Spiraling 2x1 Multilane Hybrid Roundabout



- **Multilane Turbo Roundabouts.** Turbos have recently been introduced to the United States. These have spiral road geometry and physical channelization to maintain driver lane discipline in the circulatory roadway. Spiraling and raised, mountable or flush lane dividers, as well as solid pavement markings are used to eliminate lane changes within the roundabout. Refer to NCHRP 1043 Chapter 10.7.8 and NCHRP 1043 Chapter 2.3.4 for more information.

  The designer should also refer to the FHWA publication *Advancing Turbo Roundabouts* in the United States: Synthesis Report (FHWA-SA-19-027) for the design of a turbo roundabout.

Pros and Cons of Turbo Roundabouts

Advantages:

- Fewer conflict points (14) when compared to a traditional multilane roundabout (24) with 4 legs.
- Mountable raised lane dividers discourage lane changing and maintains lane discipline within the circulatory roadway and roundabout.

Disadvantages:

- Little data on effectiveness in the United States due to limited implementation.
- Mountable raised lane dividers cause issues with snow plowing.

Exhibit 6.12.7 summarizes and compares some fundamental design and operational elements for each of the three roundabout categories. This table is also in NCHRP 1043 as Exhibit 2.9.

Exhibit 6.12.7 Roundabout Category Comparison

Roundabout Feature	Mini-Roundabout	Compact Roundabout	Single-Lane Roundabout	Multilane Roundabout
Center Island	Traversable	May be traversable	Non-traversable, but typically includes truck apron	Non-traversable, but typically includes truck apron
Splitter Islands	May be traversable with one-stage pedestrian crossing	May be traversable with one-stage pedestrian crossing	Non-traversable with one-stage or two-stage pedestrian crossing, depending on dimensions of pedestrian refuge	Non-traversable with two-stage pedestrian crossing
Common Inscribed Circle Diameter (ICD) range*	45 ft to 90 ft	65 ft to 120 ft	90 ft to 180 ft	150 ft to 200 ft
Maximum number of circulating lanes conflicting with each entry	1	1	1	2+

*ICD is measured to the outer edge of the traveled way of the circulatory roadway. These values are not to be used as design constraints or targets.

6.12.2 – Operational Analysis

From a capacity standpoint, in comparison to a similarly sized signalized intersection, a roundabout typically carries about 30% more vehicles during peak flow conditions. During off-peak conditions, roundabouts cause almost no delay, while a signalized intersection can cause delay on side streets and at left-turning traffic from the major street. The increased capacity at a roundabout is due to its continuously flowing nature, with yields only until a gap is available.

When projected traffic volumes indicate that a multilane roundabout is required for the design year, the duration of time that a single-lane roundabout can be expected to operate acceptably should be estimated. Consideration should be given to first constructing a single-lane roundabout where it is expected to be sufficient for ten years or more from the date the roundabout would open to traffic. Refer to Section 6.12.4.g. for more information on interim and ultimate configurations.

For further information on roundabout operations refer to NCHRP 1043, Chapter 8.

Common Operational Analysis Pitfalls

The following items in the initial roundabout analysis can lead to impractical / more expensive designs:

- **Traffic Forecasts** - Traffic forecasts that overestimate traffic growth and indicate more lanes will be needed too soon.
- **Conservative Capacity Models** - Capacity models that are very "conservative" and indicate failure of a single-lane design sooner than actual Design Life.
- **Considering Peak Hour Traffic Only** - Operational analysis based solely on Peak Hour traffic.

Exhibit 6.12.8 (from NCHRP 1043, Exhibit 8.2) presents typical ranges of AADT volumes to identify scenarios under which single-lane and two-lane roundabouts may perform adequately.

Exhibit 6.12.8 Planning-Level Daily Intersection Volumes

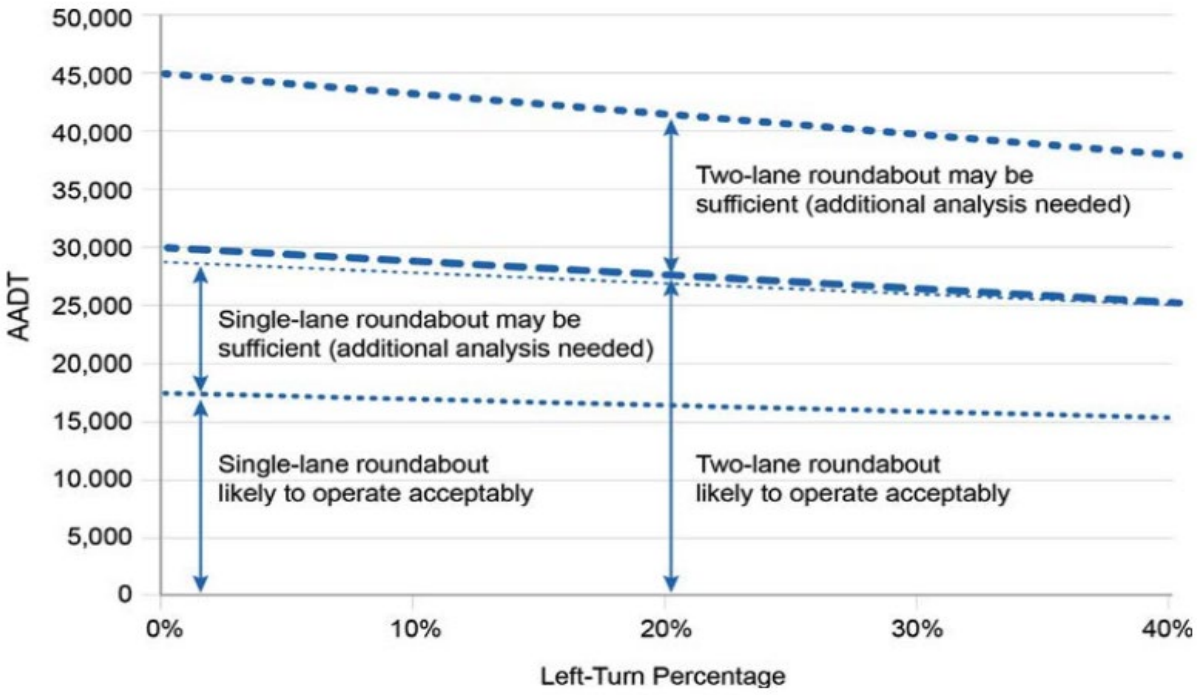
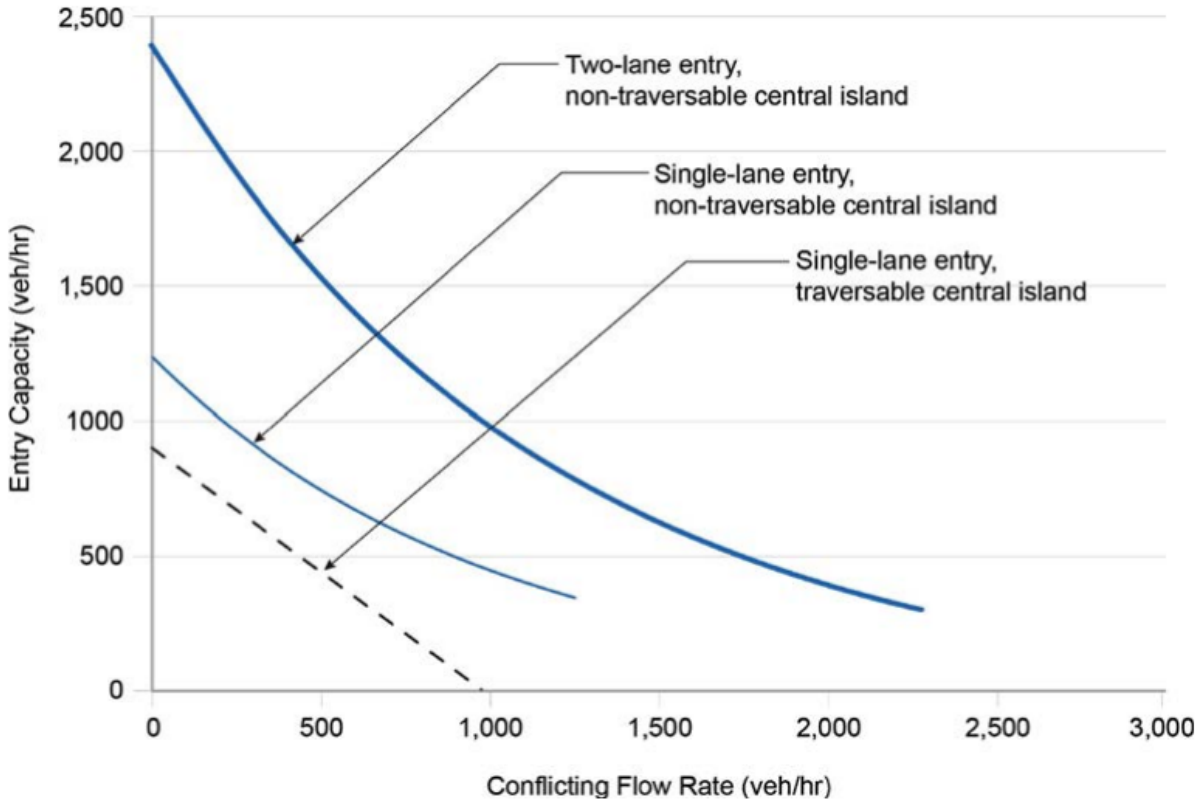


Exhibit 6.12.9 (from NCHRP 1043, Exhibit 8.5) presents typical ranges of entry capacity to conflicting flow rates to determine how many entry lanes are needed.

Exhibit 6.12.9 Planning-Level Capacity Estimates



NOTE: Practical capacity is assumed to be 90 percent of maximum capacity. Conclusions not valid at planning level for conflicting flow rates above 1,250 veh/hr for a single-lane circulatory roadway and 2,300 veh/hr for a two-lane circulatory roadway. Values beyond these practical limits may be possible, but further analysis is recommended. SOURCE: Derived from HCM (*1*) and Lochrane et al. (*9*).

Exhibit 6.12.10 (from NCHRP 1043, Exhibit 8.6) presents the type of roundabout that best fits a range of vehicles per day.

Exhibit 6.12.10 Planning-Level Sizing Guide

Sum of Peak Period Entering and Conflicting Flows (veh/hr)	Type of Roundabout and Number of Lanes
700 or less	Single-lane roundabout with traversable or non-traversable central island is likely sufficient
701 to 900	Single-lane roundabout with non-traversable central island is likely sufficient; single-lane roundabout with traversable central island may be sufficient
901 to 1,300	Single-lane roundabout with non-traversable central island may be sufficient
1,301 to 1,600	Two-lane entry into multilane roundabout is likely sufficient; detailed turning movement analysis recommended
1,601 to 2,300	Two-lane entry into multilane roundabout may be sufficient; detailed turning movement analysis recommended
Greater than 2,300	Three-lane entry into multilane roundabout may be sufficient; detailed turning movement analysis recommended

6.12.2.a – Capacity Performance Measures

Performance measures can be determined from operational analysis methods. Listed are performance measures for roundabouts:

- **Volume-to-capacity ratio.** Volume-to-capacity (v/c) ratios in the range of 0.85 to 0.90 represent an approximate threshold for satisfactory operation. When the degree of saturation exceeds this range, the roundabout's operation enters a more unstable range in which conditions could deteriorate rapidly, particularly over short periods of time. Building to a v/c ratio of 0.85, particularly for a design year of 20 years, often results in more lanes being added to a roundabout than may be necessary or appropriate for the context. A v/c ratio of 0.85 need not be considered an absolute threshold.
- **Delay.** For comparison of roundabouts with other intersection types, it may be useful to compute the average control delay by approach or by intersection. The control delay for an approach is calculated by computing an average of the delay for each lane on the approach, weighted by the volume in each lane. Similarly, the control delay for the intersection is calculated by computing a weighted average of the delay for each approach.
    - Geometric delay is the additional time a single vehicle with no conflicting flows spends slowing down to the negotiation speed, proceeding through the intersection, and accelerating to a normal operating speed. The HCM considers geometric delay in its estimates of corridor travel time but does not calculate it for individual intersection analyses.

- **Travel time.** Travel time captures broader system effects, including potential out-of-direction travel time (called extra distance travel time in the HCM). It is also useful in comparing a series of roundabouts with a series of other intersections, comparing roundabouts and other simple intersection forms with alternative intersection forms that include the indirect left-turn movements, such as median U-turn intersections, restricted crossing U-turn intersections, and other at-grade forms, and comparing roundabouts with other simple intersection forms with grade separations or interchanges.
- **Queue length.** Queue lengths need to be considered when assessing the adequacy of a geometric design. Queues at roundabouts tend to move continuously, unlike signalized intersections, and tend to be shorter than stop-controlled movements. If queues in adjacent lanes exceed available storage, the queue in the subject lane may be longer than anticipated because of additional queueing from the adjacent lane. If queues in the subject lane exceed the available storage for adjacent lanes, the adjacent lane may be starved by the queue in the subject lane.
- **Level of Service (LOS).** The HCM defines LOS for motor vehicles using control delay, with LOS F assigned if the v/c ratio of a lane exceeds 1.0, regardless of the control delay. For assessment of LOS at the approach and intersection levels, LOS is based solely on control delay. The HCM uses the same LOS thresholds for roundabouts as for other unsignalized intersections, rather than the LOS thresholds for signalized intersections.

6.12.2.b – HCM Techniques

The HCM allows for the evaluation of existing or planned single-lane and multilane roundabouts with up to two circulating lanes. It analyzes the performance of each entry lane, accounting for lane-use differences and different observed capacities. It also includes models for the estimated performance of yield-controlled right-turn bypass lanes. The HCM does not have analytical models for other types of bypass lanes that merge at a low angle with exiting traffic or from a new lane adjacent to exiting traffic (non-yielding bypass lane).

For performance measures, the HCM estimates the volume-to-capacity ratio, the control delay, and the 95th percentile queue on a lane-by-lane basis and assigns a LOS for each lane based on the control delay of that lane. The HCM also estimates control delay and LOS aggregated to the approach level and the intersection level. For corridor segments that have roundabouts, the HCM estimates travel time.

Refer to Publication 46, *Traffic Engineers Manual*, Chapter 12, for other approved analysis software.

6.12.3 – Performance Checks

Roundabout design follows a principles-based and performance-based design process. This process is focused on achieving and balancing several key objectives.

Geometrically restricting vehicle speeds to an appropriate fastest path (typically around 25 mph) is critical in designing roundabouts. There is often a tradeoff in balancing an acceptable fastest path and accommodating large vehicles.

The principles and objectives of the geometric design of roundabouts are achieved using the general design process shown in NCHRP 1043, Chapter 9. In particular, performance checks are an important element of the design process:

- Fastest Vehicle Path.
- Vehicle Path Alignment.
- Sight Distances.
- Design Vehicles.
- Oversize and Overweight.
- Truck At Multilane Roundabouts.
- Straddle vs Stay-in-lane.

6.12.3.a – Fastest Vehicle Path

Fastest vehicle paths are evaluated to estimate the maximum speeds that a vehicle can travel through a roundabout that is unconstrained by anything but the geometry. The speeds predicted are higher than the average speeds because drivers react to other vehicles and traffic control devices. The fastest paths can reasonably represent anticipated 85th percentile speeds for free-flowing vehicles.

Information on how to develop a fastest vehicle path can be found in NCHRP 1043, Section 9.4.2 and NCHRP 1043, Appendix A.1

6.12.3.b – Sight Distances

The visibility of the roundabout as a driver approaches the intersection includes the sight distance for viewing pedestrians or other users at the crosswalk and vehicles already operating withing the roundabout. The types of sight distance that designers need to check include:

- Stopping sight distance.
- Intersection sight distance.
- Decision sight distance.
- View angle.

Information on how to calculate sight distance can be found in NCHRP 1043, Section 9.5 and NCHRP 1043, Appendix A.2.

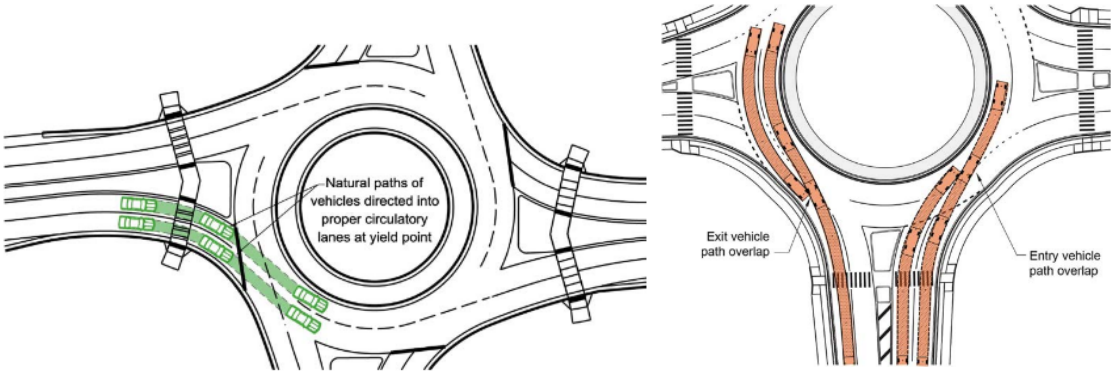
6.12.3.c – Path Alignment

Vehicle path alignment is a specific performance check that applies to multilane roundabouts. The natural vehicle paths are the paths approaching vehicles will take through the roundabout geometry.

The most common type of poor vehicle path alignment is when vehicles in the right entry lane are naturally aligned into the left circulating lane. Drivers need to be aligned with the correct circulating lane.

Exhibit 6.12.11 displays proper path alignment and poor path alignment. For more information, refer to NCHRP 1043, Section 9.6 and NCHRP 1043, Appendix A.3.

Exhibit 6.12.11 Path Alignment Configurations



6.12.3.d – Design Vehicle

A key element for roundabout performance checks is determining the design vehicle. The roundabout geometry should accommodate the swept path of the design vehicle tires and body and should be evaluated using a CAD-based vehicle turning path program for each of the turning movements. Additionally, as with other intersections, the same design vehicle does not need to be applied to all legs. Refer to Section 2.3, *Design Vehicle and Control Vehicle Selection*, and Chapter 16, *Freight*, for additional guidance.

6.12.3.e – Oversize and Overweight (OSOW) Vehicles

OSOW including large farm equipment may be challenging to accommodate. Accommodating may involve the use of removable signs, traversable splitter and central island, mountable curbing, etc. Although oversize vehicles can usually be accommodated for infrequent use, locations that frequently accommodate them, may not be optimal locations for a roundabout, especially a single-lane roundabout. OSOW vehicles may be considered as a control vehicle as

per Section 2.3.

The designer should check 3 to 5 years of Automated Permitting Routing and Analysis System (APRAS) history to determine OSOW history and should evaluate any potential new OSOW needs.

6.12.3.f – Trucks at Multilane Roundabouts

Multilane roundabouts should typically be designed with the expectation that trucks will straddle the lanes as they approach, enter, circulate, and exit the intersection. Studies have shown that even when roundabouts are designed to accommodate trucks within the lanes, they typically straddle the lanes anyway to avoid having vehicles beside them while traversing the roundabouts.

For locations with high truck volumes, consideration should be given to accommodating trucks within their own lane when approaching and entering the roundabout. Only in rare situations should the roundabout be designed to accommodate trucks entirely within a lane for entry, circulation, and exit.

6.12.4 – Horizontal Alignment and Design

Roundabout safety and operational performance depend on practitioners attaining geometrics that reduce vehicle speeds and create smooth transitions for vehicles between successive geometric elements approaching, entering, circulating, and exiting the roundabout.

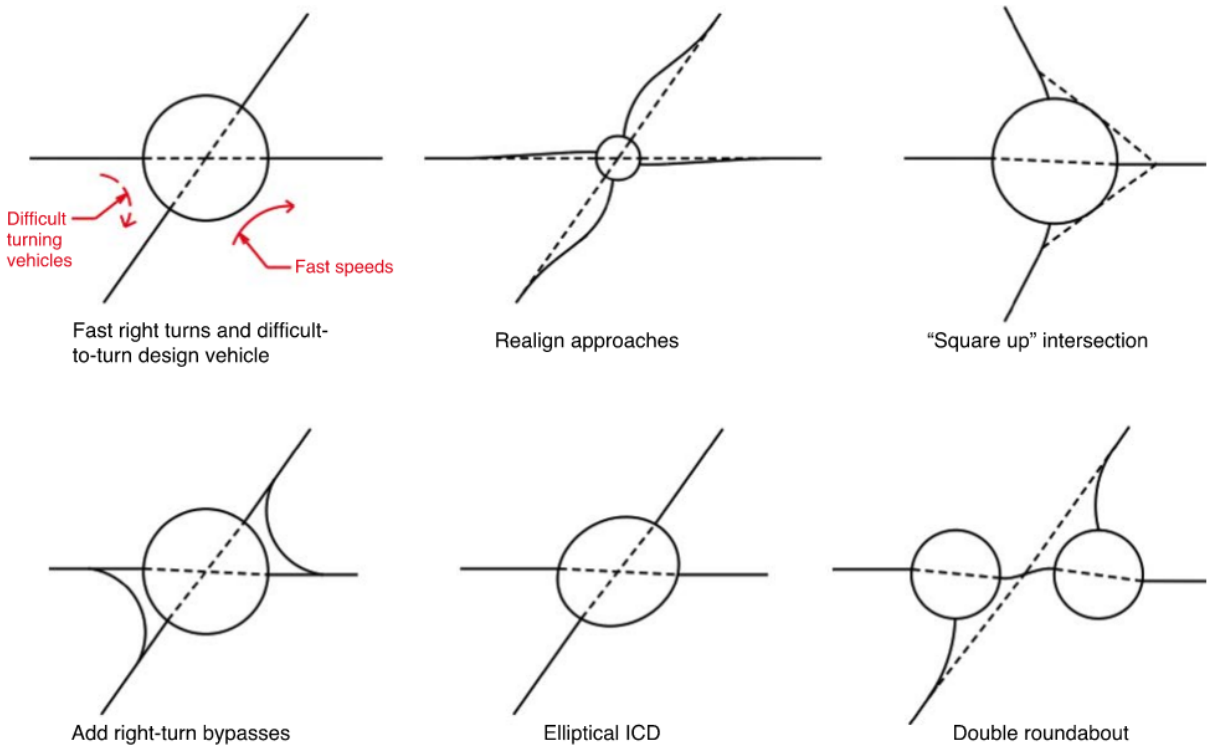
6.12.4.a – Horizontal Design Influences

- **Size and Shape.** The size and shape of a roundabout result from balancing trade-offs within a range of possible sizes for a given context. Size is typically described by the ICD and determined by the design vehicle, approach alignment, and lane configuration. Lane configuration and geometry are used to determine the shape of a roundabout.
- **Location.** Site environmental, right-of-way and other constraints and considerations for traffic maintenance during construction may influence a roundabout's position. The roundabout position affects its predicted performance. Comparing and documenting potential locations early in design can reduce the risk of needing to re-assess prior screened configurations.
- **Approach and Entry.** The approach alignment affects speed control, the ability to serve design vehicles, and view angles. It is often influenced by the need to attain entry path alignment and entry speeds.
    - **Centering of Legs.** The approach legs can be centered on the centerline, offset left of centerline, or offset right of centerline. A common starting point is centered on the centerlines, however, offset left of centerline can reduce approach speeds

and improve speed control. NCHRP 1043, Exhibit 10.13 provides benefits and tradeoffs of these approach alignments.

- **Alignment of Legs.** NCHRP 1043, Exhibit 10.12 displays different approach alignments for various skews. Refer to NCHRP 1043, Exhibit 10.14 for discussion on skew angles between roundabout legs.

Exhibit 6.12.12 Intersection Skew Angles



6.12.4.b – Single-Lane Roundabouts

- **Entry Width.** The entry width typically ranges from 14 ft to 18 ft and are usually flared from the upstream approach widths. The entry width includes curb offset for drainage purposes and design vehicle offtracking. The curb-to-curb width must be able to accommodate the control vehicle unless there is an alternate method for the control vehicle to navigate the roundabout.

- **Circulating Roadway.** The circulating roadway width should be at least as wide as the widest entry width but should not exceed 120% of the widest entry width. Since shoulders are not to be provided in roundabouts, the circulating roadway width is considered the traveled way width even though it may include a curb offset for drainage purposes. A nominal width of 15 ft is a common starting point.

- **Exit Width.** The exit width typically ranges from 18 ft to 20 ft. The exit width includes

curb offset for drainage purposes and width for design vehicle offtracking. The curb-to-curb width must be able to accommodate the control vehicle unless there is an alternate method for the control vehicle to navigate the roundabout.

6.12.4.c – Multilane Roundabouts

- **Number of Lanes and Configuration.** At least one approach has at least two lanes on the entrance or exit. The designer must ensure continuity between entering, circulating, and exit lanes so lane changes are not required to navigate the roundabout. Drivers approaching a multilane roundabout are required to choose the proper lane prior to entering the roundabout.

- **Entry Width.** The typical entry width where trucks straddle lanes ranges from 24 ft to 30 ft for a two-lane entry and from 36 ft to 45 ft for a three-lane entry, with typical individual lane widths varying from 12 ft to 15 ft. These widths include the painted "buffer", if needed, which is typically located between the approach lanes on multilane approaches. The entry width is usually flared from the upstream approach widths.

- **Circulating Roadway.** The circulating roadway width should be at least as wide as the widest entry width but should not exceed 120% of the widest entry width. Since shoulders are not to be provided in roundabouts, the circulating roadway width is considered the traveled way width even though it may include a curb offset for drainage purposes.

  Generally, multilane circulatory roadway lane widths range from 14 ft to 16 ft. Therefore, this results in a two-lane circulatory roadway width of 28 ft to 32 ft and a three-lane circulatory roadway width of 42 ft to 48 ft. It may be beneficial for the outside lane to be slightly wider than the inside lane.

- **Entry Geometry and Approach Alignment.** The designer needs to balance the need to control entry speed with the need to provide good path alignment at multilane entries. The desired result of entry design is to promote vehicles to be naturally aligned in their correct lane within the circulatory roadway.

- **Exit Geometry.** Much like the entry geometry, exit geometry needs to be balanced with maintaining low speed. If speeds can be kept low and/or there are no pedestrians at the exit, it is preferable to have tangents at the exits to avoid path overlap.

6.12.4.d – Truck Apron

A concrete truck apron is to be provided around the central island of the roundabout. This apron is a few inches higher than the roadway pavement separated by a truck apron curb to discourage passenger cars from using it, but it is designed for truck trailers to traverse it. It typically has a 1% to 2% cross slope towards the circulating roadway. In most locations the

truck apron must accommodate “lowboy” trucks. Although not desirable for snow removal or drainage, short sections of outside truck apron may be needed on the outside of the circulating roadway or at the entry/exit lanes to accommodate the design vehicle while maintaining an acceptable fastest path. Truck aprons should have a different concrete texture and/or color than sidewalks, especially outside truck aprons, to deter pedestrians from using the truck aprons. Refer to Publication 72M, *Roadway Construction Standards*, RC-65M.

6.12.4.e – Splitter Islands

Splitter islands are a raised or traversable area on an approach that separates entering traffic from exiting traffic and forms part of the geometry to slow entering traffic. If raised and of sufficient width, it provides a refuge for pedestrians to cross the road in two stages. They should be incorporated into all roundabouts, generally at least 50 ft in length, although specific situations or design constraints may necessitate shorter splitter islands. Splitter islands are to be a minimum of 6 ft wide at crosswalk locations to provide adequate refuge for pedestrians, including those using wheelchairs, pushing a stroller, or walking a bicycle. Splitter islands also alert approaching drivers to the geometry of the roundabout. For higher speed approaches, splitter island lengths of 150 ft or more are often beneficial. Splitter islands are typically mountable curb to allow for minor offtracking of large vehicles.

6.12.4.f – High Speed Approaches

The alignment of the approaches is critical in the design of roundabouts. Since geometrically restricting entry speeds is typically more important than exit speeds, an offset alignment to the left of center or through the center is usually applied and an offset alignment to the right is usually avoided. For rural locations where approach speeds are high, chicanes or curvilinear approaches may be advisable to geometrically step down the vehicle speeds prior to the roundabout. If horizontal curvature is used to manage and slow down speeds, a series a progressively sharper approach curves should be used.

Additionally, it is important to make drivers aware of the roundabout with sufficient sight distance to comfortably decelerate to the appropriate speed for entering the roundabout. Where possible, the geometric alignment of approach roadways should be constructed to maximize the visibility of the central island and the shape of the roundabout.

Refer to NCHRP 1043, Section 10.14 for more information.

6.12.4.g – Bypass lanes

Bypass lanes, also known as channelized turn lanes or slip lanes, may be used at any roundabout. The most common type is the right-turn bypass lane. Providing a bypass lane allows right-turning traffic to bypass the roundabout, providing additional capacity for the through and left-turn movements at the approach.

There are two types of right turn bypass lanes:

- **Right Turn Partial (Yielding) Bypass Lane.** A right turn yielding bypass lane with either a curbed or a painted channelization requires approaching vehicles to yield to traffic leaving circulatory roadway at the adjacent exit. This alternative should prevent the right turning vehicle from making a through movement while preserving good sight lines to the left for conflicting circulating/exiting traffic. Generally, an angle of 70 degrees or higher is desirable.
- **Right Turn (Free-flow) Bypass Lane.** Right turn free-flow bypass lanes allow vehicles to bypass the roundabout and then continue in a dedicated lane or merge into an adjacent lane. A high right turn demand when coupled with other approaching traffic may indicate the need for a full bypass lane in order to avoid a wider, faster entry. Right turn full bypass lanes create an additional conflict for pedestrians and bicyclists and should only be used when needed for additional capacity.

Refer to NCHRP 1043, Section 10.9, for more information on bypass lanes.

6.12.4.h – Interim and Ultimate Configurations

Since single-lane roundabouts tend to have higher safety benefits than multilane roundabouts, multilane roundabouts should be considered for phased implementation. A multilane roundabout, or parts of a multilane roundabout, may be built as a single-lane roundabout initially, and later expanded to a multilane roundabout. This may be appropriate if future growth needs are uncertain or if any of the additional lanes are not needed until close to the Design Year. To allow for this future expansion, the right-of-way and geometric needs of both the single-lane and multilane roundabout should be acquired.

When considering phased implementation, the designer should establish interim and ultimate configurations to meet safety and operations performance for the selected horizon and design years. Initial implementation phases need to retain critical components of the ultimate configuration to keep it viable. Both the interim and ultimate configurations need to meet all design performance objectives.

There are many possible ways to expand from interim to ultimate configurations. NCHRP 1043, Chapter 10.8.1 discusses expanding to the inside and expanding to the outside as two possible solutions.

6.12.5 – Vertical Alignment

Each roadway approaching a roundabout has a baseline (also referred to as a survey and construction or profile grade line) which may or may not be the center of the roadway. The baseline for each approach will intersect in the roundabout and typically extend through the roundabout to establish the connection between roadways and form the basis for subsequent vertical design.

Additionally, the central island circulatory roadway typically has its own baseline/profile grade line. Refer to NCHRP 1043, Exhibit 11.4 for typical baseline layout.

Refer to NCHRP 1043, Chapter 11.2 for profile design development.

6.12.5.a – Grade

Due to potential truck rollover and adverse cross slope concerns, it is not recommended for the circulatory roadway to have more than a 4% negative superelevation unless the concerns can be adequately mitigated.

Approach grades may be higher than the grade through the roundabout if approach grades are modified at the roundabout entrance. Refer to NCHRP 1043 Section 11.3.

6.12.5.b – Transverse and Cross-Slope Design

The most common approach to grading the circulatory roadway is to slope it to the outside. This avoids having inlets adjacent to the truck apron, which is undesirable. This approach is particularly common for single-lane roundabouts because the overall drainage distance from the inside of the circulatory roadway to the outer curb is limited to a single lane width. It is often desirable to have a cross slope of 2% away from the central island to balance drainage needs with driver comfort.

Refer to NCHRP 1043, Section 11.4 for more information on transverse and cross-slope design.

6.12.6 – Bicycle and Pedestrian Considerations

Design elements include pedestrian and bicycle facility types, buffers and separations, crossing locations, sidewalk treatments, splitter islands, wayfinding treatments, and curb ramps. Because these facilities can affect the roadway geometry, these facilities should be included in the design early in preliminary engineering.

If bicycle and pedestrian activity is anticipated in the design year, approaches and splitter islands are to be designed with pedestrian and bicycle facilities or with space for future facilities. Refer to NCHRP 1043, Chapter 4 and Section 10.4 for more information.

The designer should include the following considerations for pedestrian and bicyclist traffic at roundabouts:

- **Pedestrian Design Considerations.** Pedestrians must be considered at all roundabouts, and accommodations are highly recommended at locations with existing or anticipated pedestrian access. Pedestrian accommodations include ADA compliant cut-throughs on splitter islands, curb ramps and accessibility features such as detectable warning surfaces. In situations where pedestrian accommodations may not be necessary, it is recommended that splitter islands be designed to be wide enough to

accommodate potential future crossings. Where pedestrians are accommodated, for compliance with PROWAG, one or more of the following must be provided at crosswalks on multilane approaches and multilane exits: pedestrian actuated Rectangular Rapid Flashing Beacons (RRFBs), signals with pedestrian signal heads or a raised crossing.

When sidewalks will not be provided, a 7 ft graded buffer should be provided around the roundabout to the start/end of the shoulders on the approaches to allow for potential future sidewalk. If the approaches are curbed the graded area should extend to at least 50 ft beyond the circulating roadway.

Further information for the design of pedestrian accommodations for roundabouts is provided in NCHRP 1043, Section 10.4. Also, refer to Chapter 13, *Pedestrian Facilities*, for ADA compliance.

- **Bicycle Design Considerations.** Where bicycle lanes are used on approach roadways, they should be terminated in advance of the roundabout using tapers to merge cyclists into traffic for circulation with other vehicles. If a sidewalk is provided or preferably a multiuse path, it is preferable to provide bicycle ramps to allow bicyclists to exit the roadway onto the sidewalk or multiuse path.

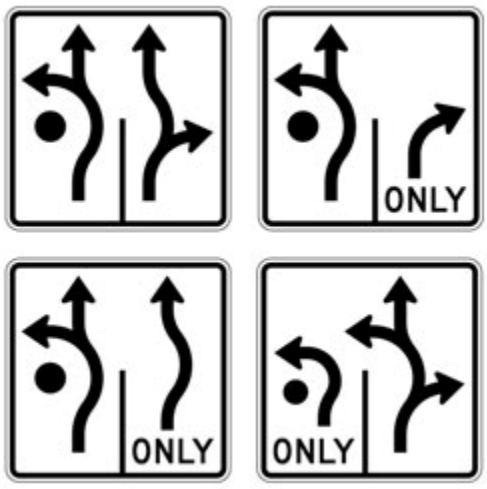
  Further information for the design of bicycle accommodations for roundabouts is provided in Chapter 14, *Bicycle Facilities*, and NCHRP 1043, Section 10.4.

6.12.7 – Traffic Control Devices

Signing and pavement markings for roundabouts are to comply with the MUTCD and Publication 236, *Handbook of Approved Signs*. However, for consistency across the state the following are recommended:

- Lane use pavement markings should not be used for mini-roundabouts, compact or single-lane roundabouts. “Fishhook” lane control signs and lane use pavement markings should be used for multilane roundabouts including hybrid roundabouts. **Exhibit 6.12.13** displays examples of fishhook signage. Refer to TC-8600 for fishhook pavement markings. Refer to NCHRP 1043, Chapter 12, for information on traffic control devices.

Exhibit 6.12.13 – Fishhook Signage



- Rectangular Rapid Flashing Beacon signs or other PROWAG acceptable devices should be provided where pedestrian crossings are provided on multilane entries and exits.

- Signing should be provided advising motorists not to pass trucks in multilane roundabouts.

- Any non-traffic control related signs within PennDOT right-of-way are to comply with PennDOT's Outdoor Advertising Policy. Refer to Publication 930 for more information.

6.12.8 – Pavement, Curbing and Drainage

Roundabouts require the following pavement, curbing, and drainage considerations:

- **Pavement.** Asphalt or concrete may be used for the circulatory roadway. However, if it is concrete, the concrete truck apron must be dyed, stained, or painted to differentiate it from the circulatory roadway. At locations where a single-lane roundabout is constructed with the intention of a later conversion to a multilane roundabout, asphalt pavement for the circulatory roadway should be considered to avoid the need to redo the concrete jointing during the conversion. For a more detailed discussion of pavement details, refer to Publication 242, *Pavement Policy Manual*, and NCHRP 1043, Chapter 13.

- **Curbing.**

    - Concrete vertical face curbing should be used on the outside of roundabouts to minimize the potential for vehicle offtracking outside the curbing, but mountable curbing may be used if offtracking needs to be accommodated; however, outside mountable curbing should not be used where pedestrian facilities are provided or anticipated along the outside of the roundabout.

- For roundabouts located along otherwise non-curbed roadways, roundabout outside curbing should extend along the roundabout approaches the length of the splitter islands, but not less than 50 ft from the circulatory roadway.

- Concrete mountable curbing is typically desirable for the splitter islands to allow for occasional vehicle offtracking.

- Provide a roundabout truck apron curb between the truck apron and the circulatory roadway.

Refer to Publication 72M, *Roadway Construction Standards*, RC-64M and RC-65M for concrete curb details. RC-20M provides curb and joint details.

- **Drainage.**

  - Gutters (as part of curb gutters) may be desirable along splitter islands and the outside of roundabouts. They are typically not desirable along truck aprons unless they are sloped the same as the roadway. If the roadway pavement is asphalt, then the gutter can make the lanes appear narrower, which may lower vehicles speeds, while still providing the width needed for truck turning templates.

  - Drainage inlets should normally be placed along the outer curb line of the circulatory roadway and shall be designed to withstand vehicle loading. Inlets should also be placed upstream of crosswalks and ideally, they should not be placed in the entry and exit radii of the approaches in the vehicle wheel path or along truck aprons. If they must be placed along a truck apron then provide gutters the width of the inlets along the inside and/or outside truck aprons to reduce the potential for roadway pavement cracking at the corners of the inlets as the trucks track over the truck aprons.

Refer to Chapter 10, for drainage guidance and requirements.

6.12.9 – Lighting

Refer to Chapter 20, *Lighting*, for PennDOT's policy on lighting for roundabouts. For guidance and details not covered in Chapter 20, refer to NCHRP 1043, Chapter 14.

6.12.10 – Landscaping

When designing landscaping features, a realistic maintenance program should be considered, including identification of the responsible party for future maintenance, water supply, drainage, and expected growth of plantings.

- Vehicular obstructions such as walls, statues, utility poles, large trees and non-breakaway signs are not recommended within the central island.

- Landscaping must not reduce sight distances below minimum criteria. However, mounding within the central island is typically recommended to obstruct the line of sight straight through the roundabout.

For a more detailed discussion of landscaping design considerations and best practices, refer to Chapter 22 and NCHRP 1043, Section 14.4.

6.13 – Other Innovative Intersections

While the following innovative intersections are not discussed in the Green Book, the designer should consider their use in Pennsylvania under the appropriate conditions. The designer should refer to the FHWA Intersection Safety website referenced in Section 6.01 for more information on these innovative intersections.

6.13.1 – Continuous Green Tee

A Continuous Green Tee (CGT) intersection, which is also known as a Turbo-T, High-T, or Seagull, is a three-leg intersection that allows one major street direction of travel (the "far side" of the intersection) to pass through the intersection without stopping and with no conflicting movement. The opposite major street direction of travel is typically controlled by a traffic signal.

Side street left-turn vehicles use a channelized receiving lane on the major street to merge on the major street. While this intersection is typically signalized, it can also be designed without a traffic signal.

Exhibit 6.13.1 illustrates an example of this type of intersection.

CGT Guidance

Consider a CGT intersection under these conditions:

- Three-leg intersection.
- Heavy through major street traffic volumes.
- Low to moderate left-turn side street traffic volumes.
- No driveways exist along the major street opposite the side street.
- There are limited pedestrian crossings of the major street or an alternative crossing nearby.

Advantages:

- Side street left-turn vehicles are channelized, which reduces angle crash potential.
- Increased efficiency, as one direction of travel on the major street is free-flow; this reduces delay for other movements.
- Traffic signal synchronization improves.
- Corridor travel times are reduced.

Disadvantages:

- Pedestrians do not cross the major street and have to use the nearest marked crosswalk.
- May require additional right-of-way.

Exhibit 6.13.1 Continuous Green Tee Intersection (US 40 at Rivers Edge Road) in Columbia, MD

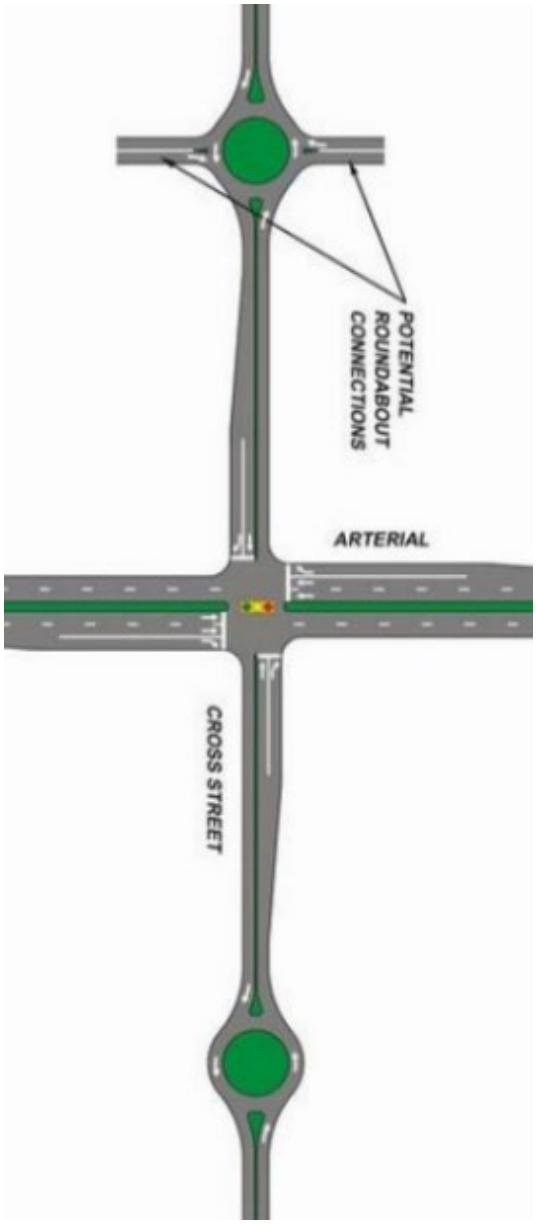


6.13.2 – Bowtie

A Bowtie intersection is an intersection where all left-turn movements are restricted. Roundabouts on the cross street accommodate arterial and cross street left turns. These roundabouts can have two or more legs.

Exhibit 6.13.2 illustrates an example of this type of intersection.

Exhibit 6.13.2 Bowtie Intersection



Source: Minnesota Intersection Control Evaluation Manual, 2017

Bowtie Guidance

Consider a Bowtie intersection under these conditions:

- Moderate to heavy through traffic volumes and low to moderate left-turn traffic volumes.
- Narrow or nonexistent medians and/or limited right-of-way at the intersection.

Advantages:

- Reduces the number of conflict points from 32 (main intersection with all movements) to 20 (right turns only allowed at main intersection and two-leg roundabouts proposed).
- Fewer traffic signal phases since there are no left turn phase and adjacent intersections are yield controlled, which reduces stops and delay.
- Corridor travel times are reduced.

Disadvantages:

- Greater distance/time for left turning motorist.
- Additional right-of-way potentially needed at roundabout locations.
- Enforcement may be required to prevent illegal left turns at the intersection.

6.13.3 – Protected Intersection

A Protected intersection, also known as a Setback intersection, provides bicyclists with physical separation through an entire intersection and reduces interactions with vehicles.

A Protected intersection consists of the following main features:

- No stopping/standing zone near the intersection.
- Pedestrian islands between the bicycle lane and vehicle travel lane.
- Bike queue area.
- Bikeway setback.
- Corner islands.
- Motorist waiting zone.
- Intersection crossing markings.
- Bike yield line.

Exhibit 6.13.3 illustrates an example of this type of intersection.

Refer to Chapter 14, *Bicycle Facilities*, for design information related to bicycles.

Protected Intersection Guidance

Consider a Protected intersection under these conditions:

- Moderate to heavy bicyclist and/or pedestrian activity mixed with moderate to heavy vehicular traffic.

Advantages:

- Shorter, safer crossings for pedestrians and bicyclists.
- Reduced speeds of turning vehicles.
- Bicyclists and pedestrians are more easily visible to turning vehicular traffic.
- Bicyclists separated from vehicular traffic through intersection.
- Bike queue areas after the crosswalk and waiting zones for turning vehicular traffic.
- Design better supports high volumes of pedestrians and bicyclists, therefore increasing intersection capacity.

Disadvantages:

- Right turn lanes may require removal, leading to longer vehicle queues.
- May be more difficult for larger vehicles to navigate.

Exhibit 6.13.3 Protected Intersection at Walnut Avenue and Paseo Padre Parkway, Fremont, California



6.14 – Driveways

The purpose of this section is to provide guidance on the location and design of driveway access connections.

Driveways are the physical interface between a site and the abutting highway. Per Pennsylvania Code, Title 67, Chapter 441, this includes "...every entrance or exit used by vehicular traffic to or from properties abutting a highway. The term includes proposed streets, lanes, alleys, courts, and ways."

It is essential that driveways be located and designed to ensure safe ingress and egress for the development and to minimize adverse impacts on the roadway.

The Americans with Disabilities Act (ADA) also requires that all pedestrians including persons with disabilities be able to safely use sidewalks that cross driveways.

Driveway Regulations

The requirements and regulations for driveways must comply with the most current requirements of the latest edition of the Pennsylvania Code, Title 67 – Transportation, Chapter 441 titled *Access to and Occupancy of Highways by Driveways and Local Roads* (67 Pa Code § 441).

To comply with PROWAG, where driveways are controlled with yield or stop control devices or traffic signals, detectable warning surfaces shall be provided on the pedestrian circulation path where the pedestrian circulation path meets the driveway.

Additional considerations for driveways not covered in this section can be found in the following publications:

- Publication 282, *Highway Occupancy Permit Operations Manual.*
- Publication 312, *Guide for Obtaining Minimum Use Driveway Permits.*
- Publication 574, *Access Management – Model Ordinances for Pennsylvania Municipalities Handbook.*
- Green Book section titled *Other Intersection Design Considerations / Driveways*.
- TRB , *Access Management Manual*, Second Edition, Chapter 13.

6.14.1 – Design Considerations

The designer shall consider multiple key objectives in designing driveway access connections:

- Preserve the functional intent of the roadway to which access is provided.
- Consider all users, including pedestrians, bicyclists, motor vehicles, transit, and as appropriate, heavy vehicles.
- Minimize difference in speeds between turning vehicles and through traffic.
- Minimize/eliminate encroachment of turning vehicles on adjacent lanes.
- Provide adequate sight distance for drivers approaching the access or exiting the access.
- Provide sufficient storage within the driveway and turn lanes for traffic entering the site to prevent spillback onto the abutting road.
- Provide sufficient queuing within the driveway and site to produce efficient traffic flow for vehicles exiting the site.
- Incorporate necessary cues (signing, striping, geometry, etc.) for a pedestrian, bicyclist, or driver to fully understand driveway operations (e.g., one-way or two-way operation, lane designations).

Access Management

TRB's *Access Management Manual* lists several roadway, site, and user characteristics to consider in access location/design, including the following:

- Functional area of nearby intersections.
- Crash history.
- Transit stop locations.
- Elevation of site relative to roadway.
- Development size.
- Proximity to major traffic generators.
- Driver familiarity.
- Mix of vehicle types.
- Pedestrian presence.

6.14.2 – Driveway and User Characteristics

Refer to 67 Pa. Code § 441, Publication 282, or Publication 574 for additional information on the four types of driveways (minimum, low, medium, and high volume) abutting Pennsylvania roadways. In general, roadways of lower classification can have more frequent, closely spaced access connections, whereas roadways of higher classification have few or no access connections.

The design and location of driveway access points can affect the ability of drivers to safely respond to their driving environment. Consider the following:

- A driver's perception-reaction time increases as the driving task becomes more complex. Simplify the driving task by long driveway spacing, limiting the number and types of movements at individual driveways, and providing adequate driveway geometrics.
- Drivers unfamiliar with an area require longer perception-reaction time than other drivers. This is especially true in tourist areas.

- Elderly drivers have a longer perception-reaction time than younger drivers. Consider this in the design of uses frequented by elderly drivers, such as religious institutions or retirement centers.
- Drivers do not expect large differences in travel speeds on expressways or major at-grade roadways.

6.14.3 – Visibility

Safety is improved when the location and geometrics of the connection are clearly visible to approaching users (drivers and non-motorized users).

Certain geometric features can influence visibility:

- **Superelevated horizontal curves**. Driveways located on the outside of superelevated horizontal curves can hinder a left turning driver's clear view of driveway geometrics. Drivers leaving a driveway can also encounter a negative superelevation. In urban and suburban settings, a potential solution is to not use superelevation.
- **Horizontal curves to the right**. A driveway on the inside of the curve may provide limited illumination from approaching vehicle headlights. A good view of the driveway may not be attainable during inclement or nighttime conditions.
- **Vertical crest curves**. The designer should consider driveway placement at the high point of a vertical curve, as driveways on the far side of a vertical crest can restrict its visibility.

Three types of sight distances (stopping, intersection, and decision) are involved in the location and design of driveway access connections. The designer should carefully consider the placement of landscaping within the intersection sight triangle as well on-street parking when determining driveway visibility.

Enhanced conspicuity, or the ability of something to be noticed or observed, allows bicyclists, motorists, or pedestrians approaching the driveway to recognize the driveway far enough in advance to make any necessary adjustments in speed. Adequate lighting and signage near the driveway access connection are important, provided that neither the light pole nor the sign are a roadside hazard or an obstruction to sight distance.

6.14.4 – Operations

The designer should consider the following for driveway operations:

- **Speed.** Research has shown that in general, over a range of commonly used driveway geometrics related to curb radii and driveway width, motorists execute a right turn into a driveway at about the same speed, i.e., approximately 8-13 mph. The motorist making this maneuver is typically decelerating from a considerable distance upstream from where the actual turn occurs. Therefore, on higher-speed roadways, auxiliary lanes are advisable to limit the speed differential between turning vehicles and through traffic on

major roads to an acceptable level.

- **Bicyclists.** Inclusion of a bicycle lane on the roadway improves available driveway sight distance by providing a buffer area within the roadway that must be free of obstacles. Do not introduce abrupt changes in surface elevation or cross slope near the driveway which could cause a bicyclist to lose balance or control.
- **Pedestrians.** Driveways intersecting sidewalks must have cross slopes compliant with the Americans with Disabilities Act. The sidewalk alignment across the driveway should be straight and have no steps or other abrupt changes in vertical elevation.
- **Public Transit.** Driveway access connections near public transit facilities should minimize adverse operational effects. Placement of the driveway in relation to the shelter/bus stop should allow driver line of sight, allow sufficient space so a bus does not block a driveway, and ensure that bus patrons loading or unloading from the transit vehicle do not block the driveway.

6.14.5 – Auxiliary Lanes

In general, placement of a driveway access connection adjacent to a full-width auxiliary lane (e.g., right turn lane, acceleration lane, or deceleration lane) should be avoided when possible. Auxiliary lanes are generally placed at locations where high turning volumes, sizable speed differentials, or crash history contributed to its placement in the first place. Therefore, priority at these locations should be given to safe operations on the roadway.

6.14.6 – Geometrics

The designer should refer to 67 Pa. Code § 441 for horizontal and vertical geometric design criteria for driveways, including driveway layout illustrations.

6.14.7 – One-Way Access Connections

When a driveway access connection is either one-way in from the public roadway or one-way out to the public roadway, the designer should consider the following basic principles and inform roadway users of one-way operation at each access:

- Use a right-turn deceleration lane.
- Use a long radius on the upstream end and a short radius on the downstream end.
- Place “No Right Turn” signs in advance of an exit only driveway.
- Place an enter or exit sign with an arrow indicating the direction of travel at its junction with the public roadway.
- Align the driveways to an angle so a roadway motorist makes a change in direction less than 90 degrees (ideally 60 to 70 degrees).

- Limit the driveway width.
- Use appropriate signing and pavement markings to clearly direct motorists to an entrance/exit (e.g., “One-Way” signs) and/or discourage improper use (e.g., “Wrong Way,” “Do Not Enter” signing).
- Use a landscaped median or flexible delineators to actively discourage left turns from the roadway into an exit driveway.

6.14.8 – Rural Driveways

In addition to design criteria found in 67 Pa. Code § 441, the designer should consider the following regarding rural driveway design:

- Large trucks, pickups with trailers, or farm tractors with wagons may require distance between the shoulder edge and any gate so the vehicle can stop and be clear of the roadway.
- Drainage design must prevent water from flowing across the roadway or carrying soil or sand onto the roadway.
- Each rural driveway should be designed to accommodate the unique vehicle types common to that site.
- Provide adequate tapers at the edge of pavement and radius to avoid depressions at the edge of the pavement and edge of the radius.

6.14.9 – Shared Access

Where possible, the designer is encouraged to use shared common access driveways between adjacent properties abutting major roadways to reduce the number of conflict points and separate conflict areas. This promotes smoother traffic flow on the abutting roadway and helps to reduce vehicular crashes and increases egress capacity. Situations that may benefit from such an arrangement include the following:

- High-turnover restaurants and gas stations, especially in tourist and recreational areas.
- A discount store or specialty mall in close proximity to a large shopping mall.
- Shopping centers anchored by competitive supermarkets.
- Neighborhood shopping centers and gas stations or branch banks.

Alternative Access

An alternative to the shared access concept is to provide vehicular, bicycle, and pedestrian connections between residential areas and compatible uses. For example, a residential area and neighborhood shopping center can be connected in a manner that encourages vehicular and pedestrian travel without accessing the major street system.

6.14.10 – ADA Driveway and Pedestrian Guidelines

Refer to the “Driveway Aprons” drawings in Publication 72M, RC-67M, for illustrations corresponding to Driveway Apron Types 1 through 5A. Refer also to Chapter 13.

1) The driveway aprons depicted in Publication 72M, RC-67M, illustrate minimum design requirements and acceptable design considerations described for driveway crossings of sidewalks. Although site conditions may not permit strict adherence to the dimensions indicated, every effort must be made to design and construct the safest and most efficient driveways leading onto state highways while ensuring that these facilities remain accessible to the public crossing them.

2) Driveway crossings without a continuous sidewalk cross slope 1V:48H (2.1%) or less forces pedestrians to travel across the driveway side-flare that can compromise balance and wheelchair stability. Driveways constructed with a return curb at the driveway crossing are also inaccessible to wheelchair users. Existing driveways not meeting these criteria should be replaced to meet new accessibility guidelines. Driveway crossings with adjacent sidewalk must have ADA compliant curb ramps provided as per RC-67M.

3) Driveway crossings should be wide enough to accommodate both the driveway ramp and a level pedestrian sidewalk landing zone. See Publication 72M, RC-67M, for Type 1, 1A, 2, and 2A Driveway Aprons. These apron types can be constructed on wide parallel sidewalk corridors where either the entire sidewalk zone that abuts the curbline is paved or a non-walk (planting strip) surface is created. As shown on RC-67M, the minimum sidewalk width is 5 ft. The minimum sidewalk width may be reduced to 4 ft where

5 ft × 5 ft passing areas are provided every 200 ft.

4) Type 1 and 2 Driveway Aprons: Used when a planting strip abutting the curbline separates the sidewalk and curb. If the driveway ramp is not part of the pedestrian sidewalk, a returned curb is better for roadway drainage and has the added effect of slowing traffic due to the tighter turning radius needed to negotiate the driveway entrance approach.

5) Type 1A and 2A Driveway Aprons: Used for driveway crossings where a wide sidewalk parallels and abuts the street curb line. These driveway aprons combine sloped side-flares or a curbed return, with a sidewalk landing.

6) Type 3 and 3A Driveway Aprons: Sidewalk corridors abutting the street curb line can also be depressed at the driveway entrance apron in many situations to provide a crossing with a maximum landing slope of 2.1% to help prevent poor drainage and ponding along the curb. The driveway ramp begins at the rear edge of the sidewalk landing. The sidewalk maximum slope of 1V:12H (8.33%) is permitted along each side of the driveway to meet the higher adjacent sidewalk elevations. This type of driveway apron is not as desirable as a level jogged crossing since pedestrians are forced to travel down one ramp and then up another ramp. These crossings can also confuse visually impaired pedestrians since they may believe that they are about to cross a street intersection at a curb ramp. A narrow driveway apron is also desirable to slow down traffic using this type of driveway entrance.

7) Type 4 Driveway Apron: Securing additional easement or right-of-way from the adjacent property is recommended for creating a level jogged pedestrian sidewalk crossing for narrow sidewalks.

8) Type 5 and 5A Driveway Aprons: A full-height curb between driveways provides access control between driveways. The sidewalk between Type 5 driveways remains at driveway elevations and maintains a full-height curb between driveways. The sidewalk between Type 5A driveways is raised but not to a full-height. This limits slopes on ramps for pedestrians and promotes defined access points to motorists in the parking lot.

9) Gradually sloped driveway crossings constructed with flat side-flares under 1V:20H (5.0%) are beneficial for people with mobility impairments but can also become a problem for visually impaired pedestrians unless there is a detectable difference in the slope at the edge of the street. Without a steeper slope to trigger the awareness of a ramp condition, a visually impaired person could inadvertently veer into the street.

10) Built-up driveway entrances that project across the curb and into the street can hinder or obstruct roadway drainage at the curb and are not recommended.

6.15 – Other Intersection Design Considerations

In addition to the design concepts presented in this chapter, additional considerations relevant to intersection design include the items listed below. For information and design guidance for these items, refer to the reference indicated.

6.15.1 – Frontage Road Design Elements

- Green Book, Chapter 9, section titled *Other Intersection Design Considerations / Intersection Design Elements with Frontage Roads*.

6.15.2 – Traffic Control Devices

- Green Book, Chapter 9, section titled *Other Intersection Design Considerations / Traffic Control Devices*.
- Publication 149, *Traffic Signal Design Handbook.*
- Publication 212, *Official Traffic Control Devices.*
- FHWA, *Manual on Uniform Traffic Control Devices for Streets and Highways.*

6.15.3 – Pedestrians

- Green Book, Chapter 9, section titled *Other Intersection Design Considerations / Pedestrians*.
- Chapter 13, *Pedestrian Facilities.*

6.15.4 – Bicyclists

- Green Book, Chapter 9, section titled, *Other Intersection Design Considerations / Bicyclists*.
- Chapter 14, *Bicycle Facilities.*

6.15.5 – Lighting

- Green Book, Chapter 9, section titled *Other Intersection Design Considerations / Lighting*.
- Chapter 20, *Lighting.*

6.15.6 – Midblock Left Turns on Streets with Flush Medians

- Green Book, Chapter 9, section titled, *Other Intersection Design Considerations / Left Turns at Midblock Locations and at Unsignalized Intersections on Streets with Flush Medians*.

6.15.7 – Traffic Calming

- Chapter 18, *Traffic Calming.*

6.16 – Highway-Railroad Grade Crossings

A highway-railroad grade crossing is a special type of intersection involving joint use of right-of-way for both railroad and highway operations. A highway-railroad crossing is the intersection of a highway with a railroad's right-of-way upon which railroad tracks can be at, above, or below the grade of the highway. Publication 371, *Grade Crossing Manual*, was developed to guide state, local, and railroad officials through this process and should be consulted for policies and procedures.

All highway-railroad grade crossings are under the jurisdiction of the Commonwealth of Pennsylvania or a local government. These crossings are also under the jurisdiction of the Public Utility Commission (PUC) and cannot be constructed or altered without their prior approval. Appropriate grade crossing warning devices, as determined by the PUC, shall be installed at all highway-railroad grade crossings. Details of the available devices to be used are given in Publication 212, *Official Traffic Control Devices*, and in the Manual on Uniform Traffic Control Devices (MUTCD), Part 8.

In designing a highway-railroad grade crossing, the roadway horizontal and vertical alignments approaching the crossing should be constructed in a manner that facilitates drivers' attention to roadway conditions. The crossing surface itself should have a riding quality equivalent to the approach roadway. A poor crossing surface may distract the driver's attention from the warning devices and/or approaching train in favor of finding the smoothest path through the crossing.

6.16.1 – Horizontal Alignment

Ideal highway-railroad crossings intersect at right angles with no nearby intersections or driveways and are not located on railroad or highway curves. Crossings located on both railroad and highway curves present poor rideability due to conflicting superelevation.

Where roadways that run parallel with the main tracks intersect roadways crossing the main tracks, sufficient distance should be provided between the tracks and roadway intersection to enable roadway traffic in all directions to move expeditiously. Refer to Publication 149, *Traffic Signal Design Handbook*, Chapter 19, for the design of traffic control signals at or near railroad grade crossings.

Refer to the Green Book, Chapter 9, section titled, *Railroad - Highway Grade Crossings / Horizontal Alignment*, for additional horizontal alignment considerations.

6.16.2 – Vertical Alignment

Highway-railroad grade crossings are as level as possible for many reasons, including sight distance, rideability, braking, and acceleration distances.

Refer to the Green Book, Chapter 9, section titled *Railroad – Highway Grade Crossings / Vertical Alignment*, for additional vertical alignment considerations. This section includes a figure which illustrates vertical alignment considerations within 30 ft of the rail centerline.

6.16.3 – Crossing Design

The geometric design of a highway-railroad grade crossing should be made jointly when determining the type of warning device (active or passive). Geometric design of a crossing involves elements including alignment, profile, sight distance, and cross section. An appropriate design may vary depending on the use of an active or passive device.

Another important consideration is the required minimum railroad vertical and/or horizontal clearances between the track and an obstruction. Refer to Publication 371, *Grade Crossing Manual*, Appendix H, for these requirements.

Refer to the Green Book, Chapter 9, section *Railroad – Highway Grade Crossings / Crossing Design* for additional discussion and references.

6.16.4 – Sight Distance

Sight distance is an important consideration at highway-railroad grade crossings, especially for crossings without train-activated warning devices. There shall be sufficient sight distance on the highway for the driver to recognize the crossing, perceive the warning device and stop if necessary.

The Green Book, Chapter 9, section titled *Railroad – Highway Grade Crossings / Sight Distance* provides guidance for the following scenarios at a highway-railroad grade intersection without train-activated warning devices:

- Case A: Moving Vehicle to Cross or Stop at Railroad Crossing (illustrated by the Green Book Figure titled *Case A: Moving Vehicle to Cross or Stop at Railroad Crossing*)
- Case B: Departure of Vehicle from Stopped Position to Cross Single Railroad Track (illustrated by the Green Book Figure titled *Case B: Departure of Vehicle from Stopped Position to Cross Single Railroad Track*)

A table in the Green Book section titled *Railroad – Highway Grade Crossings / Sight Distance* provides the design sight distance values for Cases A and B. The motor vehicle for this table is assumed to be a 73.5-ft long truck.

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 chapters that are currently not included in this Publication 13.

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

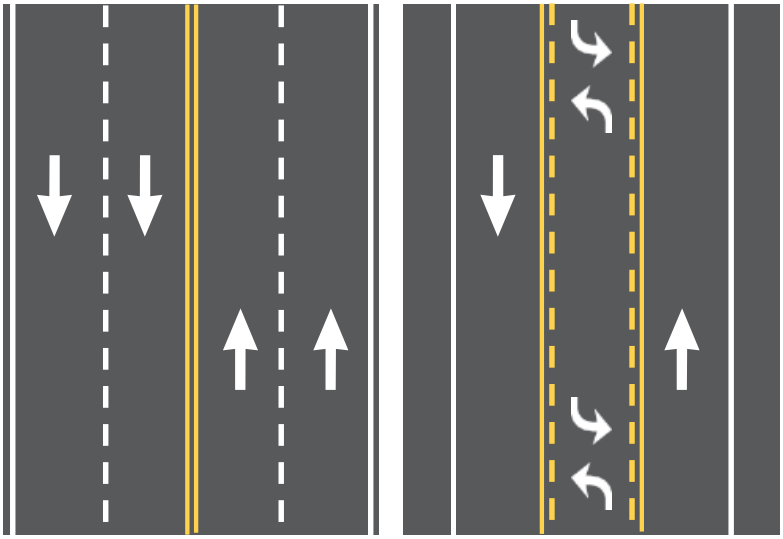
Chapter 8 – Road Diet

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.

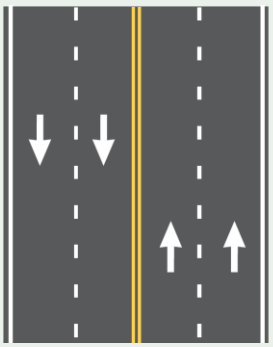
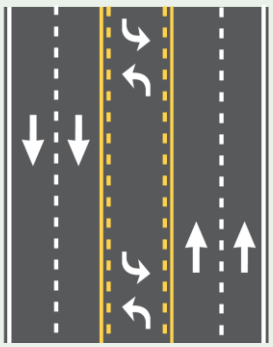
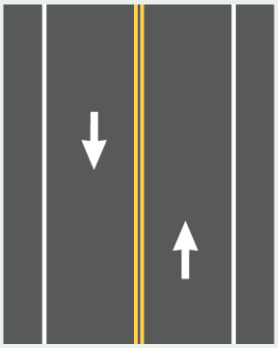
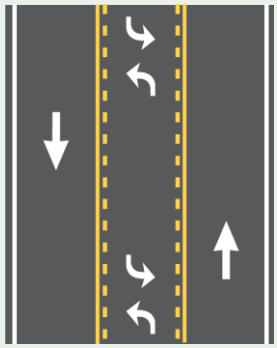
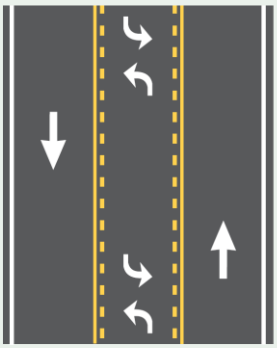
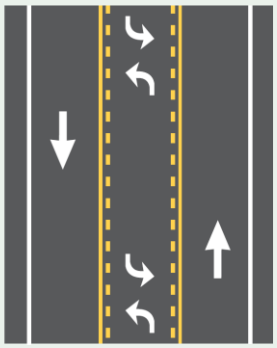
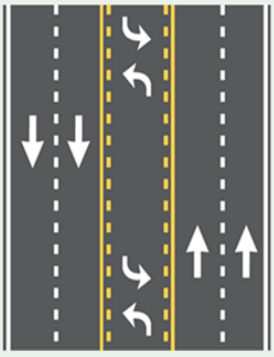
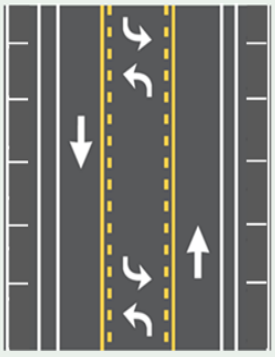
Exhibit 8.0.1 Four-Lane to Three-Lane Road Diet



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

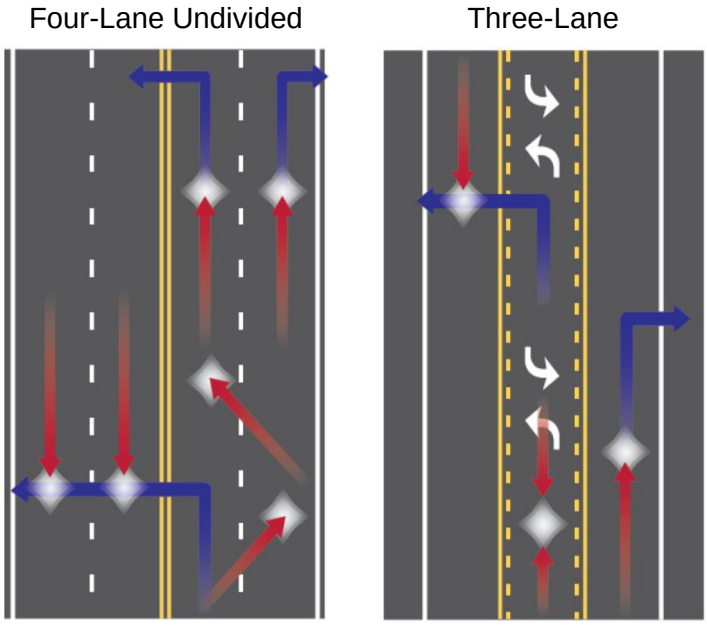


Exhibit 8.1.2 Crossing and Through Traffic Conflict Points at Intersections for a Four-Lane Undivided Roadway and Three-Lane Cross Section

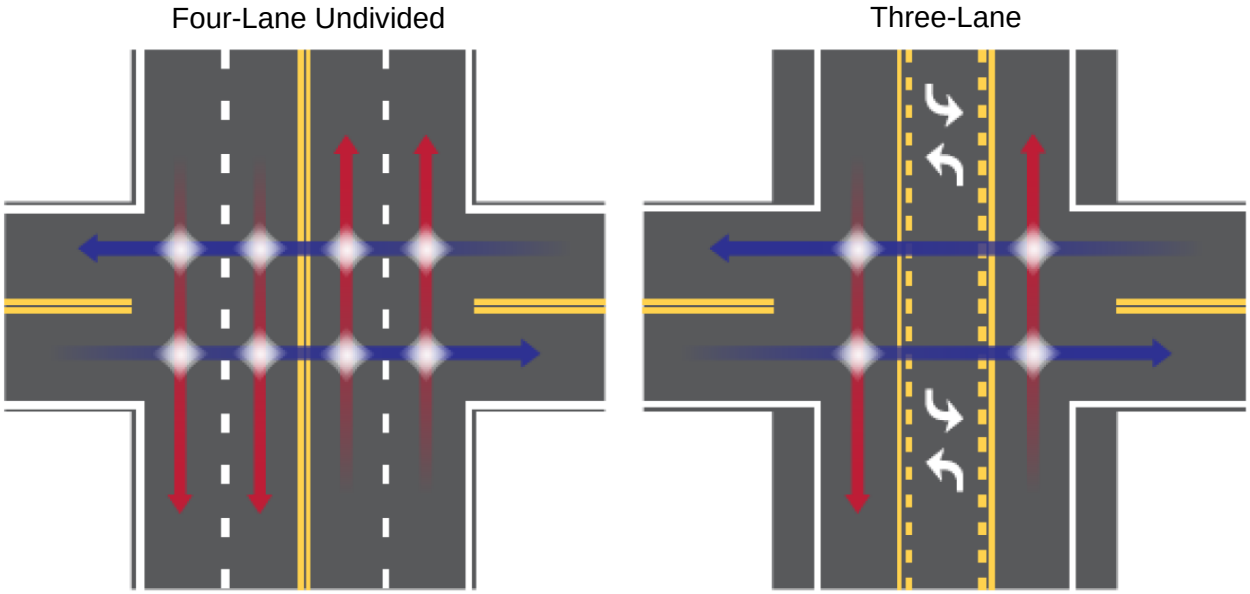
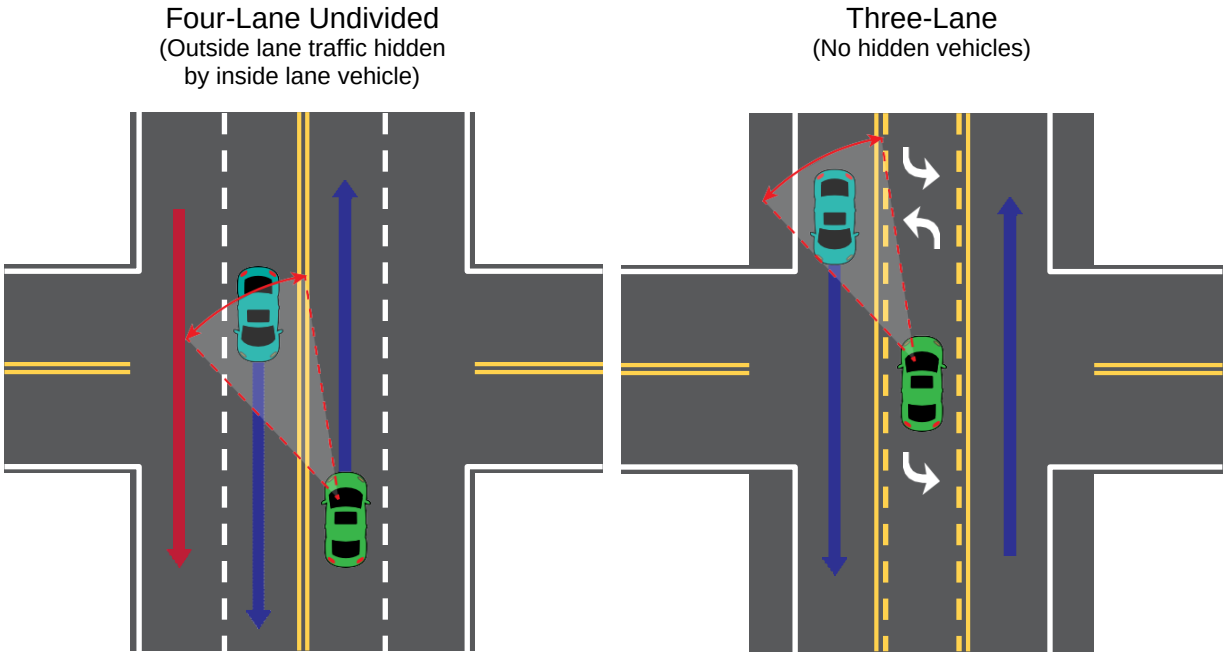


Exhibit 8.1.3 Primary-Street Left-Turn Sight Distance for Four-Lane Undivided Roadway and Three-Lane Cross Section



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.

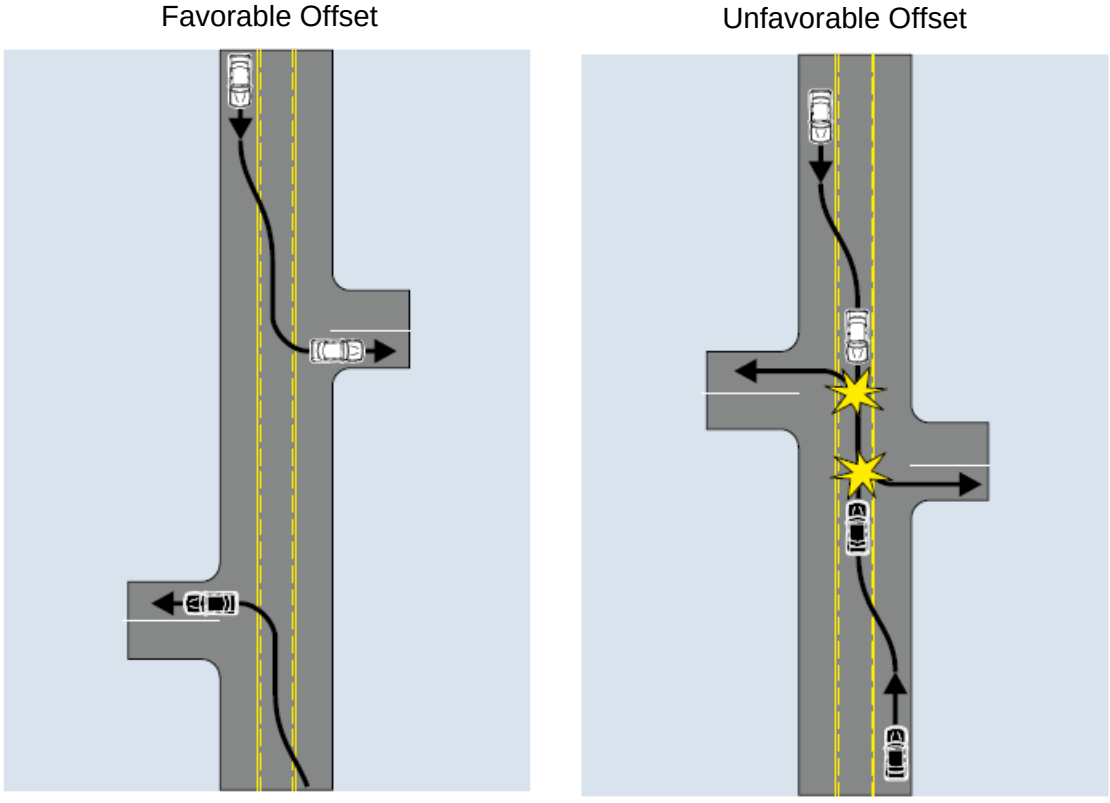
8.6.5.a – Intersecting Roadways and Driveways

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



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

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

In this chapter there are references to future chapters 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 9 – Maintenance and Protection of Traffic

9.0 – Introduction

Temporary Traffic Control (TTC) is an important part of transportation project design and operations. A key component of TTC design is the safety of both road users (e.g., motorists, bicyclists, and pedestrians) and workers performing the many varied tasks within the work space. This chapter provides highway designers with TTC elements for consideration through the various project design phases, from project scoping through final design.



A key TTC component is the development of the Traffic Control Plan (TCP). The design and deployment of effective TCP includes the understanding of how safety, mobility, and constructability are affected by the following types of issues, including:

- Project characteristics.
- Travel and traffic characteristics.
- Corridor, network, and community issues.
- Design, procurement, and construction options.
- Work zone design and safety issues.
- TTC strategies.
- Transportation operations (TO) strategies.
- Public information (PI) strategies.

While TCP design is somewhat unique to each project's context and complexity, this chapter provides designers with a framework of TTC tools for use in decision-making and the development of safe and efficient project work zones. PennDOT's perspective regarding TTC and the associated plans coincides with the fundamental principles and guidance within the Manual on Uniform Traffic Control Devices (MUTCD), Part 6, Temporary Traffic Control.

Historically, the bulk of work zone impacts assessment has typically taken place during the later design stages of project development. In some cases, work zone issues identified during the later design stages have led to changes in the overall project approach. For example, during design if it is identified that an alternate route chosen for a particular project will also be under construction at the same time, the entire transportation management approach for the project may have to be changed, potentially resulting in project delays and increased costs. If such issues are identified just prior to, or during construction, it could be even more problematic because construction may have to be stopped on the project resulting in increased costs. This

chapter provides guidelines on what items should be considered in each part of the project development process.

9.0.1 – Definitions

Definitions for terms used in this chapter include:

- **Active work zone** – The portion of a work zone where construction, maintenance, or utility workers are on the roadway or on the shoulder of the highway, and workers are adjacent to an active travel lane. Workers are not considered adjacent to an active travel lane if they are protected by a traffic barrier and no ingress or egress to the work zone exists through an opening in the traffic barrier.
- **Activity area** – Area of a temporary traffic control zone comprised of the buffer space and the work space usually separated from traffic flow by channelizing devices or barrier located parallel to the travel lanes.
- **Advance warning area** – The section of highway where road users are informed about the work zone or incident area ahead.
- **Detour** – The road user's diversionary roadway or pedestrian path to avoid a construction zone.
- **Normal speed limit** – The regulatory speed limit or the 85th percentile speed that existed before temporary traffic control was established.
- **Public Information Plan (PIP)** – A plan that informs the public of the impacts on traffic and the general area prior to and during construction.
- **Significant Project** – A project that, alone or in combination with other concurrent projects nearby, is anticipated to cause sustained work zone impacts that are greater than what is considered tolerable based on State policy and/or engineering judgment.
- **Temporary Traffic Control (TTC) Zone** – An area of a highway where road user conditions are changed due to the use of TTC devices, flaggers, uniformed law enforcement officers, or other authorized personnel.
- **Termination area** – The section of the highway where road users are returned to their normal driving path, extending from the downstream end of the activity area to the last TTC device (such as END ROAD WORK signs, if posted).
- **Traffic Control Plan (TCP)** – A supplemental plan currently required for all projects that addresses traffic flow and control through the work zone which must conform to the MUTCD and PennDOT Publication 213, *Temporary Traffic Control Guidelines*.
- **Transition area** – The section of the highway where road users are redirected from their normal path.

- **Transportation Management Plan (TMP)** – A document that lays out a set of coordinated strategies and describes how these strategies will be used to manage the impacts of a project during construction. It includes the TCP, TOP and PIP.
- **Transportation Operations Plan (TOP)** – A plan that includes Demand Management Strategies, Corridor/Network Management Strategies, Work Zone Safety Management Strategies and Traffic/Incident Management and Enforcement Strategies.
- **Work zone (WZ)** – The area of a highway where construction, maintenance, or utility work activities are being conducted.

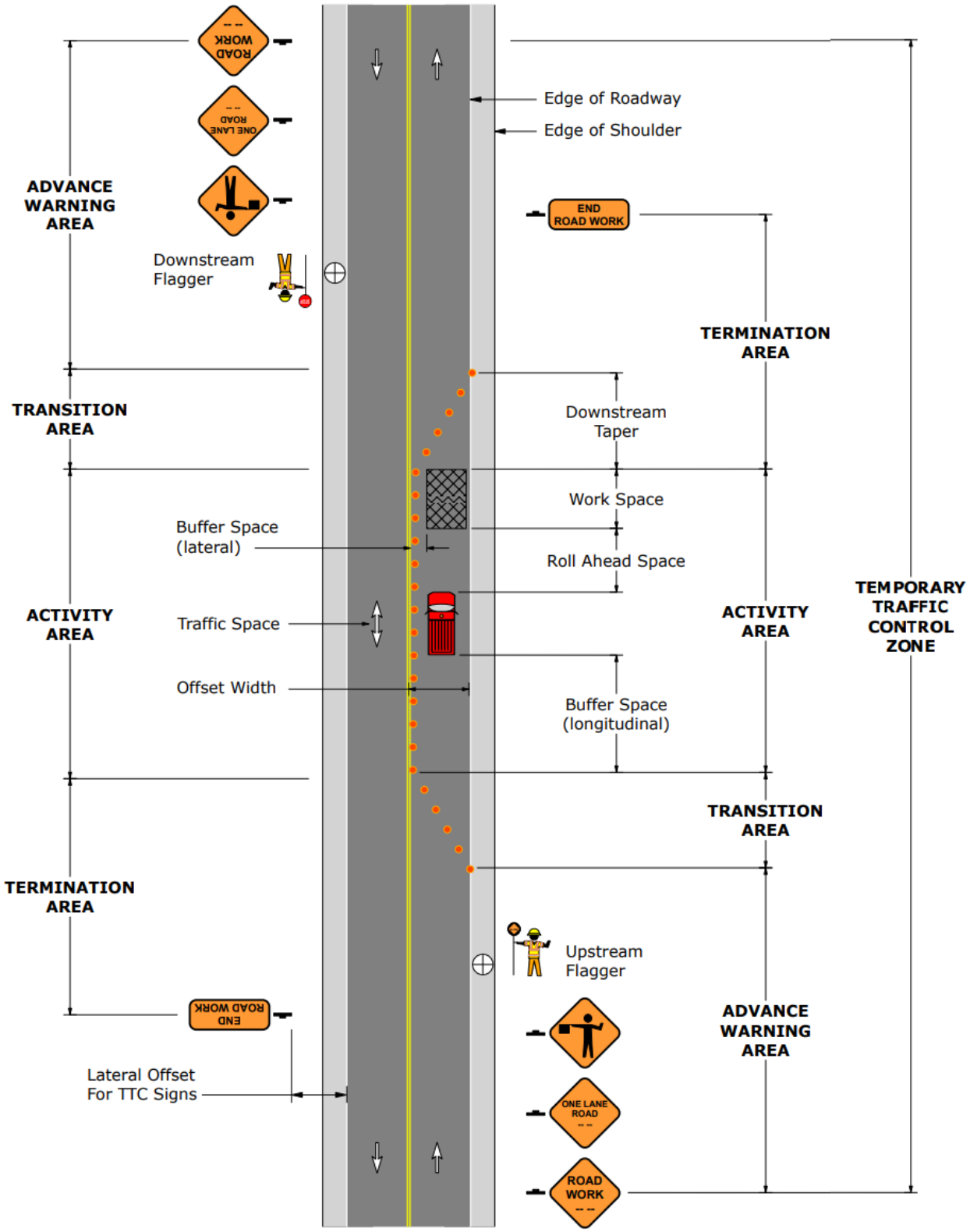
9.0.2 – Resources and References

- FHWA, *Manual on Uniform Traffic Control Devices* (MUTCD), (edition defined in Publication 212).
- FHWA, *Work Zone Management Website*: https://ops.fhwa.dot.gov/wz/index.asp
- FHWA, *Work Zone Impacts Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects*, 2006.
- National Work Zone Safety Information Clearinghouse Website: https://www.workzonesafety.org/
- PennDOT, Publication 46, *Traffic Engineering Manual*, (most recent version).
- PennDOT, Publication 111*, Traffic Control - Pavement Markings and Signing Standards*, (most recent version).
- PennDOT, Publication 200, *Changeable Message Sign (CMS) Operating Standards*, (most recent version).
- PennDOT, Publication 212, *Official Traffic Control Devices*, (most recent version).
- PennDOT, Publication 213, *Temporary Traffic Control Guidelines*, (most recent version).
- PennDOT, Publication 234, *Flagging Handbook*, (most recent version).
- PennDOT, Publication 236, *Handbook of Approved Signs*, (most recent version).

9.0.3 – Use of Publication 213

Publication 213 is a key reference for the development of project TCPs. It includes a comprehensive list of work zone definitions and illustrated typical general applications. An example is shown in **Exhibit 9.0.1**.

Exhibit 9.0.1 Publication 213 Example TTC Layout

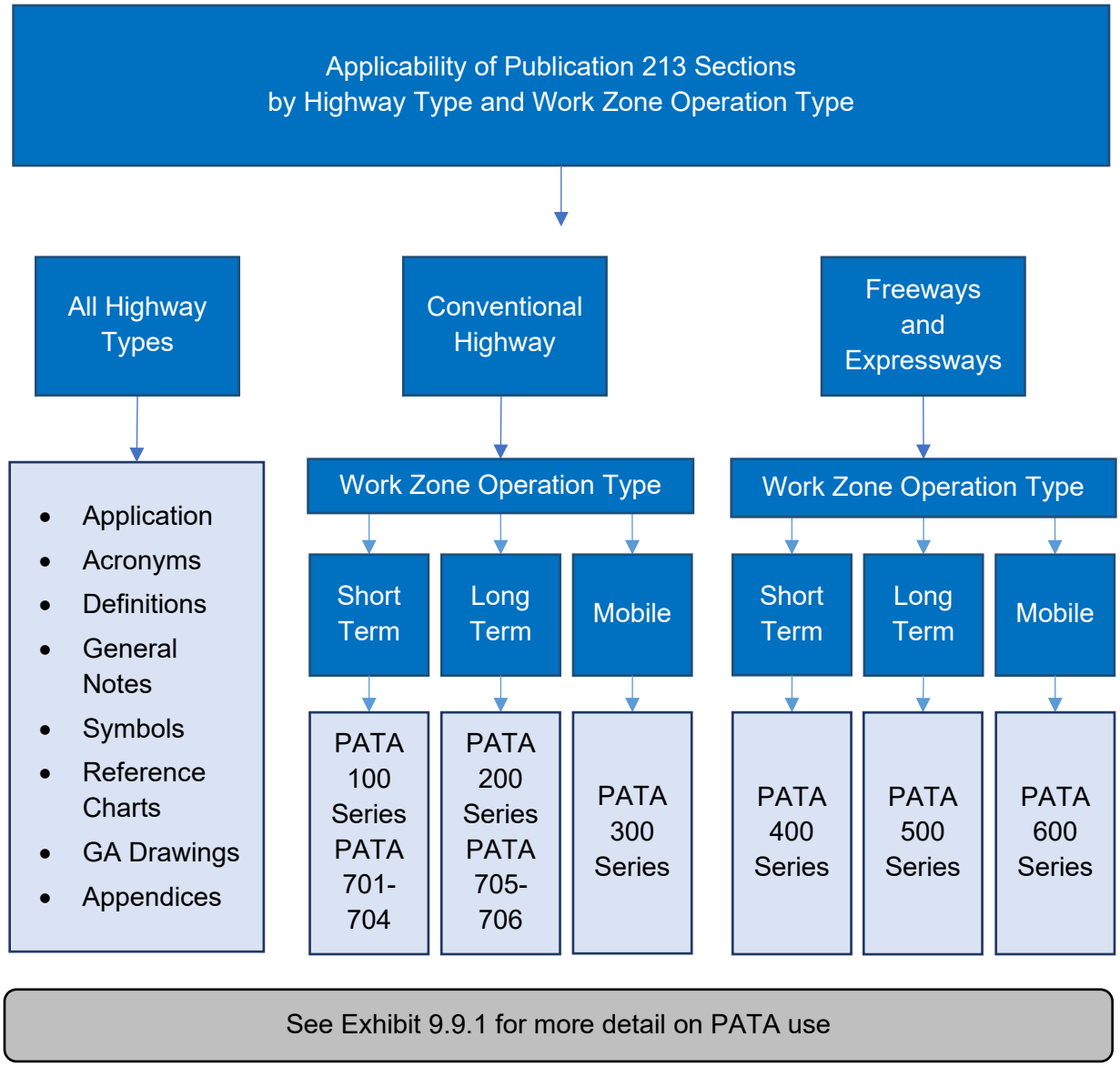


Publication 213 contains the following:

- **General guidance.** Applies to all highways and situations. Aids on applications, acronyms, definitions, general notes, symbols, reference charts, and other items.
- **General Applications (GA) typical drawings.** Notes and drawings with additional general information to be used on their own or in conjunction with a TCP.
- **Pennsylvania Typical Application (PATA) typical drawings.** Notes and drawings for applications on a variety of typically encountered situations. While not every situation is addressed, the information illustrated can generally be adapted to a broad range of conditions. **Exhibit 9.0.2** provides guidance on how specific PATA series apply to work zones based on work zone operation type and highway type.

Publication 213 PATA and GA drawings are regarded as minimum requirements. In many instances, appropriate TCPs are achieved by combining features from various PATA and GA typical drawings. By defining the project highway facility type, paired to the identified work zone operation type(s) will determine which Publication 213 PATA drawings apply to the project work zone.

Exhibit 9.0.2 Applicability of Publication 213 by Highway Type and Work Zone Operation



See Exhibit 9.9.1 for more detail on PATA use

9.0.4 – Law, Regulation, and Policy Flow

Exhibit 9.0.3 provides the hierarchy of how PennDOT's TTC policies and guidance relate to federal and state laws and regulations, which define the MUTCD as the national standard for uniformity of TCDs, including TTC.

Exhibit 9.0.3 – Law and Regulation or Policy Hierarchy MUTCD Through PennDOT Regulations and Publications

Federal Law-Regulations and MUTCD

- The MUTCD is approved by the FHWA as the National Standard in accordance with Title 23 U.S. Code, Sections 109(d), 114(a), 217, 315, and 402(a), 23 CFR 655, and 49 CFR 1.48(b)(8), 1.48(b)(33), and 1.48(c)(2).
- The MUTCD is incorporated by reference in and shall be recognized as the national standard for all traffic control devices installed on any street, highway, bikeway, or private road open to public travel (as defined in MUTCD, Section 1A.13).
- The MUTCD includes Part 6, which pertains to TTC.

Pennsylvania Regulations

- PennDOT adopts the MUTCD as published by the FHWA.
- The MUTCD is adopted in its totality except where Title 67 Pa. Code, Chapter 212, *Official Traffic Control Devices* clearly indicates that it is not adopted or that additional warrants or criteria are provided.

PennDOT Publications

- **Publication 212**. Publication 212, *Official Traffic Control Devices* is directly tied to Title 67 Pa. Code, Chapter 212 (and is sometimes referred to as Chapter 212). This publication acts as a supplement to the MUTCD.
- **Publication 213**. The traffic control phases shown in Publication 213 are consistent with the general provisions found in the most recent editions of Title 67 Pa. Code, Chapter 212 and the MUTCD as issued by FHWA.
- **Publication 408,** *Specifications.* This document details the standard construction specifications for PennDOT projects including construction items, materials permitted, installation, payment, and appropriate item number for reference in construction plans.
- All PennDOT publications are developed with the understanding that the MUTCD is adopted and that any PA revisions or additions are listed in Publication 212.

The publications used as the primary references for TTC include:

- **FHWA MUTCD (edition defined in Publication 212).** The federal document that provides guidance on traffic control setups and details appropriate signing and marking placement.
- **PennDOT Publication 212.** This document adopts the MUTCD to establish new regulations regarding additional study requirements, warrants, principles, and guidelines not included in the MUTCD, but specific to Pennsylvania, and to establish greater uniformity for the design, location, and operation of all official traffic signs, signals, markings, and other TCDs within Pennsylvania.
- **PennDOT Publication 213.** This document serves as the primary reference for short-term and long-term standard traffic-control setup and defines several design elements.
- **PennDOT Publication 408.** This document details the standard construction specifications for PennDOT projects including construction items, materials permitted, installation, payment, and appropriate item number for reference in construction plans.

9.1 – Fundamental Principles of Temporary Traffic Control

The control of road users (motorists, bicyclists, and pedestrians) through a temporary traffic control zone is an essential part of highway construction, utility work, and maintenance operations. When planning for temporary traffic control in these zones, it can be assumed that it is appropriate for road users to exercise caution. Even though road users are assumed to be using caution, special care is still needed in applying temporary traffic control techniques.

Special plans preparation and coordination with transit, other highway agencies, police and other emergency units, utilities, schools, and railroad companies might be needed to reduce unexpected and unusual road user operation situations. During temporary traffic control activities, commercial vehicles might need to follow a different route from passenger vehicles because of bridge, weight, clearance, or geometric restrictions. Also, vehicles carrying hazardous materials might need to follow a different route from other vehicles. Experience has shown that the fundamental principles of this chapter will assist road users and help protect workers in the vicinity of temporary traffic control zones. While these principles provide guidance for good temporary traffic control for the practitioner, they do not establish standards and warrants.

General plans or guidelines should be developed to provide safety for motorists, bicyclists, pedestrians, workers, enforcement/emergency officials, and equipment, with the following factors being considered:

- The basic safety principles governing the design of permanent roadways and roadsides should also govern the design of temporary traffic control zones. The goal should be to route road users through such zones using roadway geometrics, roadside features, and temporary traffic control devices. These devices should be as close as possible to those for normal highway situations.
- A temporary traffic control plan, in detail appropriate to the complexity of the work project or incident, should be prepared and understood by all responsible parties.

Road user movement should be inhibited as little as practical, based on the following considerations:

- Temporary traffic control at work sites should be designed on the assumption that motorists will only reduce their speeds if they clearly perceive a need to do so.
- Frequent and abrupt changes in geometrics such as lane narrowing, dropped lanes, or main roadway transitions that require rapid maneuvers should be avoided.
- Provisions should be made for reasonably safe operation of work, particularly on high-speed, high-volume roadways.
- Road users should be encouraged to use alternative routes that do not include temporary traffic control zones.

- Bicyclists and pedestrians, including those with disabilities, should be provided with access and reasonably safe passage through the temporary traffic control zone.
- When possible, roadway occupancy by contractors should be scheduled during off-peak hours including consideration of night work.
- Early coordination with officials having jurisdiction over the affected cross streets and providing emergency services should occur regarding roadway or ramp closings.

Motorists, bicyclists, and pedestrians should be guided in a clear and positive manner while approaching and traversing temporary traffic control zones. The following principles should be applied:

- Adequate warning, delineation, and channelization should be provided to assist in guiding road users in advance of and through the temporary traffic control zone or incident site by using proper pavement marking, signing, or other devices that are effective under varying conditions. Providing information that is in usable formats by pedestrians with visual disabilities should also be considered.
- Permanent traffic control devices inconsistent with intended travel paths through temporary traffic control zones should be removed or covered. However, in short duration and mobile operations, where visible permanent devices are inconsistent with intended travel paths, devices that highlight or emphasize the appropriate path should be used.
- Flagging procedures, when used, should provide positive guidance to road users traversing the temporary traffic control zone.

Provisions for effective continuity of transit service should be incorporated into the temporary traffic control planning process because often public transit buses cannot efficiently be detoured in the same manner as other vehicles (particularly for short-term maintenance projects). Where applicable, the temporary traffic control plan should provide for features such as temporary bus stops, pull-outs, and satisfactory waiting areas for transit patrons, if applicable (see the MUTCD for additional transit issues to consider for temporary traffic control).

Provisions for effective continuity of railroad and/or rail transit service, as well as acceptable access to abutting property owners and businesses, should also be incorporated into the temporary traffic control planning process.

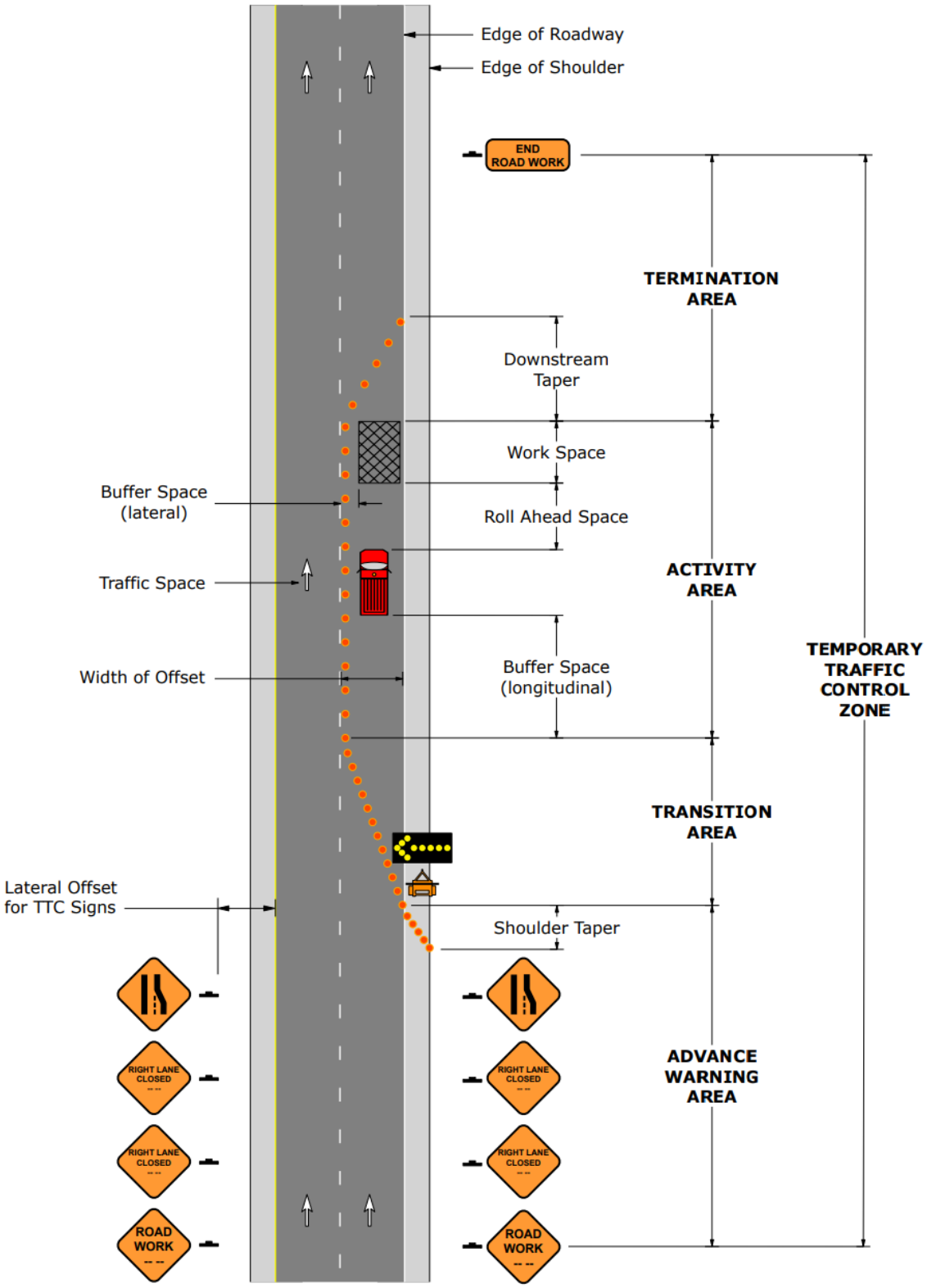
Reduced speed zoning should be avoided as much as practical. Reduced speed limits should be used only in the specific portion of the temporary traffic control zone where conditions or restrictive features are present. However, frequent changes in the speed limit should be avoided.

9.2 – Component Parts of Temporary Traffic Control Zones

A temporary traffic control zone is an area of a highway where road user conditions are changed because of a work zone, police, or other authorized personnel. A work zone is typically

marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign to the END ROAD WORK sign or the last temporary traffic control device. Traffic control zones are divided into five areas: the advance warning area, the transition area, the activity area, and the termination area. **Exhibit 9.2.1** illustrates these four parts. Additional detail is provided in Publication 213.

Exhibit 9.2.1 Component Parts of a Work Zone



9.2.1 – Advance Warning Area

The advance warning area is the section of highway where road users are informed about the upcoming work zone or incident area. The advance warning area may vary from a single sign to a series of signs in advance of the temporary traffic control zone activity area. Typical distances for placement of advance warning signs on expressways and freeways should be longer because motorists are conditioned to uninterrupted flow. Therefore, the advance warning sign placement should extend on these facilities as far as two miles or more.

9.2.2 – Transition Area

The transition area is the section of highway where road users are redirected out of their normal path. When redirection of the road users' normal path is required, they shall be channelized from the normal path to a new path. In mobile operations, the transition area moves with the work space. Transition areas usually involve strategic use of tapers.

9.2.3 – Activity Area

The activity area is the section of the highway where the work activity takes place. The work space is that portion of the highway closed to road users and set aside for workers, equipment, and material and a shadow vehicle if one is used upstream. Work spaces are usually delineated for road users by channelizing devices or, to exclude vehicles and pedestrians, by temporary barriers. The work space may be stationary or may move as work progresses.

Since there may be several work spaces (some even separated by several miles) within the project limits, each work space should be adequately signed to inform road users and reduce confusion. The maximum length of the work space should not exceed four miles unless approved by the Highway Design and Technology Division. The traffic space is the portion of the highway in which road users are routed through the activity area.

Refer to Publication 213 for information on the buffer space, roll ahead space and the traffic space.

9.2.4 – Termination Area

The termination area shall be used to return road users to their normal path. The termination area shall extend from the downstream end of the work area to the END ROAD WORK signs. An END ROAD WORK sign, a Speed Limit sign, or other signs shall be used to inform road users that they can resume normal operations. Conditions may exist where posting the END ROAD WORK signs may not be helpful. For example, the END ROAD WORK signs should normally not be used if other temporary traffic control zones begin within a quarter-mile of the work zone terminating temporary traffic control.

9.3 – Work Zone Impacts Considerations

The essence of assessing and managing the work zone impacts of road construction and maintenance projects lies in:

- **Safety.** Maximizing the safety of road users and highway workers.
- **Mobility.** Maximizing mobility and accessibility on roadways.
- **Constructability.** Planning, designing, and building projects as effectively and efficiently as possible.

Safety, mobility, and constructability are the three critical work zone related issues that need to be addressed while planning, designing, and building road projects. Constructability can be defined as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. The objective of constructability is to facilitate rational bids and minimize problems during construction. Benefits of constructability include cost reduction, schedule adherence, higher productivity, enhanced quality, and more safety and convenience for the traveling public. Constructability reviews are performed to facilitate the practicality of construction and minimize project delays, changes, and costs, while at the same time maximizing productivity, quality, safety, and convenience.

As work zone impacts assessment is performed progressively through the various program delivery stages, the three basic issues of safety, mobility, and constructability are addressed in an iterative manner. Information from one stage feeds into the next, with the level of detail of the assessment progressively increasing from stage to stage. The objective is to achieve constructability without compromising safety and mobility. Safety, mobility, and constructability are affected by the following types of issues, including:

- Project characteristics.
- Travel and traffic characteristics.
- Corridor, network, and community issues.
- Design, procurement, and construction options.
- Work zone design and safety issues.
- TTC strategies.
- Transportation operations (TO) strategies.
- Public information (PI) strategies.

Exhibit 9.2.2 provides an overview of different work zone impacts considerations for each of these issues. This table is replica from FHWA's *Work Zone Impacts Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects*. Additional details on these considerations are provided throughout this document.

Exhibit 9.2.2 Work Zone Impacts Considerations

Project Characteristics
• Project type. • Project size, extent, duration, and complexity. • Roadway classification. • Area type (urban, suburban, rural).
Travel and Traffic Characteristics
• Traffic demand and volumes. • Seasonal and temporal variations in demand (hourly, daily, or weekly). • Occurrence of special events. • Percentages of different vehicular volumes (autos – Single-Occupancy Vehicle, High-Occupancy Vehicle; trucks; or buses). • Type of travel (commuter or tourist), freight corridor, transit corridor. • Public and private facility access issues. • Potential impacts of weather. • Other such similar characteristics.
Corridor, Network, and Community Issues
• Impacts of the project at both the corridor and network levels including parallel corridors, alternate routes, the transportation network, other modes of transportation, and impacts of other work zones in the vicinity of the project, either at the corridor level or the network level. • Impacts on nearby transportation infrastructure such as key intersections and interchanges, railroad crossings, public transit junctions, and other junctions in the transportation network. • Impacts on evacuation routes in the vicinity of critical transportation or other infrastructure.
Corridor, Network, and Community Issues
• Impacts on affected public properties, including parks, recreational facilities, fire stations, police stations, and hospitals. • Impacts of the project on affected private properties, including businesses and residences.
Design, Procurement and Construction Options
• Temporal alternatives for work performance such as season, month, day of week (weekend versus weekday), and time of day (nighttime versus day, off-peak versus peak). • Alternative lane closure strategies such as full closure, partial closure, crossovers, multiple lane closure, single lane closure, and impact of alternative traffic management strategies on lane-closure decisions.

- Alternative design solutions that address the durability and economy of maintenance of the roadway.
- Alternative design solutions and strategies that impact decision-making on right-of-way (ROW) acquisition.
- Alternative construction staging plans, and construction techniques and methodologies (e.g., accelerated construction techniques) that may have varying types and severity of work zone impacts.
- Alternative contracting methodologies such as design-build, A+B bidding, and incentive/disincentive contracting.

Work Zone Design and Safety Issues

- Cross-sectional issues such as lane widths, shoulder availability and widths, and number of lanes available for travel.
- Longitudinal issues such as taper widths, taper lengths, and stopping sight distance.
- Horizontal and vertical sight distance.
- Project signing and advance warning.
- Roadside devices and safety.
- Work area separation, channelization, and protection (e.g., positive separation, barrels, cones, clear zone considerations, construction zone intrusion detection).
- Work area and worker delineation (visibility, retroreflectivity, etc.).
- Work site access and access points.
- Visibility issues (e.g., night-time work, lighting, fog).
- Curvature and gradient – vertical and horizontal.
- Speed – posted speed limits, speed zoning, etc.
- Work zone enforcement (e.g., use of uniformed police officers and/or patrol cars, active enforcement using radar guns and/or automated enforcement).

TTC Strategies

- Traffic safety and capacity requirements.
- Alternate route scenarios.
- Potential impacts on other corridors, nearby intersections/interchanges, and the larger transportation network.
- Lane closure types and strategies (full-closure, lane-width restrictions, cross-overs, positive separation, etc.).
- Work zone and work area configurations.
- Traffic safety and control checklists for developing a TMP.

TO Strategies

- Deployment of ITS technologies for work zone traffic monitoring and management.

- Provision of real-time traveler information to the public, including web-based information.
- Application of transportation systems management (TSM) and corridor management strategies, including mitigation treatments for alternate routes (e.g., traffic signal timing adjustment on affected corridors), and alternate modes (e.g., public transit subsidies, incentives, and special programs).
- Coordination of transportation management with existing regional transportation management centers (TMCs).
- Conduct of mobility and safety reviews and audits.
- Speed enforcement and management in work zones using either police officers or automated techniques.
- Traffic incident management plans for work zones.
- Policies on work zone traffic management during emergencies (e.g., hurricane evacuations).

PI Strategies

- Provision of project and work zone information prior to the commencement of the work in order to make the public aware of the expected work zone impacts and the State's actions to mitigate the impacts.
- Recommendations to the public on commuter alternatives, such as information on alternate routes and/or modes.
- Provision of information on changing conditions on the project during implementation (e.g., changes in lane closure scenarios, construction staging, construction times, or alternate routing).
- Obtaining public input for the development of appropriate work zone impacts management strategies during the planning and design phases of the project; refinement of work zone management strategies during project implementation; and feedback on performance of the work zone and the project following the completion of the project.
- Dissemination of information through brochures, pamphlets, and media sources including newspapers, television, radio channels, and web sites.
- Public meetings and hearings.
- Coordination and cooperation with affected public and private parties.

9.4 – Different Work Zone Types

According to FHWA, a work zone is an area of a trafficway with highway construction, maintenance, or utility-work activities. A work zone is typically marked by signs, channeling devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or flashing lights on a vehicle to the END ROAD WORK sign or the last traffic control device. A work zone may be for short or long durations and may include stationary or mobile activities. Inclusions:

- Long-term stationary highway construction such as building a new bridge, adding travel lanes to the roadway, and extending an existing trafficway.
- Short-term stationary utility work such as repairing electric, gas, or water lines within the trafficway.
- Mobile highway maintenance such as striping the roadway, median and roadside grass mowing/landscaping, and pothole repair.

The descriptions that follow examine the different operation types and methodologies for TTC, revolving around the impact to the roadway, the driving force for the impact, and the duration of the impact. In some cases, these descriptions may overlap on projects.

9.4.1 – Stationary or Mobile

Stationary operations occupy a fixed location for a period of time, and the TTC strategy is based on the space required by the stationary operation and the duration of its impact. In many cases, standard applications from Publication 213 can be utilized for both short and long-term impacts. However, stationary operations often require project-specific TCPs, particularly for work on major facilities (e.g., major crossings, interstate and national highways).

In a mobile operation, the work zone beginning and ending points move as the work activity moves intermittently (100 ft per 15 minutes) or continuously (up to 24 hours). Publication 213 provides a complete definition of mobile operations and the permitted work as part of a mobile operation.

Examples of mobile operations may include:

- Milling.
- Roadside maintenance.
- Pavement marking installation.
- Mechanized patching.

These mobile operations often use Publication 213 standard traffic control applications.

9.4.2 – Short-Term or Long-Term



Short-term operations are defined as those lasting up to 72-hours, while long-term operations exceed 72-hours. As discussed in Publication 213, this determination plays a role in identifying the type of traffic control that is required since the TTC standards differ for short and long-term operations. For example, long-term detours have more complex signing than short-term detours. Often, a

project requiring a specific TCP will require some combination of short- and long-term traffic control, depending on construction operations and MPT needs.

9.4.3 – Off Roadway (No Roadway Encroachment)

Some projects do not involve physical work within the immediate roadway vicinity but they may still have potential direct or indirect impacts to traffic operations. These potential impacts need to be considered evasive or distracted driving that may disrupt the normal traffic flow. Examples of such projects may include:

- Work outside of the clear zone.
- Nearby blasting or controlled burns.
- Work above travel lanes.
- Borings below travel lanes.
- Sinkhole restorations.
- Traffic-signal timing adjustments.

In addition to TCP considerations, there are often state or municipal permit requirements. Traffic control for these types of projects often involves maintenance of traffic at a “tie-in” or connector point back to the primary facility.

9.4.4 – Special Events

Often, major planned events will require specific TCP to accommodate traffic volume and distribution, significantly different from that typically experienced on the roadways adjacent to the events. These events may include:



- Sporting events.
- Concerts.
- Political gatherings.
- Religious gatherings.

Impacts from special events can range from localized street closures to strategies requiring access and mobility restrictions. When developing plans for these types of events, consider that large stakeholder groups are often involved and interagency coordination among the following is critical:

- Transportation facility owners.
- Transit operators.

- Event security.
- Event organizers.
- Local emergency response personnel.
- Local jurisdictions and political leaders.

Unique factors to consider in a special-event TCP include:

- Parking accommodation.
- Interfaces between private vehicles and transit.
- Pedestrian ingress and egress.
- Evacuation planning.
- Security requirements.
- Contraflow traffic operations.
- Manual intersection traffic control and staffing requirements.
- Separation of vehicle types (e.g., private vehicles, recreational vehicles).

These plans are rarely “one size fits all”; rather, they are often highly localized and event specific. Some plans may be highly repeatable (e.g., sporting events, annual festivals, and concerts), while others may be used only once (e.g., visiting foreign dignitaries, international sporting events).

9.4.5 – Historical or Pre-Planned TCPs

Throughout a facility’s history, maintenance and repair operations may require the use of specific TCPs, such as bridge repair and inspection, or historical slide repair. It is acceptable to recycle historical TCPs, and public and private engineers/designers may be willing to share archived TCPs at their discretion, per common professional practice.

When considering the use of any historical TCP, the plan needs to be validated and perhaps updated before re-using. Do not assume that an old TCP was successful or a best practice.

Check/validate all items before re-using a historical TCP. A list of typical items includes:

- Comparison of roadway geometry.
- Comparison of traffic volumes. Operationally, if current traffic counts or reasonable estimates are not available, control counts may be warranted to compare with the design parameters of the historical TCP.
- Operational changes.
- Changes in roadway users.
- Changes in right-of-way.

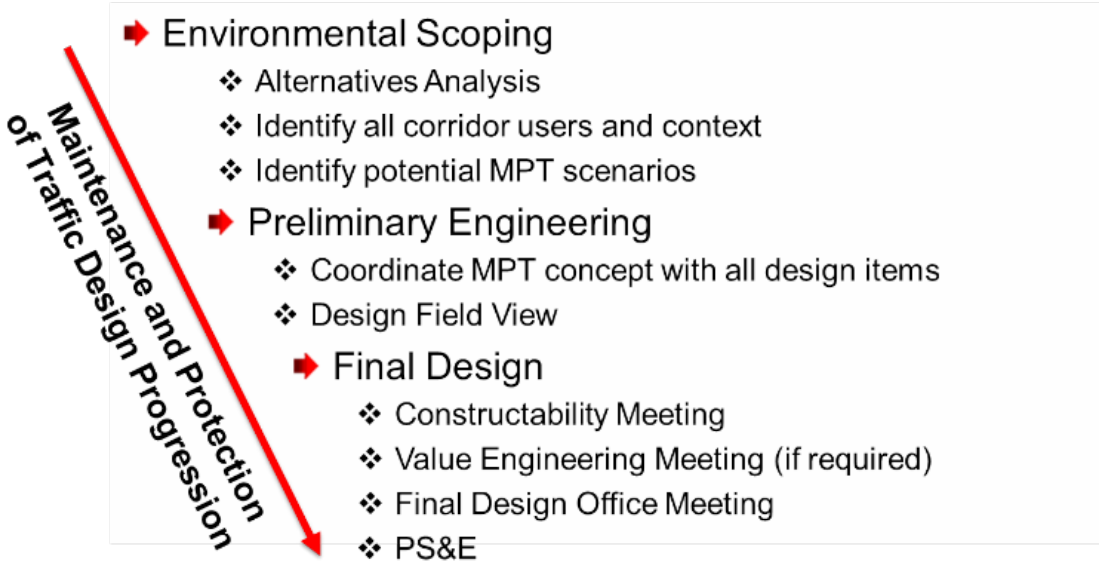
- Environmental context.
- Changes to PennDOT or Federal standards.
- Historical feedback on traffic control (if available).

Any consequential changes to the above items may void a historical TCP, and a new or revised plan may be warranted.

9.5 – Project Delivery Phases Linkage to Work Zone Assessment

The project design process involves various project delivery phases. The level of detail and type of work zone assessment varies depending upon the project delivery phase. For example, during an alternatives analysis phase, the work zone impacts assessment may involve qualitatively identifying the potential work zone impacts of a project, whereas, during preliminary and final design it will involve a more detailed analysis of the impacts. Project design activities (from Preliminary Engineering through Final Design) identify and address various details, such as issues, impacts and clearances, as the TCP development progresses from concept to an actual plan with specifications and estimates. **Exhibit 9.5.1** generally shows the project delivery phases.

Exhibit 9.5.1 Generalized Project Delivery Phase



Project-level work zone impacts assessment practice includes systematically assessing work zone impacts through the project development stages and by looking at work zone impacts

mitigation from a transportation management perspective rather than just a traffic control perspective.

A work zone impacts assessment should be conducted for each alternative solution being evaluated. The purpose is to consider work zone impact issues in selecting the best alternative(s). The idea of conducting a work zone impacts assessment for every alternative may seem daunting. However, the assessment will always be proportional to the type, size, and complexity of the project. For many projects a qualitative assessment may be sufficient, with quick identification and documentation of work zone impacts issues.

9.5.1 – Environmental Scoping and Alternatives Analysis Activities

During the scoping and alternatives analysis phase, the major categories of information that may be needed include:

- **Project Scope**. Including goals and objectives, location, type of work, context, land use, roadway classification, project length, and duration.
- **Roadway/Traffic Characteristics**. Including number of lanes, roadway capacity, cross-sectional details, pre-existing safety issues, grade, curvature, and traffic (all modes) demand/patterns/volumes, available alternate routes, crash history.
- **Other Influencing Factors**. Including community and public outreach information, weather variation, school-zone issues, bike routes, emergency vehicle traffic issues, whether project is located in a Central Business District (CBD), presence of other nearby transportation junctions (e.g., railroad crossings, transit junctions), availability of alternate modes, tourist traffic issues, upcoming and planned special events, coordination issues with other projects, utility coordination issues, and local regulations (e.g., noise restrictions).

The types of information listed above are intended to serve as a guide for the different factors that may influence work zone impacts. All of the above information may not be needed – it may be sufficient to just take note of major issues that are apparent or readily identifiable. For example, if there are no viable alternate routes for a project, that information needs to be noted and recognized, so that it may be accounted for when identifying work zone traffic control and management strategies.

Hard data (e.g., traffic counts, crash records) may not be required at this point. It may be sufficient to qualitatively identify issues (e.g., whether there are any pre-existing safety issues, whether there is a history of weekend congestion at the location). Such information, if noted at this early stage, will help in the selection of a suitable work zone strategy for the project. For example, if there is a major event that occurs every Memorial Day at a location nearby, construction starting before June may not be a good option for the project. If hard data is readily available, it may be useful to note the availability of data.

9.5.1.a – Project Scoping and Alternatives Considerations at a Screening-Level

Project scoping and alternatives activities (from initial scoping through project outset) are important for setting the best TTC direction and TCP development. Phasing changes based on the design, permissible methods, and anticipated impacts at scoping will carry through the entire design process. It is essential that alternatives be analyzed, and that project "Significance" and allowable impacts are discussed and defined at this phase.

The objective of this step is to get a first-cut understanding, for each alternative, of potential work zone impacts focusing on minimizing area disruption. The assessment is generally qualitative and relies upon engineering judgment and available information. The result of this screening level assessment will be a summary-level list of the work zone impacts and related issues for the project.

At this point in the project, it is important for the designer to identify the potential impact area and coordinate this area with the environmental analysis. Work zone impacts of some projects may be restricted to the immediate vicinity of the work zone or may be felt on the corridor on which the work is being performed. However, the work zone impacts of some projects may be felt on a good portion of the corridor and roadway network, affecting other roadways, interchanges, intersections, and/or multi-modal junctions in the transportation network. This is especially true for work zones in urban/suburban settings (e.g., commercial business districts (CBDs), arterial grid networks).

Scoping and alternatives work zone impacts assessment may include the following activities:

- **Identification of High-level Construction/Traffic Control Approach(es) for the Project.** The types of issues to be considered include:
    - **Potential construction approach(es).** Examples include phased construction, design-build, asphalt pavement vs. concrete pavement, and pre-cast concrete members vs. cast-in-place concrete members.
    - **Potential traffic control and management approach.** Examples include lane closure, total roadway closure, shoulder closure, use of shoulder for travel during construction, cross-over, and use of detour routes.
    - **Potential time of construction.** Examples include off-peak, night work, weekend work, intermittent closures, as well as winter shutdowns and multi-year activities.
- **Identification of Safety Issues**. Issues to be considered include:
    - **Pre-existing safety issues.** Examples include high crash history at the project location, known safety issues, curve issues, line of sight issues, weather related safety issues, lack of adequate shoulder width, and prevailing speeds.
    - **Safety implications of potential construction approach(es).** Examples include implications of night work, lane width issues, lane-closure related safety issues, channelization and work area separation issues, construction staging

areas, construction traffic access issues, and management/enforcement of speed in advance of and through the work zone.

- **Identification of Traffic Capacity/Demand Issues.** Issues to be considered include:
    - **Traffic and travel characteristics at the project location.** Examples include pedestrian and bicycle traffic, heavy traffic volumes, congested urban/suburban corridor, rural corridor with heavy truck traffic, and recreational or seasonal traffic issues.
    - **Recurring congestion issues.** Examples include capacity and level of service (LOS) issues, unidirectional peak hour congestion, heavily congested urban/suburban corridor, high-volume interchange(s), and pre-existing bottlenecks and chokepoints in the vicinity of the project.
    - **Non-recurring congestion issues.** Examples include high potential for incident related traffic congestion, special event traffic issues, and weather-related traffic delays.
    - **Mobility implications of potential construction approach(es).** For example, lack of shoulders during construction may require a work zone traffic Incident Management Plan (IMP). Doing work at night may preclude the need for an elaborate IMP. Traffic capacity and management issues may exist on a detour route.
- **Identification of Community Impacts and Related Issues**. This involves the identification of the work zone impacts on the community, businesses, and residents likely to be affected by the project. Types of issues to be considered include:
    - **Accessibility issues.** Examples include business access relocation, ramp-closure related access issues, and detour related mobility impacts on communities.
    - **ROW related issues.** Examples include property relocation, easement, and realignment of property lines.
    - **Other coordination issues.** Examples include utility-related issues, and construction noise issues.
- **Identification of Combined Impacts and Coordination Issues with Nearby, Concurrent Projects**. This involves the identification of nearby and/or concurrent projects and assessing whether the projects may have an impact on the project under consideration, or vice-versa. It also involves the assessment of potential combined impacts of multiple projects at the corridor/network level. This assessment may be performed using a qualitative fatal-flaw type approach to identify potential conflicts and coordination opportunities. The process may be informal (e.g., based on any readily available information), or formal (e.g., through a coordination process for identifying district/region-level project coordination issues).

- **Identification of Whether the Project is a Significant Project**. Some projects are likely to have greater work zone impacts than other projects (e.g., greater congestion, more effects on road safety, or greatly reduce access to businesses or event venues). Such projects may warrant additional attention during project delivery and additional funding for work zone transportation management strategies.

9.5.1.a.i – Determination if Project is Significant

Beginning in the Project Scoping Phase, an estimation of impacts resulting from the facility's construction is undertaken to determine if a project is considered "Significant". According to Publication 46, *Traffic Engineering Manual*, a Significant Project meets three criteria: 1) the project is located on a fully-controlled, limited access highway such as an interstate, PA Turnpike, or freeway (interstate look-a-like); 2) a project occupies a location for more than 3 days with either intermittent or continuous lane closures; and 3) the traffic control set-up results in additional travel time greater than 20 minutes for two consecutive hours. **Exhibits 9.5.3, 9.5.4, 9.5.5, and 9.5.6** provide flow charts for decision making on determination of Significance, decision points within the project development process, and appropriate analysis tools to use in evaluating the capacity analysis impacts of differing traffic-control strategies. There are a variety of potential software packages available that can be utilized to identify potential congestion impacts during facility construction and the potential cost to users. The type of facility and available data will determine the appropriate software package. Refer to Publication 46, Chapter 6, *Temporary Traffic Control*, for additional guidance on potential software and the benefits and limitations of each.

Exhibit 9.5.3 – Determination of Significant Project

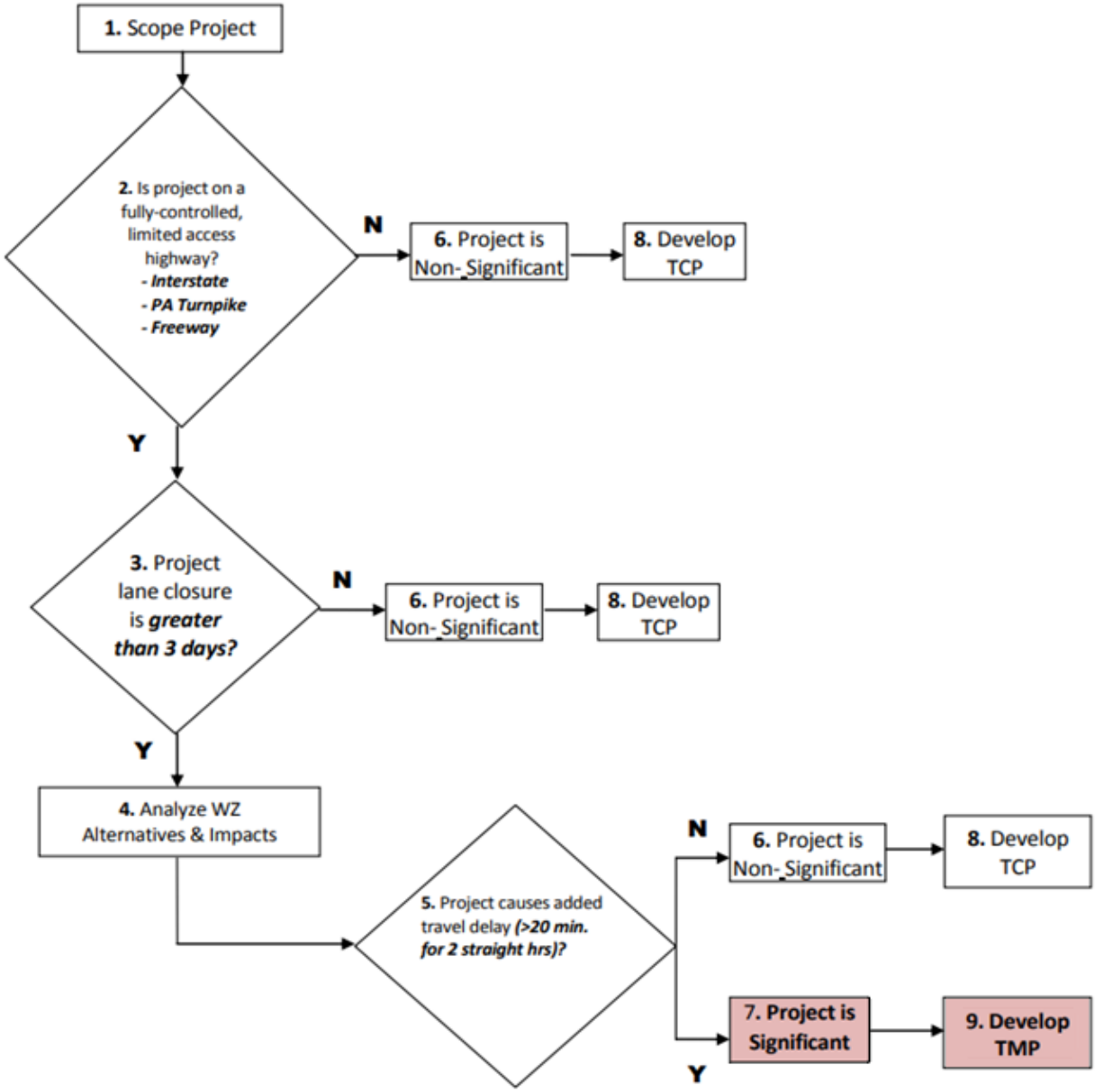


Exhibit 9.5.4 Determination of Significant Project – Step Descriptions

Steps	Process Title	Comments
1	Scope Project	• Refer to Design Manual (DM) 1C, Chapter 2
2	Project Location	• Is the project located on an interstate (including the PA Turnpike) or a freeway with fully- controlled, limited access?
3	Project lane Closures	• Will the project have either intermittent or continuous lane closures (including detours) for more than 3 days?
4	WZ Alternatives Analysis & Impacts	WZ Alternative Analysis - identify **potential, practical (viable)** WZ alternative setups which fit the nature of the project and will minimize traffic impacts to motorists (could be 1 or more). • Conduct WZ impacts analysis for these viable WZ alternatives as indicated below. WZ Impacts - use FREEVAL-PA or other similar computer modeling programs. • Note: Prior analysis (≤3 yrs. old) done for a recent similar project may be used to estimate impacts in lieu of new model development, if project characteristics are similar (WZ setups, location, traffic volumes, grades, access, etc.); if this prior analysis & impacts meets acceptable delays, there is no need for additional impact analysis.
5	Traffic Delay Thresholds	Acceptable Project Delay Impacts (Project is Non-Significant) • Additional (project-related) travel time through the project area (includes detours) is ≤ 20 minutes. Unacceptable Project Delay Impacts (Project is Significant) • Additional (project-related) travel time through the project area (includes detours) is > 20 minutes for time periods of 2 or more consecutive hours. *Note: Added travel time shall be determined as per Step 4 (under WZ Impacts).*
6	Non- Significant Project	Project does not meet policy parameters for being a Significant Project • For selected WZ approach, request approval as a Non-Significant Project. Refer to Exhibit 9.5.3. • Traffic delay analysis and preliminary project mitigation strategies (for the selected WZ approach) must be submitted & approved as part of **the Non- Significant** determination process.

Steps	Process Title	Comments
7	Significant Project	Project meets policy parameters for being a Significant Project • For selected WZ approach, request approval as a Significant Project. Refer to Exhibit 9.5.3 • Work zone alternative analysis and preliminary project mitigation strategies (for the selected WZ approach) must be submitted & approved as part of the Significant Project determination process.
8	Develop TCP	Must develop and complete a Traffic Control Plan (TCP) for the approved WZ approach. • While a formal TMP submission isn't required, appropriate-level TMP elements need to be considered on these Non-Significant Projects as well. • Consider the development of an appropriate level TMP for the project, even though not required by policy.
9	Develop TMP	Must develop and complete a Transportation Management Plan (TMP) for the approved WZ approach. • Includes a Traffic Control Plan (TCP), Transportation Operations Plan (TOP) and Public Information Plan (PIP).

Exhibit 9.5.5 Determination of Significant Project – Submission Approval Process

Approval Process	PennDOT Oversight (PennDOT has approval authority)	Federal Oversight (FHWA has approval authority)
Non-Significant Project Determination	**Step 6** • **District Executive must approve** the traffic delay analysis & preliminary project mitigation strategies. • Bureau of Design receives a copy of the DE approval along with the delay analysis.	**Step 6** • Bureau of Design must review/concur with the traffic delay analysis & preliminary project mitigation strategies. • **FHWA must approve.**
Significant Project Determination	**Step 7** • District Executive must review/concur with the work zone alternatives analysis & preliminary project mitigation strategies. • **Bureau of Design must approve.**	**Step 7** • Bureau of Design must review/concur with the work zone alternatives analysis & preliminary project mitigation strategies. • **FHWA must approve.**

Exhibit 9.5.6 Work Zone Safety and Mobility (WZSM) in Project Development Process – Key Items

Project Development Stage	Key Items Due
Planning	• Potentially Significant Projects shall be identified as early in the project development process as possible so that work zone impacts may be fully evaluated, appropriate funding allocated and overall network & region- wide impacts considered. • Districts shall work with MPOs and RPOs in the programming of projects to consider minimization of road user impacts and appropriate sequencing of projects. The cumulative impacts of multiple projects in the region's TIP shall be considered.
Scoping Field View (SFV)	Preliminary considerations shall be given to potential work zone alternatives & impacts and to what degree those considerations may influence the evaluation and selection of a build alternative. Additional studies and information needs shall be identified that will assist in determining whether the project is Significant. Determine the status of the project as: • Non-Significant • Significant • To be determined (TBD)
Preliminary Engineering	An analysis of work zone alternatives & impacts is required prior to the Design Field View, this analysis shall be conducted using prior analysis or prior documented delays for another project through use of FREEVAL-PA or other similar computer modeling programs.
Prior to Design Field View (DFV)	Make final determination of the project as: • Non-Significant • Significant Note: Approval of either the delay analysis or work zone alternatives analysis must occur prior to the DFV. Attach final approvals to the ECMS project development checklist.
Design Field View (DFV) Submission	• Non-Significant Projects – provide a DFV level TCP. • Significant Projects – provide a draft TMP, including DFV level TCP.
Final Design Office Meeting (FDOM) Submission	• Non-Significant Projects – provide a Final TCP. • Significant Projects – provide a Final TMP, including Final TCP.

9.5.1.b – Supplemental Reports and Design Documents

As part of traffic control for Significant Projects, the following items must be provided to contractors as part of the bid package:

- Transportation Management Plan (TMP) (which includes a TCP).
- Draft Incident Management Plan (IMP).

These documents are critical in providing the contractor with the scope of coordination required as part of the TCP, as well as any additional requirements for changeable message signs, devices, stationary or detour signage, or materials not denoted in the project summary and tabulations. The requirements for these documents are covered in Publication 46, Chapter 6.

9.5.2 – Preliminary Engineering

At this stage in project development, the main objective is to identify ways to implement the project and develop appropriate plans and design concepts, including an understanding of the work zone impacts. The key to work zone impacts assessment during preliminary engineering lies in advancing work zone considerations as early as possible in project development; identifying the potential work zone impacts of the project early enough so that work zone related project delays or costs are not incurred in later design stages; and identifying and developing work zone management strategies in a more streamlined manner. Therefore, during preliminary engineering more project-specific information is collected and synthesized.

To help identify the project-specific information that is needed, the designer should consider these and other questions when assessing work zone impacts during preliminary engineering:

- Is the project definition any different than what was identified during planning and are there additional work zone impacts concerns that need to be addressed?
- Given the concept design for the project, what are the possible construction staging and traffic control approaches that can be used for the project?
- What are the work zone impacts of the potential construction staging and traffic control approaches?
- Are there any other concurrent projects nearby that were not identified during planning/scoping that may have an impact on the project?
- Based on site visits, are there any other coordination issues such as utilities, environmental, ROW, and community?

9.5.2.a – Why Be Concerned About Work Zone Impacts During Preliminary Engineering

The bulk of work zone impacts assessment has typically taken place during the later design stages of project development. This can be a problem if work zone issues identified during the later design stages lead to changes in the overall project approach. Often, designers and construction staff express frustration when they encounter issues that could delay project development and/or implementation. For example, during design if it is identified that an alternate route chosen for a particular project will also be under construction at the same time, the entire transportation management approach for the project may have to be changed, potentially resulting in project delays and increased costs. If such issues are identified just prior to, or during construction, it could be even more problematic because construction may have to be stopped on the project. As a result, sometimes to keep the project moving, decisions may be made that may not best address the work zone safety and mobility needs of the project.

Guidance

Key Decisions and Items:

- Advancement of scoping preferred alternative into Preliminary Engineering.
- Determination of the extent of traffic control impacts.
- Completion of a Significant Project determination.
- Identification of potential safety issues.
- Communication of anticipated impacts to public.
- Concurrence with approved environmental clearance document.
- Identification of project specific impacts (e.g., temporary signal locations, impacts to corridors/existing bottlenecks, roadway closures and detour routes, project ITS integration).
- Construction phasing/sequencing.
- Preliminary and Design Field View TCPs, with work areas, lane reductions and shifts/tapers, typical sections with lane widths, and barrier and device placement.
- Incorporation of feedback from public involvement.

9.5.2.b – Compile Project Information

Compilation of available project information includes:

- **Project planning material from the systems planning phase.** This material includes the project definition and scope and the other information on the PennDOT Connects form. Utilizing this information, the work zone strategy will now be refined based on more project-specific information to develop the "Preliminary Work Zone Strategy." This preliminary work zone strategy will have more project-specific detail and will serve as a foundation for the subsequent design stage. This initial strategy will be identified from roadway/traffic

characteristics, other contributing factors (public/community issues, weather considerations, and special events, etc.)

- **Preliminary engineering development information.** This is the concept design for the project and consists of preliminary decisions on roadway alignment and ROW, cross-sectional details, elevation and super-structure details, and other information necessary to initially depict what the new facility will look like after it is built. In the case of preservation projects, the new facility may not be very different from the current facility. For rehabilitation, reconfiguration, and new projects, the vision of the new facility may be drastically different from the present state. The information that is collected in this stage is essential to be able to perform work zone impacts assessment in later steps and at later stages. The following are some examples of information that need to be collected and/or developed:
    - Engineering plans, documents, and supporting information that define the project environment in detail.
    - Information from available or ongoing studies and environmental/NEPA assessments (e.g., project constraints, impact mitigation requirements, recommended assessments and/or analyses).
    - Topographical, soil, and hydraulics information.
    - Existing and future roadway and traffic characteristics.
    - Base plans showing existing and planned roadway alignment, existing and planned ROW, existing and proposed traffic control devices (e.g., signs, signals, pavement markings), and existing and proposed overhead/underground utilities.
    - Information on other nearby transportation facilities and/or junctions (e.g., adjacent routes, highway interchanges/intersections, railroad crossings, rail stations, bus stops).
    - Coordination issues with other ongoing or planned projects.
    - Any other relevant information specific to the project location (weather, special events, etc.).

9.5.2.c – Reassess Project Definition

This step involves performing a reality check as to whether the previously developed project definition still holds true, given that there is more detail available on the project. Additional data may be collected in this phase to provide a more complete set of information with which to complete the assessment and evaluation of project and work zone issues. Examples of the types of additional data that may be required to redefine the project definition are:

- Additional traffic counts.
- Information from other projects and studies.

- Information related to project specific issues and concerns, such as:
    - Pedestrian counts in residential areas.
    - School bus schedules.
    - Existing incident response times from accidents in the project area.
- Coordination issues with other projects (within the impactable vicinity).
- Posted roadways and bridges on potential diversion and detour routes.

All data elements may not be required for all projects. The required data elements and the level of effort will depend on agency policy/procedures and on the type, duration, complexity, and expected work zone impacts of the project.

The following are examples of issues that may be considered in reassessing the project definition:

- Project purpose, location, extent, duration, nature of work, and type of work zone.
- Roadway alignment and ROW issues.
- Cross-sectional details, elevation and super-structure details.
- Related pavement and structural needs.
- Soil, hydraulics, and environmental needs.
- Utility related infrastructure and coordination issues.
- Design parameters.

9.5.2.d – Develop Candidate Construction Approaches

This is where a preliminary decision as to how the project will be built is made and an overall strategy for the construction (e.g., phased construction, design-build) and the work zone type (e.g., night work, lane-closure, cross-over, full-closure) is developed. Given the information available at this juncture, the designer may now consider and develop candidate construction approach(es). The planning-level construction staging and traffic control approaches are revisited and potentially modified, and other alternatives are developed. Transportation management issues related to the project and candidate construction, staging, and traffic control approaches are also identified.

9.5.2.e – Perform Preliminary Work Zone Impacts Assessment

Preliminary engineering is accomplished by conducting field investigations, surveys, and public/community outreach using the principles of highway and traffic engineering. This is also the phase where potential ROW acquisition issues; environmental impact/NEPA issues, including impact of the new facility and the construction project on the environment; and

community impact issues, including impact of the new facility and the construction project on the community, are addressed. Therefore, this is a very suitable time to incorporate work zone impacts issues into the investigations and assessments that are already being performed. The information obtained from the assessments can help PennDOT take further action, such as involve appropriate personnel, contact stakeholders, and take necessary actions to facilitate the availability and use of transportation management strategies for construction.

This step is expected to be a qualitative assessment involving a quick identification of work zone impacts issues, re-confirmation whether a project is a Significant Project, identification of potential work zone management strategies, and determination of whether more detailed (quantitative) work zone impacts analysis is needed. The assessment will be based on the candidate construction staging, traffic control approaches, and transportation management issues, and will help flush out and identify potential concerns prior to Design Field View (DFV). In later stages of design, designers may use the work zone issues and impacts identified in this step to "design their way out of" any potential problems or obstacles.

It is important at this stage to re-confirm whether a project is Significant because more detailed project specific information is now available. For example, during preliminary engineering the project approach may be modified to construct the project at night as opposed to the planning level assumption of constructing the project during the day. As a result, the work zone impacts of the project may be lower than what was anticipated in the systems planning assessment, resulting in a re-classification of the project to a Non-Significant Project. Conversely, an assumption may have been made during planning that designated a project as Non-Significant. Additional preliminary engineering data during this step may void that assumption, leading to a re-classification of the project as Significant.

The activities that need to be performed in preliminary engineering are focused on identifying alternatives that best meet a given need and have the least impacts from an environmental, work zone, and societal perspective. The following are some examples of issues to consider.

- If the project strategy has changed from what was originally assumed are the work zone impacts any different now, and are there additional issues that should be addressed? Does the potential impact area of the project need to be reassessed or identified?
- Do ongoing (or completed) environmental/NEPA or other studies provide any constraints and information that may limit project location, design, and construction options?
- What are the safety implications (e.g., lane width issues, lane/shoulder closure issues, line-of-sight issues, horizontal and vertical curvature, ramp-closure issues) of the potential construction approaches?
- What are the traffic/mobility implications of the potential construction approaches? (e.g., lane closure restrictions, potential choke points, whether delays are expected, need for detour routes, potential impact on detour routes, potential impact on other transportation infrastructure such as railroad crossings and interchanges).

- Identify and list out major impacts (safety and mobility) of the project and possible mitigation strategies, including project/work zone design options, contracting strategies, and other mitigation measures.
- Based on the concept design and potential construction and work zone strategies, is the originally assumed designation of Significant Project still valid for my project?
- Based on site visits, are there any other coordination issues such as utilities, environmental, ROW, and community?
- Are there any obvious issues that can be addressed right away and noted down so that they need not be addressed in later design stages (e.g., history of high weekend traffic volumes at the project location due to tourist traffic as a result of which weekend lane closures may not be a good option)?
- The level of work zone impacts assessment needed for the project: Is a high-level (qualitative) assessment sufficient or will a more detailed (quantitative) analysis be needed?

9.5.2.f – Analyze Potential Impacts (Optional)

Typically, work zone impacts assessment is not a major focus of preliminary engineering activities. However, quantitative analysis does have its benefits, especially because more project-specific information is available during preliminary engineering, and any analysis conducted with this information can help the designer better understand the potential work zone impacts of the project. For example, preliminary engineering site visits, investigations, and conceptual design activities may yield more detailed (project-specific) information on aspects such as the exact scope of work for the project, design concepts, ROW issues, utility issues, environmental issues, traffic data and studies, and base plans.

At this stage of project development, quantitative impacts analysis may generally be done for Significant Projects that are expected to have major impacts at the corridor, network, or regional levels, but this does not mean that it will not be needed for other projects. Any decision to analyze or not to analyze should be made on a project-by-project basis.

- The analysis may be performed at the work zone, corridor, and/or network levels. Appropriate measures may be considered in the analysis for safety, mobility, societal impacts, road user-costs, life-cycle cost implications, and benefits of the work zone management strategies.
- The analysis may be combined with an ongoing project study such as corridor/sub-area study, EIS, etc. Environmental/NEPA assessments must cover the range of impacts of the project, and address issues such as design alternatives that would decrease pollution emissions, construction impacts, esthetic intrusion, relocation assistance, possible land use controls that could be enacted, and other possible efforts. Any work zone impacts analysis that is conducted during preliminary engineering may be combined with other such project assessments, can provide information towards

effective completion of other assessments, and can use information and constraints that come out of the other assessments.

9.5.2.g – Identify Preliminary Work Zone Management Strategies

This involves the preliminary identification of potential work zone management strategies based on the impact assessments conducted previously. At this point enough information should be available on the project with regards to the potential design, construction/staging, overall work zone/traffic control approach, environmental issues, other coordination issues (utility, ROW, community/business impacts, etc.), and the resultant work zone impacts of the project. This information should be used to identify the management strategies and estimate their costs sufficiently enough to initiate the implementation plans for those management strategies.

The objective of this step is not to develop the TMP, but to identify the potential management strategies that could constitute the TMP and take the necessary actions that set the basis for TMP development in subsequent design stages. The level of effort is expected to be minimal compared to that required for actual design and development. Often, it may just involve a compilation of the work zone impacts issues, quick identification of appropriate management strategies, estimation of their costs based on simplistic procedures and available data, and identifying resources and means to implement them.

Another aspect to note in preliminary engineering is that in addition to identifying management strategies and estimating their costs, implementation plans for the management strategies are also initiated. For example, the management strategies that are identified in this step may include a work zone traffic monitoring system, work zone traffic incident management program, and a public information campaign including a web-based traveler information program.

9.5.2.h – Compile Preliminary Work Zone Strategy

In this step, the information from the impact assessment conducted in the previously is compiled to develop a "Preliminary Work Zone Strategy" which consists of:

- The project definition.
- Candidate construction/staging and traffic control approaches.
- Anticipated/estimated work zone impacts.
- Preliminary transportation management strategies.
- Cost estimate for the transportation management strategies (may be one or multiple sets of strategies, depending upon whether there is more than one construction/staging alternative).
- High-level identification of implementation resources, challenges, and opportunities, and initiation of appropriate action items for the management strategies.

Potential coordination and/or conflicts with other projects may also be addressed. The alternative(s) that best suits the needs of constructability, safety, and mobility should be selected. In some instances, it may not be clearly evident that one particular alternative is most appropriate, in which case, multiple alternatives may be carried over to the design phase where more detailed investigation and analyses may be performed.

9.5.3 – Final Design

Final design is the stage where the final work zone impacts assessment is conducted so as to choose the best construction/staging option(s), the most suitable design and contracting approach, and the most appropriate work zone transportation management strategies. The impacts assessment during final design is an iterative process progressing through the various stages of design, and addressing the basic issues of safety, mobility, and constructability. Basic assumptions are re-examined, and appropriate changes are made. Consensus of all involved parties is sought, and performance objectives for the work zone are developed.

The focus of this guidance is to enhance design-level work zone impacts assessment by considering and addressing work zone impacts from a broader transportation management perspective, rather than solely from a traffic safety and control perspective. This broader approach leads to the development of a TMP for the project that includes a TTC plan, as well as other appropriate strategies.

Work zone impacts assessment during design is an iterative process progressing through the different design stages, leading to the final design, TMP, performance requirements/criteria, and PS&Es for the project. Each design stage consists of specific activities, milestones, and concurrence points. Work zone impacts assessment is not intended to be a separate activity, rather it should be included in the ongoing design activities, with work zone impacts issues being accounted for at each concurrence/decision point. The objectives of a work zone impacts assessment during design are to:

- Perform a detailed project-level work zone impacts assessment progressively and comprehensively through the various design iterations.
- Reassess and confirm whether the project is a Significant Project.
- Develop recommendations for final construction approach and construction staging.
- Identify final design and contracting strategies – consider innovative design and contracting approaches.
- Develop final recommendations and plans for work zone management strategies.
- Estimate the final costs for the chosen work zone management strategies.
- Identify performance requirements for the work zone.
- Develop the TMP, appropriate PS&Es, and other documents that are required to implement the TMP.

- Develop contracting documents.

9.5.3.a – Reassess Work Zone Impacts

The purpose of this step is to reassess the work zone impacts of the project so that any issues are identified and addressed before the final design is completed. Reassessment of work zone impacts starts with the preliminary work zone strategy and progresses through the various design stages. As design progresses, more detailed project information becomes available and project-related decisions are finalized (e.g., pavement choice may be finalized, which will influence the total duration of construction). Decisions may be made during later design stages that may change the project parameters, potentially changing the work zone impacts implications of the project. Therefore, the reassessment of work zone impacts should be conducted along with the ongoing design activities, with work zone impacts issues being accounted for at each concurrence/decision point. For example, any design-level constructability review and value engineering (VE) studies should be encouraged to look at the potential for work zone impact reductions. Such reassessment can help avoid the propagation of errors to the final design, and potentially avoid costly changes later during construction.

As more design decisions are finalized and more information becomes available, a qualitative reassessment of work zone impacts is done to double-check the validity of the assessments and assumptions that were made in earlier stages. If the assessment indicates that the work zone impacts may be different from what was expected, further investigation and analysis may be needed. The key difference in final design is that the assessment is more detailed and specific, and the issues that are identified will lead to the final TMP strategies and design recommendations for the project.

The following are some issues to consider in reassessing work zone impacts during design:

- **Project Definition.** As design progresses, final decisions are made on various aspects related to the project definition. These include decisions on the exact nature of work to be performed, location, extent, and duration; roadway alignment and ROW; cross-sectional, elevation and super-structure details; pavement and structural needs; soil, hydraulics, and environmental needs; utility related infrastructure and coordination issues; and design parameters. When such decisions are finalized, an assessment should be made to determine if those decisions influence the work zone impacts of the project. Project design options should be chosen with consideration for minimizing their life-cycle work zone impacts (e.g., choosing long-life pavements, designing wider shoulders to facilitate easier maintenance, incorporating other features that reduce the work zone impacts of maintenance/rehabilitation).
- **Constructability/Construction Staging Approach(es).** During preliminary engineering and early design, it may not be possible to finalize the construction/staging approach for the project. In design, further investigation is performed, and decisions are made on the most suitable construction/staging approach for the project, and constructability issues are identified and addressed. The choice of construction/staging approach directly

influences the potential work zone impacts of the project. Therefore, as design progresses and decisions are made, any variations from prior decisions/assumptions should be noted and assessed for their work zone impacts implications. In choosing the construction/staging approach and in conducting constructability reviews, work zone impacts issues should be considered and the selection of construction/staging approach(es) should seek to minimize work zone impacts.

- **Work Zone Management Strategies.** Design-level decisions can influence the choice of work zone management strategies. As specific decisions are made and milestones are attained, the work zone management strategies should also be reassessed to determine if they still apply and whether they adequately serve the purpose of mitigating the work zone impacts of the project. If not, additional management strategies need to be identified. This reassessment is a quick review as to whether the prior assumptions (from preliminary engineering or other design stages) still apply, or whether the previously identified management strategies need to be modified. For example, the preliminary engineering assessments may result in the identification of two alternative "construction and work zone management approaches" – the first being a night work option with a basic TMP (i.e., TTC plan only), and the second being a daytime work option with a complete TMP (i.e., TTC, TO, and PI included). As design progresses, more information may become available on the feasibility of each of the construction approaches, leading to the elimination of the night work option. Therefore, the second option would be chosen and further developed.
- **Work Zone Impacts.** Work zone impacts should be reassessed when decisions are made on the construction/staging approach(es) and the accompanying work zone management strategies. The reassessment is expected to be an iterative process that progresses along with the ongoing design activities, with checks and balances being made at the respective design milestones and concurrence points. Work zone impacts issues to address include safety, traffic capacity/demand, community impacts, local business impacts combined impacts with nearby, concurrent projects; Significant Project designation, modifications to management strategies, and work zone performance requirements (either policy-level or project-specific).

9.5.3.b – Analyze Work Zone Impacts (As Needed)

This step may be considered as an extension of the work zone impacts reassessment. The purpose of this step is to conduct a more detailed (quantitative) investigation and analysis of the work zone impacts. This quantitative analysis should also be performed iteratively, progressing along with the design activities, with the design milestones and concurrence points being used as junctures for work zone related checks.

Quantitative analysis may be used to:

- Confirm and re-examine whether the project is a Significant Project.

- Choose between alternative project design, construction/staging, and traffic control and management approaches.
- Estimate the life-cycle costs of the project, considering the cost of maintaining and rehabilitating the facility over its life-cycle.
- Choose between alternative work zone transportation management strategies.
- Understand specific aspects of work zone impacts of the project (e.g., choke points, bottlenecks, diversion patterns, queue lengths, queue build-up and dissipation rates).
- Understand the work zone impacts implications of any value engineering proposals that recommend the removal of certain project elements for cost-cutting purposes.
- Understand the combined impacts and coordination issues with other nearby, concurrent projects.
- Identify the work zone performance requirements/goals for the project (e.g., by analyzing the work zone impacts under different scenarios and developing a range of potential impacts, which can then serve as the basis for the performance goals).
- Set the parameters for any innovative/alternative contracting approach (e.g., in the case of A+B bidding, the objective is to minimize construction duration by getting contractors to bid on the actual work items (Part A), and the total number of days to complete the project multiplied by the daily road user cost stipulated in the contract (Part B). The combined values of A and B determine the winning bid. The agency may need to conduct a quantitative analysis of the work zone impacts to estimate the associated daily road user costs that it needs to stipulate in the contract).
- Justify additional funds for work zone management strategies, or to justify why a project will not have major work zone impacts. (e.g., by quantifying the work zone impacts, the associated user-costs, and the benefits and costs of the work zone management strategies).
- Determine and design the specific aspects of the management strategies.
    - **TTC Plan.** Quantify expected queue length and incorporate that information in designing the taper for the project; design the lane-widths; set the work zone speed limits; estimate costs of TTC strategies; etc.
    - **TO Component.** Determine the communications and detector requirements for a work zone traffic monitoring and incident management system; estimate traffic diversion patterns and rates to determine potential impacts on the alternate route(es) and appropriately improve operations on the alternate route (e.g., signal timing adjustments); evaluate the positioning of dynamic message signs (DMS) which may affect the diversion patterns; estimate the number of people who would switch to transit so as to structure the transit incentive program; estimate the costs of the TO strategies; etc.

- **PI Component.** Estimate the volume of traffic that would be affected by the project to determine the PI needs; determine the types of PI strategies to use (e.g., real-time updates through email, telephone-based information); coordinate with stakeholders to initiate the PI program; estimate the costs of the PI strategies; etc.

Quantitative analysis can be performed at the work zone, corridor, and/or network levels. Appropriate measures may be considered in the analysis for safety, mobility, societal impacts, road user-costs, life-cycle cost implications, and benefits of the work zone management strategies. The key difference in design is that the analysis is more detailed and will lead to the development of the final design and TMP for the project. The level of detail and clarity of analysis is expected to be higher. For example, early work zone impacts analysis performed during preliminary engineering (e.g., using a sketch-planning tool) for a particular project may indicate that traffic diversion to the designated alternate route for the project would be Significant, leading to a preliminary decision to upgrade and re-time the traffic signals on the alternate route. In design, a more detailed analysis (e.g., using a micro-simulation tool) may be conducted to determine the actual diversion patterns, the volume of traffic expected to divert to the alternate route, and the actual intersections that would be affected. This analysis may then be used to identify the number of traffic signals that need to be upgraded and the exact nature of the upgrades, and to develop the signal timing plans and estimate the costs for the same.

Key technical issues to be addressed in the analysis include:

- **Constructability.** Project cost, schedule, construction effectiveness and efficiency, construction staging, work area access, construction quality, environmental constraints, utilities, noise, weather interference, project coordination and interdependencies, any interference with/to ongoing maintenance activities, etc.
- **Work Zone Impacts.** Crashes; queues; recurring delay; non-recurring delay; traffic diversion; nearby railroad crossings; transit junctions; interchanges/intersections; impacts to businesses/residents; combined impacts with nearby, concurrent projects; user-costs of the impacts; etc.
- **Work Zone Management Strategies.** TTC, TO, PI, innovative design and contracting, advanced construction technologies, coordination with other projects, combining multiple projects, etc.

Deterministic/Highway Capacity Manual (HCM) based tools, traffic simulation models, and other tools that can help perform a detailed analysis may be most appropriate for this level of analysis. The objective of quantitative analysis during design is to analyze and address specific issues in detail and make final decisions and recommendations towards development of the final design and TMP for the project. Detailed analysis tools such as deterministic tools and traffic simulation models may be most suitable. Higher-level travel demand models and sketch planning tools may also be used if the project situation warrants their use (e.g., budgetary constraints, regional impacts, readily available model from the agency's planning division).

Sometimes a combination of different levels of tools may be needed to appropriately analyze the impacts.

The quantitative analysis may be combined with an ongoing project study such as corridor/sub-area study, EIS, etc. Environmental/NEPA assessments must cover the range of impacts of the project, and address issues such as design alternatives that would decrease pollution emissions, construction impacts, esthetic intrusion, relocation assistance, possible land use controls that could be enacted, and other possible efforts. Any work zone impacts analysis that is conducted during design may be combined with other such project assessments, can provide information towards effective completion of other assessments, and can use information and constraints that come out of the other assessments. This applies especially to large projects for which planning, preliminary engineering, and design are performed as part of the same study.

9.5.3.c – Develop/Recommend Final Construction Staging and TMP

In this step, information from the previous steps is used to complete the final design, the construction staging, the TMP, and the cost estimates for the project. These are then compiled into the PS&E package. Also, TMP development responsibility and sequencing may vary according to the chosen design approach and contracting strategy.

- **Traditional Design-Bid-Build process.** In this case, the final plans, TMP, PS&E and bid package are developed by the agency (or consultant as appropriate).
- **Design-Build.** This involves a stage-by-stage approach to designing and building the project, where design and construction take place in tandem. When construction is taking place on one phase, the subsequent phase is designed. This generally saves project time and money. This approach is more often adopted for major infrastructure reconstruction or rehabilitation projects and is performed by a team of engineering consultants and contractors.
- **Contractor Developed TMP.** In this case, the agency includes basic TMP requirements and recommendations in the bid package, rather than the agency developing the TMP itself. Contractors may then include appropriate TMPs in their bids.
- **Performance Based TMP.** In this case, work zone performance requirements are established by the agency. Contractors may then include TMPs that help meet those performance requirements in their bids.

The following provides some general guidance and resources for TMP development:

- **A TTC plan** describes TTC measures to be used for facilitating road users through a work zone or an incident area. The TTC plan plays a vital role in providing continuity of reasonably safe and efficient road user flow and highway worker safety when a work zone, incident, or other event temporarily disrupts normal road user flow. In developing and implementing the TTC plan, pre-existing roadside safety hardware must be maintained at an equivalent or better level than existed prior to project implementation. The scope of the TTC plan is determined by the project characteristics, and the traffic

safety and control requirements identified by the agency for that project. The TTC plan must either be a reference to specific TTC elements in the MUTCD, approved standard TTC plans, Publication 213, or be designed specifically for the project.

- **The TO component** of the TMP includes strategies that will be used to mitigate impacts of the work zone on the operation and management of the transportation system within the work zone impact area. Typical TO strategies may include but are not limited to demand management, corridor/network management, safety management and enforcement, and work zone traffic management. The scope of the TO component should be determined by the project characteristics, and the transportation operations and safety strategies identified by the agency.
- **The PI component** of the TMP includes communications strategies that seek to inform affected road users, the general public, area residences and businesses, and appropriate public entities about the project, the expected work zone impacts, and the changing conditions on the project. This may include traveler information strategies. The scope of the PI component should be determined by the project characteristics and the public information and outreach strategies identified by the agency. Public information should be provided through methods best suited for the project, and may include information such as the project characteristics, expected impacts, lane closure details, and commuter alternatives.
- **The PS&Es must include either a TMP or provisions for contractors to develop a TMP** at the most appropriate project phase as applicable to the agency's chosen contracting methodology for the project. A contractor developed TMP must not be implemented before it is approved by the Department.

9.6 – Design Standards, Factors, and Devices

This section provides design guidance on various standards, factors, and TTC devices that need to be considered in the development of the project's TCP and/or TMP. Remember that each project is different. On an individualized-project basis, the various design standards and factors may have differing relevance and importance based on the project scope and complexity.

9.6.1 – Methods of Traffic Control

The identification of design standards, factors, and devices can vary based on the type of traffic control. For short term set-ups, consider those in Publication 213. For long term set-ups, individual traffic control plans may be required. Project specific traffic control plans may be necessary for the following traffic control scenarios:

Total Closure with Detour. A detour is a temporary rerouting of road users onto an existing highway to avoid a temporary traffic control zone. Detours should be clearly signed over their

entire length so that road users can easily use existing highways to return to the original highway.

With any detour of traffic, the route utilized should be evaluated for postings related to heavy vehicles (e.g., height, length, width, and load postings) that might require installation of a separate truck detour. When a truck detour incurs minimal additional delay, consider signing a single detour to minimize driver confusion.

At critical intersection points within the detour, consider capacity and adequate room for turning radii, where applicable.



Total Closure with Temporary Roadway, Bridge, and Temporary Crossovers (Diversion). A diversion is a temporary rerouting of road users onto a temporary roadway or alignment placed around the work area. With any "runaround" or temporary structure, operation of the design vehicle needs to be confirmed against any reverse curvature entering and exiting the temporary facility, as well as the location of any temporary structure appurtenances.

One-Lane, Two-Way Traffic Control. When traffic in both directions must use a single lane for a limited distance, movements from each end shall be coordinated. Provisions should be made for alternate one-way movement through the constricted section via methods such as flagger control, a flag transfer, a pilot car, or traffic control signals. When proposed traffic flow is contrary to the normal direction, guide rail end treatments need to be updated to conform to MASH Standard for the new direction of flow.

Control points at each end should be chosen to permit easy passing of opposing lanes of vehicles. If traffic on the affected one-lane roadway is not visible from one end to the other, then flagging procedures, a pilot car, or traffic control signal should be used to control opposing traffic flows.

Phased Construction. In any TCP plan where partial-width construction is taking place, any lane transitions, or entry and exit ramp access adjacent to barrier or device placement, should be confirmed with a turning-envelope analysis.



In construction involving urban intersections, turns at the intersection should be evaluated relative to barrier and attenuator placement to confirm adequate lane widths and intersection openings.

Consider identifying available work zone widths relative to lane space, deflection distance criteria for phased construction behind barrier, and proposed scope of work relative to contractor equipment sizes and access points. Verify TCP and E&S sequencing are aligned.

9.6.2 – Work Zone Design Standards

The TTC standards found in the MUTCD and Publication 213 are the foundation for the various attributes needed when designing a work zone TCP, including fundamental principles, TTC elements, devices and typical applications. The design of project-specific TCPs will incorporate these standards, ensuring compliance with federal and Pennsylvania criteria. The following sections provide guidance on several key considerations.

9.6.2.a – Design Vehicle

It is recommended that the design vehicle for development of a traffic control plan match the design vehicle for the final roadway facility. If this is not possible, then the selection should be made with knowledge of the following:

- Existing vehicle composition on the impacted roadways.
- Design vehicle currently permitted on the roadway.
- Design vehicles for a project design. Criteria within a traffic-control design may be controlled by different design vehicles. For example, turning movements may be controlled by transit or freight vehicles. Other elements may be determined by standard vehicles or in certain designs, pedestrians and bicycles.
- Potential geometric restrictions presented by the TCP design (e.g., vertical and horizontal alignments).

9.6.2.b - Heavy Vehicle Considerations

The presence of heavy vehicles contributes to increased crashes within the work zone. Consider the following potential strategies in developing the design:

- Include temporal effects of heavy vehicles in work zone impact analyses.
- Factor heavy vehicle presence into queue estimation for lane closures.
- Consider the use of optimum (not minimal) design criteria in areas with higher heavy vehicle traffic.
- Incorporate Smarter Work Zones (SWZ) concepts into the design to better notify road users of work zone impacts.
- Consider heavy vehicle operating conditions when setting design elements, such as cross sections and transitions into and out of work zones. This may result in slightly longer transitions and wider lane widths.

9.6.2.c – Oversized and Overweight Loads

When construction projects impact truck routes which serve as Surface Transportation Assistance Act (STAA) routes to carry oversized and overweight loads, special consideration needs to provide for travel of these vehicles. These routes are identified by their ability to accommodate oversized vehicles without creating operational issues for larger vehicles. In rural locations, there may be limited alternate routes capable of serving as adequate detour routes for oversized vehicles.

Where possible, the TCP should attempt to provide for the continued operation of these vehicles during construction.

- Closure and detour should not be considered a primary alternative unless construction methods or other factors dictate.
- If the roadway or lane widths are restricted, consideration should be given to the installation of a “VEHICLES OVER (___) FT. WIDE PROHIBITED” (R14-16-1) sign. If lane widths are restricted because of construction, coordinate with the District Permit Office.
- Publication 46 provides additional guidance related to accommodation of these vehicles during construction.

9.6.2.d – Temporary Traffic Control Zone Regulatory Speed Limit

All work zones must be designed to accommodate the existing posted regulatory speed limit unless adequate justification for a reduction can be provided. A 10-mph work zone regulatory speed limit reduction can only be implemented if it is justified. If assigning lower work zone

speed limits than the typical operating speed, advance signing should be obvious and redundant to ensure the proper speed is communicated to the user.

Freeway or expressway projects may have a work zone speed-limit reduction not greater than 10 mph below the normal speed limit. This is accomplished through long transitions, good sight distance, maintaining the existing number of travel lanes, and delineation.

For any reduction of a regulatory speed limit, Form TE-162, **Temporary Traffic Control Zone Regulatory Speed Limit Reduction Evaluation,** must be completed as part of the project design. This form will provide the District Traffic Engineer (DTE) with adequate information to review the request. The form will also inform the Bureau of Operations (BOO) Division Chief about work zones considered for the Work Zone Speed Safety Camera (WZSSC) Program.

Once approved by the appropriate PennDOT personnel, District traffic staff will generate a TTC zone regulatory speed-limit reduction permit for the required duration, calendar period, and roadway limits.

Exhibits 9.6.1 and **9.6.2** provide guidance on work zone regulatory speed limits.

When using these exhibits and designing work zone speed-limit reductions, ensure that the reduction only applies to the area of need. For example, if the speed limit is intended to improve worker safety, confine the reduction to the active work area and not throughout the limit of work or during those times when workers are not present. In this example, it would be necessary to cover and uncover Speed Limit signs, or to include special provisions in the contract to require remotely activated changeable Speed Limit signs.

Exhibit 9.6.1 Work Zone Regulatory Speed Limit Types

Regulatory Speed Limit Type	Description	Typical Applications
Variable 	Changeable speed limit used only when an active work zone is in effect or when a mobility degradation justifies a lower operational speed. This type of speed limit is based on actual field conditions and cannot exceed 24 consecutive hours.	• Occasional lane, shoulder, median closure, or shift when workers are present near active travel lanes with no positive protection. • Intermittent flagging operation. • Time-of-day specific to recurring congestion or queuing.
Continuous 	Speed-limit reduction in effect 24 hours a day for the duration of the work zone condition.	• Work zone condition where roadway geometry cannot be designed to accommodate design standards (e.g., taper lengths, travel lane widths, sight distance, temporary alignments). • Unprotected workers adjacent to travel lanes on a daily basis. • Congestion or queuing throughout the day.

Exhibit 9.6.2 Continuous Work Zone Regulatory Speed Limit Guidance

Work Zone Length	Guidance
<0.5 mile	An advisory speed-limit reduction should be considered if the zone is less than 0.5 mile.
Between 0.5 and 1 mile	Consider extending the lowest reduced speed zone to encompass the entire work zone.
>1 mile	Consider an advisory speed or a short regulatory speed-limit reduction zone for the specific condition, instead of reducing the regulatory speed limit for the entire work zone.

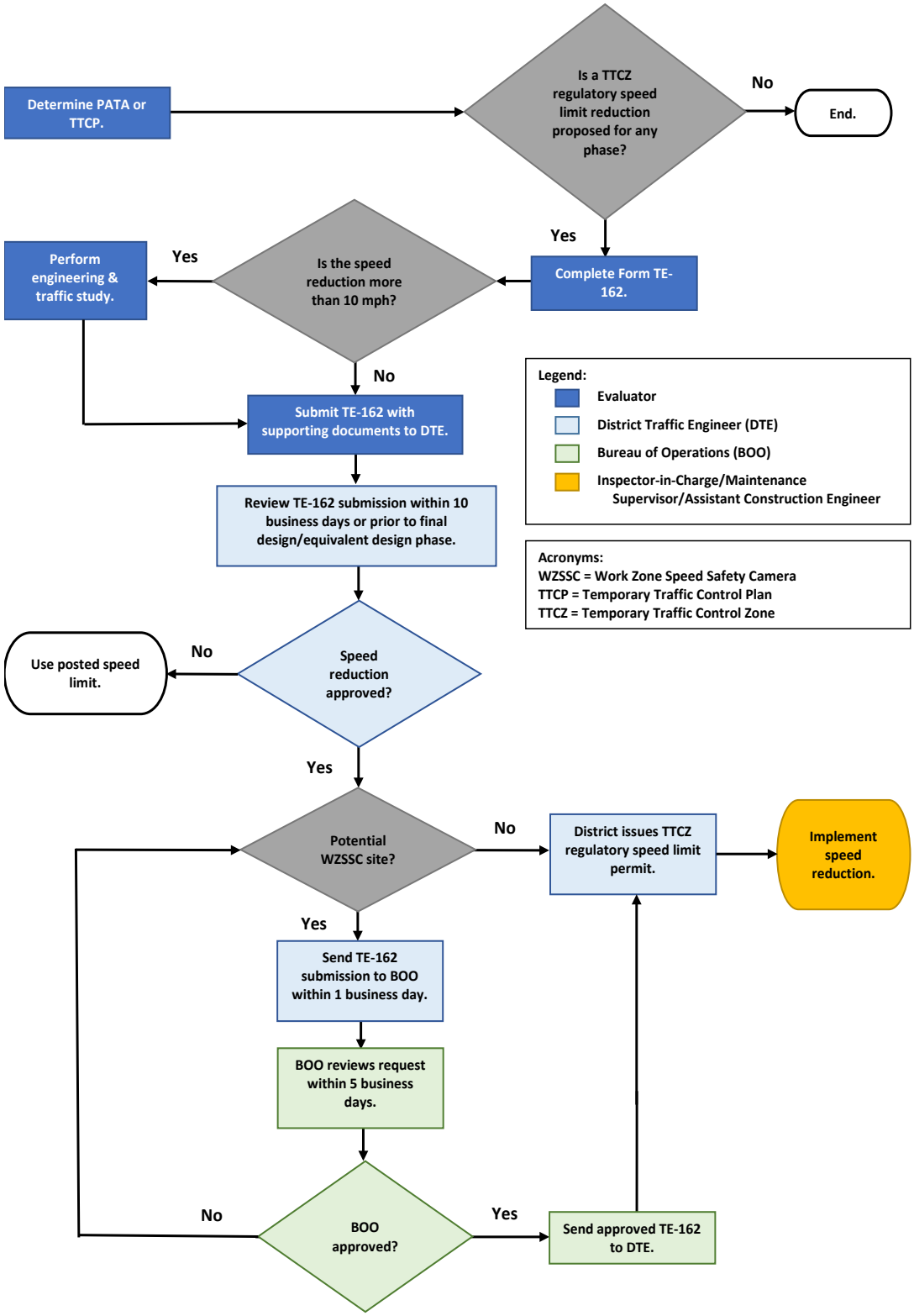
To improve credibility and compliance, more than two separate regulatory speed-limit reduction zones within one work zone should be avoided.

Work zone regulatory speed-limit reductions should only be requested for the applicable timeframe and type of regulatory speed-limit reduction needed to complete the necessary work activities.

The DTE will be responsible for approving and issuing the temporary traffic control zone regulatory speed limit reduction permit. If the work zone being evaluated is proposing to use automated speed enforcement, BOO Highway Safety & Traffic Operations Division Chief will need to concur with the DTE's approval. It is the responsibility of the designer or field overseer to clearly justify why a work zone regulatory speed limit reduction is necessary.

The flowchart shown in **Exhibit 9.6.3** provides the procedure for requesting and reviewing the work zone regulatory speed limit reduction for two timelines: (1) Prior to the start of work activities and (2) After work activity begins. Work zone regulatory speed limits must be evaluated during the temporary traffic control design or PA Typical Application (PATA) selection process. However, a work zone regulatory speed limit may be re-evaluated at any time during temporary traffic control activities.

Exhibit 9.6.3 Work Zone Regulatory Speed Limit Reduction Request and Review Procedure



9.6.3 – Design Factors

Design factors for the development of TTC plans are to understand all road user behavior, to further the understanding of roadway user needs so that those needs can be incorporated into the design. PennDOT's strategies for improving safety and enhancing operations throughout the highway transportation system benefit from the appropriate consideration of driver behavior. The following sections outline analyses to gain an understanding of TTC road user behavior.

9.6.3.a – Engineering and Traffic Study Considerations

Each project will have different capacity analysis and study needs for determining the most appropriate traffic-control phasing.

- Often, the capacity analysis of traffic control phasing must be done in conjunction with the constructability and overall cost of the project.
- As the project advances into the Design Phase, potential traffic impacts resulting from the Preliminary Engineering Phase are better known and can be further evaluated.

Depending on the project type, some of the analyses in **Exhibit 9.6.4** may need to be completed as part of the project design.

Exhibit 9.6.4 Possible Studies to Consider

Type of Traffic Control	Studies to Consider
Total closure with detour	• Intersection capacity analysis • Running/travel time studies • Turning envelope analysis
Partial-width construction	• Capacity/queuing analysis • Sight distance evaluation
Single-lane bidirectional traffic control	• Capacity/queuing analysis • Sight distance evaluation
Lane closure/restriction on freeway/expressway	• FREEVAL-PA (or equivalent work zone capacity analysis) • Capacity/queuing analysis
Special event traffic studies	• Historical traffic data review • Regional travel demand modeling • Travel time studies
Accelerated construction/weekend closure	• Historical traffic data review • Regional travel demand modeling • Travel time studies • Emergency/incident management planning and simulation (tabletop exercises)

9.6.3.a.i – Travel-Demand Strategies

Any quantitative analysis is intended to provide an understanding of work zone impacts related issues (e.g., whether a project may be a Significant project, choice of construction/traffic control approach, early identification and cost estimation of work zone management strategies). For example, an agency may want to evaluate the feasibility of closing one lane in each direction for a future Interstate project. The designer, with the assistance of PennDOT, may contact the region's MPO to perform an analysis of potential travel impacts of such a construction scenario. The MPO may then use the region's travel demand model to conduct this analysis and determine if the construction scenario would be feasible. If the project complexity and the desired level of accuracy for estimating the work zone impacts warrant a more detailed analysis (e.g., simulation), then the designer can choose to do so using appropriate analysis tools, such as through the use of FREEVAL-PA.

For longer-term projects, a travel-demand strategy that may need to be studied is supplemental transit service.

9.6.3.a.ii – Evaluation of Diverted Travel

To study traffic impacts of the construction project as designed, including related incidents in work zones, adjacent routes, and/or detour routes:

- Traffic volume data should be collected to determine where vehicular demand may be shifting as a result of impacts to the facility.
- Analysis should consider possible diversion routes users may use to avoid work zone delays. A “before/after” analysis can determine possible bottlenecks or degradations of level of service. Documenting this analysis will aid in working with effected communities during construction.
- Data should be used to provide a more adaptive response to travel demands, including adjustments to traffic-signal timings for actual conditions, as opposed to the estimated conditions from designed pre-construction estimates and studies.

Consider the effects of work zone diversions and possible short-term and long-term improvements to these routes to mitigate the increase in traffic.

This information also provides a historical perspective for future project designs of similar scale or within the project area.

9.6.3.a.iii – Safety Impacts Evaluation

It may not be possible to perform an accurate estimation of transportation safety impacts of a project’s work zone because of the various factors that influence crash occurrence, especially in and around work zones. However, analysis tools can provide order-of-magnitude estimates based on several factors including highway capacity, traffic demand, trip distribution and attraction patterns, quality of highway safety features, and the presence of special safety improvement strategies/technologies. For example, a lane-closure for road construction may change the traffic dynamics on a particular corridor. Analysis tools may be useful for assessing the safety impacts of various project options.

9.6.3.a.iv – Level of Service (LOS)

LOS provides some measure of the operational behavior of a roadway. As it relates to traffic control, one goal is to avoid degradation to LOS E (recurring congestion) or worse during construction.

However, this is not feasible with all projects. Sometimes the requirements of a LOS threshold conflict directly with the construction needs of the project or create cost demands that are not reasonable (relative to project cost). In cases where either the facility operates at an existing LOS that is deficient, or the need to maintain a sufficient LOS during construction is not feasible, other measures (for example, travel time delay) should be used as a primary measure.

Where LOS is measured should be determined on a project-by-project basis. For major interstate reconstruction, this may consist of analyses of roadway segments, intersections along primary diversion routes, or merging and ramps at junction points impacted by the construction. Determining appropriate measures and which analyses are to be completed should be established in scoping and modified as project demands change.

9.6.3.a.v – Travel Time and Delay

Delay is an important measure for interrupted flow, and its consideration is vital in congestion management. There are several types of delay, as explained in the *Highway Capacity Manual*:

- **Control delay.** Caused by the presence of a Traffic Control Device (TCD), such as a traffic signal.
- **Geometric delay.** Caused by geometric features when vehicles negotiate a system element, such as a sharp horizontal curve.
- **Incident delay.** Caused by an incident's effect on normal traffic flow.
- **Traffic delay.** Caused by the interaction with other vehicles, such as during congestion.
- **Total delay.** The sum of control, geometric, incident, and traffic delays.

Facility construction, and the subsequent TTC requirements, often contribute to additional delays compared to that typically experienced. Where possible, applicable, and practical, congestion mitigation strategies should be utilized to reduce construction-related delays. There are three basic criteria which should be considered as overall guidelines when analyzing delays for construction and the associated TTC:

- Avoid LOS E, if possible, by maintaining all travel lanes or by specifying the work hours for times when congestion will be minimal. When this is not possible, recurrent congestion should be minimized by using innovative contracting procedures.
- Minimize delay times (stoppage) to no more than five minutes (if practical) for construction operations normally encountered on resurfacing of two-lane highway projects.
- Minimize delay problems associated with incidents in the work zone through proper planning, and where practical, develop an IMP even if not required as part of a TMP.

For freeways (i.e., fully controlled, limited-access highways), conduct travel-time delay analysis as specified in Publication 46 and utilize the specified traffic delay thresholds for assessing the project's work zone impacts.

9.6.3.a.vi – Various Other Analyses and Studies

- **Intersection Capacity Analysis.** Intersection capacity analysis can identify bottlenecks at junction points (resulting from phased construction) and divert traffic from a detour or

lane removal in a variety of traffic-control phases. Measures such as LOS and delay can be used for comparisons to different phases, as well as to existing operations. If determined to be relevant, ensure that adequate data collection is completed to perform a thorough analysis**.**

- **Running/Travel Time Studies.** Determining typical travel times for detours serves to better inform decisions on potential detour routes and provides a comparison measure during construction to evaluate work zone performance. When performing running/travel time studies, perform an adequate number of runs to provide a complete data set for analysis.
- **Turning Envelope (Heavy Vehicle Turning Movement) Analysis.** With any TTC, intersection operations may be impacted by geometry changes due to phased traffic control or detoured heavy vehicles that may not typically use the intersection. Performing a turning envelope analysis will confirm if the vehicle can safely navigate the intersection. This analysis can be performed with several available software packages. Traffic-class data should be obtained for potential users of the intersection to determine the most appropriate design vehicle.
- **Capacity/Queuing Analysis.** Capacity and queuing analysis determines the anticipated impacts resulting from traffic control phasing. As with the intersection capacity analysis, anticipated bottle necks can be identified. Capacity analysis can be expanded to roadway segments, ramp junctions, as lane reductions, and in identifying congestion-related queues that may create safety issues.
- **Sight Distance Evaluation.** Where driveways or intersections are modified as part of TTC, sight distance should be confirmed to ensure safety issues are not created as a result of the modifications. Detour routes should also be examined to confirm that existing sight distance deficiencies will not create operational issues.
- **FREEVAL (or equivalent work zone capacity analysis).** This is the preferred—and often required—method for analyzing traffic mobility and safety concerns by evaluating work zones prior to deployment to avoid congestion during the project. See Section 9.2.2.c for more details.
- **Regional Travel Demand Modeling.** Existing regional travel demand modeling data can provide origin-destination data, as well as a model from which to determine the extents of a traffic control measure (e.g., closure of a critical bridge, removal of a lane on an expressway) that may spillover on to other facilities.
- **Historical Traffic Data Review.** For situations where a past event or traffic control measure is similar to that proposed and where traffic data is available, historical data can provide some indication of driver behavior when a critical link is impacted or removed from the roadway network.
- **Emergency/Incident Management Planning and Simulation (Tabletop Exercises).** In planning for projects with significant impacts, perform planning exercises with emergency responders, design personnel, construction staff, and other stakeholders.

This allows for identification of potential conflicts between the design and incident response operations, as well as the opportunity to model different emergency scenarios and establish procedures for possible incidents.

9.6.4 – Types of Devices

Traffic control devices shall be defined as all signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, pedestrian facility, or bikeway by authority of a public body or official having jurisdiction. All traffic control devices used on street and highway construction, maintenance, or utility operations shall conform to the applicable provisions of PennDOT's publications and the MUTCD.

When designing TTC, there are a variety of TCDs that are required to communicate and provide safe, efficient, and positive guidance through the work zone. Key reference documents for TCDs are as follows in **Exhibit 9.6.5**:

Exhibit 9.6.5 Reference Documents for TCD

Publication	TCD Relevance
MUTCD	• Part 6 TTC
13	• Guide rail, barrier, and impact attenuating devices
35	• Prequalified TCDs for use
46	• Special guidance (e.g., signing, marking, signals, TTC)
111	• Signing • Pavement markings and delineation
148, 149, and 191	• Traffic signals
200	• Changeable message sign operating standards
212	• Additional requirements not included in the MUTCD
213	• TTC (covering the various TCD types)
236	• Approved signs
408	• Specifications
646 and 647	• ITS

9.6.4.a – Signs

Temporary traffic control signs convey both general and specific messages by means of words or symbols and have the same three categories as all road user signs: regulatory, warning, and guide. Additionally, signing serves to communicate the traffic pattern changes created by the work zone to the road user. The keys to appropriately located work zone signing include:

- Clarity.
- Accuracy.
- Relevance.
- Timeliness.
- Visibility.

The colors for regulatory signs shall follow the standards for regulatory signs per Publication 213 and the MUTCD. Warning signs in temporary traffic control zones shall have a black legend on a fluorescent orange background. Guide signs along highways provide road users with information to help them along their way through the TTC zone. The design of guide signs is presented in Part 2 of the MUTCD. The following guide signs should be used in TTC zones as needed.

- Standard route markings, where temporary route changes are necessary.
- Directional signs and street name signs.
- Special guide signs relating to the condition or work being done.

If additional temporary guide signs are used in TTC zones, they shall have a black legend and border on an orange background. When directional signs and street name signs are used in conjunction with detour routing, these signs may have a black legend and border on an orange background. When permanent directional signs or permanent street name signs are used in conjunction with detour signing, they may have a white legend on a green background.

9.6.4.b – Channelizing Devices

The function of channelizing devices is to warn road users of conditions created by work activities in or near the roadway and to guide road users. Channelizing devices include cones, tubular markers, vertical panels, plastic drums, barricades, and temporary raised islands. Channelizing devices provide for smooth and gradual motor vehicle traffic flow from one lane to another, onto a bypass or detour, or into a narrower traveled way. They are also used to separate motor vehicle traffic from the work space, pavement drop-offs, pedestrian or bicycle paths, or opposing directions of motor vehicle traffic.

Channelizing devices should be constructed and ballasted to perform in a predictable manner when inadvertently struck by a vehicle. Channelizing devices should be crashworthy. Fragments or other debris from the device or the ballast should not pose a significant hazard to road users or workers in the immediate area. When channelizing devices have the potential of leading motor vehicle traffic out of the intended motor vehicle traffic space, the channelizing devices

should be extended a distance in feet of two times the speed limit in mph beyond the end of the transition area.

Approved channelizing devices are considered equally effective in guiding motorists through the work area and around hazards. If the TCP directs the use of drums (or a particular type of channelizing device), it should be specified in the special provision and clearly indicated on the plan sheets. In addition, a clear and sufficient reason for specifying the type of channelizing device should be documented in writing and kept in the project file.

Spacing for channelizing devices is as follows:

- Channelizing device spacing intervals should be maintained as shown on Publication 213 PATA drawings and spacing charts.
- Spacings shown in Publication 213 are minimum standards and may be decreased to fit field conditions.
- Spacings may be tightened to create a “walled” effect as motorists pass through the work zone.
- Publication 213 spacings designated as maximum cannot be increased.

9.6.4.c – Temporary Traffic Barriers

Temporary traffic barriers are devices designed to help prevent penetration by vehicles while minimizing injuries to vehicle occupants and designed to protect workers, bicyclists, and pedestrians. The primary functions of temporary traffic barriers are:

- To keep vehicular traffic from entering work areas, such as excavations or material storage sites.
- To separate workers, bicyclists, and pedestrians from vehicular traffic.
- To separate opposing directions of vehicular traffic.
- To separate vehicular traffic, bicyclists, and pedestrians from the work area such as false work for bridges and other exposed objects.
- To shield motorists from work zone drop-offs adjacent to the travel lane.

Temporary traffic barriers shall be supplemented with standard delineation, pavement markings, or channelizing devices for improved daytime and nighttime visibility. The delineation or pavement marking color shall match the applicable pavement marking color. When serving the additional function of channelizing traffic, portable barriers should be of a light color for increased visibility. More specific information on the use and design of portable barriers and impact attenuators can be obtained from Publication 213 and the AASHTO Roadside Design Guide. The effect of striking the ends of barriers shall be mitigated by use of impact attenuators or by flaring the ends of barriers away from the traveled way. Following in the order of preference are the methods to be used in mitigating the effect of striking the ends of barriers:

- Where a guide rail exists, the guide rail shall be attached to the barrier with the appropriate fixed object attachment.
- Where a cut slope exists, the barrier shall be buried into the cut slope. Drainage shall be provided as needed.
- Extend the end of barrier until it is beyond the established Clear Zone.
- When the barrier end is inside the desired Clear Zone, an impact attenuator shall be used.

Barriers should be considered for all freeway and multi-lane work zones when all of the following apply:

- The speed limit is 45 mph or greater.
- Workers are present within one lane width from an active travel lane.
- Long term, stationary lane closures.

Other design considerations should be the width, height, and mobility of the selected temporary barrier:

- In areas with horizontally limited cross sections, certain barrier types may serve to better utilize the available horizontal width for contractor operations, travel-lane use, and/or pedestrian-path use and mobility.
- Whenever possible, a 50-in minimum temporary glare-screen barrier should be used as the standard for separating traffic through crossovers, in two-way traffic operations, and in areas with higher percentages of truck traffic, to reduce headlight glare.
- Per Chapter 12, *Roadside Design*, temporary barriers should be identified per test level and deflection distance.

9.6.4.c.i – Delineation of Temporary Median Barriers

Publication 111, TC-8604, and Publication 72M, RC-57M, Standards provide guidance on barrier delineation, with the exception that temporary barrier-mounted delineation may be installed at 20-ft spacing within transitions and curves.

Edge lines installed on, or along temporary barrier may be accomplished by:

- Installing temporary pavement-marking tape or paint on the roadway, at a distance of 6-in or more from the base of the barrier. Pavement-marking tape or paint will therefore be located 6-in inside common travel lane edge/face of barrier.
- Applying an edge line (paint and glass beads or temporary pavement-marking tape) on the lower sloping surface of the barrier, instead of on the road surface.
- Attaching temporary RPMs to the road surface at a minimum distance of 6-in from the base of the barrier, at a 40-ft spacing within transitions and curves and an 80-ft spacing on tangent sections.

Installing edge lines as described in the last two bullets eliminates the need to eradicate the edge line, thereby reducing costs and eliminating eradication scars.

9.6.4.d – Movable Barrier Systems

A movable barrier is a linear system of connected barrier segments that can rapidly be shifted laterally by using a specially designed transfer vehicle. The transfer is accomplished in a manner that does not interfere with motor vehicle traffic in adjacent lanes. Applications of movable barriers include the following:

- Closing an additional lane during work periods while maintaining the advantage of having the travel way separated from the work space by a barrier.
- Closing an additional lane during off-peak periods to provide extra space for work activities without adversely impacting motor vehicle traffic flow.
- Creating a temporary reversible lane, thus providing unbalanced capacity favoring the major direction of motor vehicle traffic flow. More specific information on the use of temporary traffic barriers is contained in the AASHTO Roadside Design Guide.

A movable barrier system should be considered when the relocation of barriers daily (or multiple times of the day) can restore travel lanes and improve overall capacity. When considering the use of movable barrier systems, the designer should ask the following questions:

- Are lane closures required? If so, are they frequent and short-term or stationary and long-term?
- Are only single lane closures permitted?
- Is there a need to adjust traffic flows during peak-traffic periods, such as restoring the closed lane/shoulder or altering lane configuration to improve or maintain acceptable directional flow?
- Will using movable barriers allow for expedited and/or improved quality of construction, while maintaining a minimum level of acceptable traffic performance?
- Will using moveable barriers allow for improved traffic without negatively impacting construction operations?
- In terms of reduced delay, are the benefits (e.g., road-user cost savings) worth the extra cost? Can the project budget absorb the cost increase that may result from the use of a movable barrier system?
- Is positive protection of the work zone desired for preventing workers from being exposed to high speed or heavy traffic?

9.6.4.e – Barricades

Differing barricade types are used to mount signs and block access to areas within the work area. For construction standards related to the different barricade types and applications, refer to Publication 111. All barricades must be crashworthy.

9.6.4.f – Pavement Markings

The provisions of this Section shall not be considered applicable for short-term or mobile temporary traffic control zones. Pavement markings in work zones provide guidance in low visibility driving situations (e.g., fog, rain, night) and for drivers operating in an unfamiliar location. Pavement markings shall be maintained along paved streets and highways in all long-term stationary temporary traffic control zones. Pavement markings shall match the markings in place at both ends of the temporary traffic control zone. Pavement markings shall be placed along the entire length of any surface detour or temporary roadway prior to the detour or roadway being opened to road users. Warning signs, channelizing devices and delineation shall be used to indicate required road user paths in temporary traffic control zones where it is not possible to provide a clear path by pavement markings.

When temporary pavement markings are placed, all existing pavement markings and raised pavement marker lenses that conflict with the temporary traffic pattern must be removed. Temporary pavement markings must be removed when the permanent markings are reinstalled.

Removable temporary black pavement marking tape is approved. It can be used to cover existing pavement markings that are in acceptable condition and will be reinstated after the temporary traffic pattern has concluded. Refer to Bulletin 15 for more information on what is approved.

It is permissible to use any approved temporary non-removable pavement marking tape in lieu of paint. In some instances, channelizing devices may be substituted for temporary pavement markings; refer to Publication 213.

To assist motorists on nighttime wet roadways, use temporary raised pavement markings (RPMs), waterborne pavement markings, or wet reflective temporary pavement marking tape throughout the project, unless channelizing devices are used along the travel lanes to provide high visibility of nighttime delineation.

9.6.4.g – Lighting Devices

Lighting devices should be provided in temporary traffic control zones based on engineering judgment.

Utility, maintenance, or construction activities on highways are frequently conducted during nighttime periods when motor vehicle traffic volumes are lower. Large construction projects are sometimes operated on a double-shift basis requiring night work. When nighttime work is being

performed, floodlights should be used to illuminate the work area, flagger stations, equipment crossings, and other areas.

Floodlighting shall not produce a disabling glare condition for approaching road users. Research indicates that five foot-candles are a desirable nighttime illumination level where workers are active.

9.6.4.h – Rumble Strips

Transverse rumble strips consist of intermittent narrow, transverse areas of rough textured or slightly raised or depressed road surface that extend across the travel lanes to alert motorists to unusual vehicular traffic conditions. Through noise and vibration, they attract the motorist's attention to such features as unexpected changes in alignment and to conditions requiring a stop. Longitudinal rumble strips consist of a series of rough-textured or slightly raised or depressed road surfaces located along the shoulder to alert road users that they are leaving the travel lanes.

Intervals between transverse rumble strips may be reduced as the distance to the approached conditions is diminished to convey an impression that a closure speed is too fast and/or that an action is imminent. A sign warning motorist of the onset of rumble strips may be placed in advance of any rumble strip installation.

Transverse rumble strips should be placed transverse to vehicular traffic movement. They should not adversely affect overall pavement skid resistance under wet or dry conditions. In urban commercial areas, even though a closer spacing might be warranted, transverse rumble strips should be designed in a manner that does not promote panic braking or erratic steering maneuvers by road users. Transverse rumble strips should not be placed on sharp horizontal or vertical curves. Rumble strips should not be placed through pedestrian crossings, horse and buggy areas, or bicycle routes.

For guidance on temporary portable rumble strips, refer to Publication 213. For guidance on temporary bituminous rumble strips, refer to Publication 72M, RC-22M, and Publication 46. The use of temporary rumble strips within work zones should consider traffic phasing so that any temporary rumble strips are not milled into final wearing course or within the final lane condition wheel path.

9.6.4.i – Screens

Screens are used to block the road users' view of activities that can be distracting. Screens might improve safety and motor vehicle traffic flow where volumes approach the roadway capacity because they discourage gawking and reduce headlight glare from oncoming motor vehicle traffic. Screens should not be mounted where they could adversely restrict motorist visibility and sight distance and adversely affect the safe operation of vehicles. Screens should be mounted on the top of temporary traffic barriers that separate two-way motor vehicle traffic,

especially in crossover areas. The design of screens should be in accordance with the AASHTO Roadside Design Guide.

9.6.4.j – Dynamic Devices

This section provides various types of dynamic TCDs that involve change or interaction. **Exhibit 9.6.6** illustrates examples of dynamic devices.

Exhibit 9.6.6 Examples of Dynamic Devices



9.6.4.j.i – Flashing Warning Devices

There are multiple types of supplemental lights that might be used to aid in visibility and prominence of the signage utilized on the project. These lights must be mounted and placed on signs in accordance with the MUTCD, Publication 213, and Publication 111.

These lights include:

- **Type A Low-Intensity Flashing Light.** Used to warn road users during nighttime hours that they are approaching or proceeding in a potentially hazardous area. They may be mounted on channelizing devices.
- **Type B High-Intensity Flashing Light.** Used to warn road users during both daytime and nighttime hours that they are approaching a potentially hazardous area. May be mounted on TTC signs or independent supports.
- **Type C Steady Burn Light.** Used during nighttime hours to delineate the edge of the traveled way or merge area. When used to delineate a curve, they should only be used on devices on the outside of the curve, and not the inside of the curve.
- **Type D 360-Degrees Steady Burn Light.** Used during nighttime hours to delineate the edge of the traveled way or merge area. When used to delineate a curve, they should only be used on devices on the outside of the curve.
- **Sequential Flashing Light.** Used on channelizing devices that form a merging taper. The lamps provide a low-intensity steady burn light equivalent to a Type C light, with a high-intensity luminous pulse equivalent to a Type B light.

9.6.4.j.i.1 – Type A and Type B Flashing Warning Light Usage

The designer should recognize that Type A and Type B flashing warning lights:

- Have a minimum mounting height of 30-in (to bottom of lens).
- Are mounted at or above the midpoint of the sign face without obscuring any part of the face.
- Require a red lens when mounted to a stop sign.
- Are used to mark obstructions and potential hazards.
- Are not to be used for delineation (as a series of flashers would tend to obscure the desired vehicle path) or in a series (unless the spacing is greater than 250 ft).
- Are not to be used where two-way Type A lights are not permitted (i.e., where they would be visible and confusing to drivers in other directions of travel).

9.6.4.j.i.2 – Type C and Type D Steady Burn Light Usage

The designer should recognize that Type C and Type D steady burn lights:

- May be mounted on barricades, drums, vertical panels, barriers, or other supports.
- May be used in series or to delineate the proper vehicle travel path through a work zone.
- Are not to be used where they would be visible and confusing to drivers traveling in the opposite direction to that of which the lights are meant to serve.

9.6.4.j.i.3 – Sequential Warning Light Usage

The designer should recognize that sequential warning lights:

- Are required in merge tapers for long-term applications on freeways/expressways.
- Must provide positive guidance in transition and taper areas where traffic is performing a horizontal shift.
- Are useful for areas where TCDs will remain in place during overnight periods.
- Provide safer operation at the merge where early merging is encouraged.
- Are encouraged for use where:
    - Locations where traffic is expected to transition and/or merge.
    - Nighttime TCD restrictions will be in place.

9.6.4.j.ii –Changeable Message Signs (CMSs)

9.6.4.j.ii.1 – Portable Changeable Message Signs (PCMSs)

PCMSs can be effective on high-speed highways by furnishing drivers with real-time information about incidents, weather, and unexpected conditions and providing them with the best course of action. PCMSs can be particularly useful at highway construction and maintenance work sites that frequently present drivers with unexpected traffic or detour situations.

Their primary purpose in work zones should be to advise drivers of unexpected traffic and routing conditions. However, drivers accustomed to the situation may not read the message. Therefore, consider changing the message slightly to help keep drivers' attention.



When using PCMSs, be sure that the messages are correct and displayed at the proper time. Drivers may react negatively to the sign if it:

- Displays information that is contrary to existing conditions.
- Displays information that is not easily understood or read in ample time to make the appropriate maneuvers.
- Tells drivers something they already know.

When using multiple signs to convey information, maintain 1,000 ft between signs. The message must be:

- Short enough so that an approaching driver can read the entire message.
- Displayed long enough so that the message is readable at the travel speed of the highway.
    - Normally, a driver needs at least one second per short word (up to eight characters) and two seconds per unit (direction) of information.
    - A 12-in message is normally readable from approximately 450 ft.
    - An 18-in message is normally readable from approximately 650 ft.
    - Consider placement on both the left and right side of roadway for freeways and interstates.
- Limited to two screen phases per board.

Example messaging is shown in **Exhibit 9.6.7**.

Exhibit 9.6.7 Example Changeable Message Sign Messaging



Where applicable, modems can be provided to allow cellular communication for dynamic message signs. Adding this capability offers additional communication for drivers, such as:

- Traffic control (where project staging requiring various lane or side-road closures).
- Weather-related travel information.
- Event traffic restrictions.
- Travel times.

9.6.4.j.ii.2 – Dynamic Speed Display Signs (DSDs)

DSDs are changeable message signs, which display operating speed to approaching motorists. DSDs are activated by speed-detection methods, such as radar. They may be installed in conjunction with a variety of supplementary stationary work zone signs, including:



- Regularly posted speed limit or work zone speed limit signs
- Active work zone speed limit signs
- Advisory speed plaques

DSDs are required on freeway construction projects that exceed a cost of $300,000.

DSDs:

- May be on temporary, portable signs on barricades or trailers.
- May be permanent installations attached to new or existing roadside hardware.
- Have shown increased reductions in travel speed by drivers, compared to installations of standard passive stationary signs.
- Can be applied regardless of speed limit value. However, they may have better utility and more observable speed reductions in areas with higher speeds.

- Should only be used at key locations, such as speed transitions or on a temporary basis for maintenance and construction work zones, to avoid overuse.

9.6.4.j.ii.3 – Arrow Panel Function and Placement

An arrow panel should be used in combination with appropriate signs, channelizing devices, or other temporary traffic control devices. Typically, an arrow panel should be placed on the shoulder of the roadway or, if practical, further from the traveled lane. It should be delineated with retroreflective temporary traffic control devices, or when within the clear zone, shielded with a barrier or crash cushion. When an arrow panel is not being used, it should be removed; if not removed, it should be shielded; or if the previous two options are not feasible, it should be delineated with retroreflective temporary traffic control devices. Arrow panel information is found in PennDOT Publication 213 and Publication 408, Section 901. Department approved arrow panels are listed in Publication 35, Bulletin 15.

Arrow panels included in the design of a TTC plan should generally be located as shown in the typical applications in Publication 213. However, the location may be adjusted to optimize visibility of the device. For additional guidance, refer to Section 6L of the MUTCD.

9.6.4.j.iii – Traffic Control Signals

Traffic control signals are typically used in work zones such as temporary haul road crossings; temporary one-way operations along a one-lane, two-way highway; temporary one-way operations on bridges, reversible lanes, and intersections.

One-lane, two-way motor vehicle traffic flow requires an all-red interval of sufficient duration for road users to clear the portion of the temporary traffic control zone controlled by the traffic control signals. Safeguards shall be incorporated to avoid the possibility of conflicting signal indications at each end of the temporary traffic control zone. When temporary traffic control signals are used, conflict monitors typical of traditional traffic control signal operations should be used.

Temporary traffic control signals should only be used in situations where temporary traffic control signals are preferable to other means of traffic control, such as changing the work staging or work zone size to eliminate one-way motor vehicle traffic movements, using flaggers to control one-way or crossing movements, using STOP or YIELD signs, and using warning devices alone. Temporary traffic control signals not in use should be covered or removed.

Publication 213 provides information regarding the use of these signals. **Exhibit 9.6.8** provides a summary table of how Publication 213 addresses the various types of TTC signals by type of highway or work zone application. There are complex and non-complex conditions outlined in Publication 213:

- **Complex Condition.** A condition where driveways and/or side roads exist between the TTC signals. Additional signal installations or flaggers are required to control traffic in addition to those shown on PATA 700 series drawings.

- **Non-Complex Condition.** A condition where driveways and/or side roads do not exist in the TTC zone utilizing temporary traffic signals. PATA 700 series drawings can be implemented and run automatically exactly as shown without flagger assistance or additional signals.

It is also important that the designer is knowledgeable about Publication 408 specifications for TTC signals and how measurement of payment and pay items are defined, as these TTC specifications differ from conventional permanent traffic-signal work. This will ensure that the project PS&E are properly developed.

Exhibit 9.6.8 TTC Signals (Publication 213 PATA References)

TTC Signals (Publication 213 PATA References)				
Type of Highway	**Type of Application**	**Type of TTC signal support**		
		Pedestal-mounted portable	**Trailer-mounted portable**	**Overhead span wire fixed supports**
Existing two-lane or two-way highway. Operates with temporary one-lane or two-way traffic flow.	Short-Term Non-Complex	PATA 701	PATA 702	N/A
	Short-Term Complex	PATA 703	PATA 704	N/A
	Long-Term Complex or Non-Complex	N/A	PATA 706	PATA 705

9.6.4.j.iii.1 – Temporary Traffic Control Signals

Temporary traffic control signals may be a necessary TTC component for the following work zone applications:

- Existing two-lane/two-way highway operating with temporary one-lane/two-way traffic work zone flow.
- Newly established intersections that need temporary management of traffic.
- Existing unsignalized intersections need temporary management of traffic due to a significant increase in traffic volume caused by the construction project. (Note: Before the installation of a temporary traffic signal can occur, the need and function of the signal

and the indication that the signal will be removed upon completion of the relevant phase or project must be communicated to the impacted municipality.)

- Existing unsignalized intersections while permanent traffic signals are constructed.

Temporary signals are usually installed with one of the following three methods:

- Fixed supports (long term).
- Portable trailer mounted (long term or short term).
- Portable pedestal mounted (short term).

Refer to Section 9.4.1.e for a summary of how Publication 213 addresses these types of TTC signals by type of highway/type of work zone application.

For additional information on temporary signal design, refer to:

- Publication 213, PATA 700 series and Appendix D, which contains standard temporary signal applications for all of the support systems mentioned above, as well as detailed notes and an appendix.
- Publication 408, Section 958, *Temporary Traffic Control Signals*. Pay attention to the measurement and payment portion of this specification as the pay items are measured differently for temporary signals versus conventional permanent signals.
- ECMS Master Items (0958) as there are various items and options available dependent upon the specific TTC use.

9.6.4.j.iii.2 – Temporary Work on Existing Permanent Traffic Control Signals

For many projects, work zone impacts may lead to significant traffic-volume diversions to existing signalized intersections or corridors. Publication 408, Section 958, contains specifications for the following type of work on existing permanent signals that may be needed as part of TTC design:

- Temporary timing adjustments to permanent traffic signal controller.
- Temporary modifications to permanent traffic signal.

Additionally, when the project scope includes work on a signalized corridor, providing appropriate timing coordination can serve to mitigate some of the work zone impacts that may result.

Modern adaptive signal technology can allow for signal timings to adjust based on variable demand, as well as the opportunity for data collection on changing volumes. Improvements to these systems as part of the TTC design can often be completed with minor equipment upgrades and communication systems.

Refer to Publication 149 for more information on permanent traffic signal design and coordination.

9.6.4.j.iv – Shadow Vehicles/Truck-Mounted Attenuators

As shown in Publication 213 PATA drawings, shadow vehicles are required with a truck-mounted attenuator on all freeways and expressways but are optional on other facilities.

Additionally, for purposes of short-term maintenance, it is recommended to use shadow vehicles per **Exhibit 9.6.9**.

Exhibit 9.6.9 Shadow Vehicle Use

Short-Term Maintenance Shadow Vehicle Use Guidance	
Roadway or Use Type	**Use**
All freeways and expressways	• Full-lane or partial-lane closures. • All shoulder work. • If the shoulder is not wide enough to safely park the vehicle, close adjacent lane.
Other roadways	Optional
Stop-and-go operations	Always

Indicate the location of the shadow vehicle on the TCP:

(1) All shadow vehicles that are not behind other work-area protection devices should be visible from behind for a distance (in feet) of ten times the posted legal speed limit.

(2) When only one shadow vehicle is used, it must be located behind the work area at an approximate distance of 150 to 250 ft.

(3) When two shadow vehicles are used, except for stationary short-term operations in a two-way, left-turn lane (per PATAs 121 and 122 in Publication 213):

- The first shadow vehicle must be located as in (2) above.
- The second shadow vehicle must be located completely on the shoulder and a minimum distance upstream from the first, as detailed in **Exhibit 9.6.10.**

(4) When two shadow vehicles are used on short-term stationary operations in a center-two-way, left-turn-lane (per PATAs 104 and 122 in Publication 213), one shadow vehicle must be located on each side of the work area at an approximate distance of 150 to 250 ft.

(5) All shadow vehicles must be positioned so that the back of the vehicle is facing oncoming traffic.

Exhibit 9.6.10 2nd Shadow Vehicle Distance from 1st Shadow Vehicle

Speed Limit	Distance (ft)
25 mph	250
30 mph	300
35 mph	350
40 mph	400
45 mph	450
50 mph	500
55 mph	550
All freeways and expressways	1,000

9.6.4.j.iv.1 – Size, Weight, and Equipment for Shadow Vehicles

When used with a truck-mounted attenuator, the size and weight of the vehicle should be in conformance with the manufacturer's specifications.

9.6.4.j.v – Work Zone ITS Systems

With the advent of modern technology related to traffic signals, communications, automated vehicles, and several other applications, there are opportunities to apply this technology to improve the safety and efficiency of work zone operations. The use of ITS can be approached in several different areas, depending on the project type and adjacent roadway network. A flow chart for the development of the SWZ concept is provided in Section 9.5.2.e.

9.6.4.j.v.1 – Queue Detection and Protection

Work zones and subsequent lane restrictions on major roadways can lead to significant queuing approaching the work area, as heavy volumes approach an area with significantly reduced capacity. To provide drivers with advance notification of the work zone, as well as reduce the risk of significant multiple vehicle crashes, queue detection should be considered in advance of the work zone.



Critical elements to the design include:

- Location of detection and allowable tolerance.
- Viability of communication of advance notification signage.
- Location of advance notification signage.

- Ability to detour traffic from primary route.

9.6.4.j.v.2 – Connected and Automated Vehicles (CAVs)

Highly connected and automated vehicles (CAVs) continue to make up a greater percentage of existing vehicles. Accordingly, accommodating these vehicles in work zones is a major operational concern.

Work zones present changes to typical roadway conditions, such as geometry, lane width, pavement markings, and lighting—all things that automated vehicle systems are designed to detect.

When considering the accommodation of these vehicles as part of TTC, several factors should be considered:

- Continuity of communication networks.
- Clarity of delineation, pavement markings, and TCDs through the work area.
- Advance notice of work zone to mapping and traveler information services.
- Lane reservation system.
- Compatibility between information sources and CAV systems.

9.6.4.j.v.3 – Other Work Zone Technologies and ITS Strategies

The designer should be aware of new and emerging technologies and look for opportunities to incorporate them into their projects. These new technologies have great potential of being beneficial to the project.



Other potential strategies for consideration may include:

- Closed-circuit television (CCTV).
- Ramp metering.
- Interconnected permanent changeable message signs.
- Social media outreach.
- Dynamic lane-closure systems.
- Automated enforcement.
- Advanced notification for temporary signal devices.
- Variable Work Zone Speed Limits.
- Dynamic lane merge.

9.7 – Surrounding Transportation Network Considerations

When designing project traffic control, it is important to consider and account for the surrounding network elements and the impact on both a proposed TTC and these elements. The following sections are some surrounding network elements that need to be considered.

9.7.1 – Land Use and Context Considerations

It is important to know what land uses exist within the project area or surrounding network area so they can be inventoried and addressed. Addressing these land uses for access of all travel modes in the project's TTC phases helps with public and local buy-in, and potential avoidance of issues during the implementation phase.

A partial list of context concerns that need to be considered include:

- Area type (Commercial, Industrial, Residential, Farming, Rural, etc.).
- Land Use Specifics (School, Fire/Police Station, Hospital, Curbside Restaurants/Commercial, etc.).
- Community needs and issues (Plain People Considerations, etc.).
- Special event attractions.
- Economic drivers.
- School locations.
- Transit requirements.
- Bike/Pedestrian facilities and needs.

9.7.2 – Intersections

Signalized intersections and coordinated signal systems may be impacted by a project's proposed TTC through operational changes in traffic volumes, traffic direction patterns, vehicle types, geometric needs, and other factors. These operational changes may necessitate revisions to existing signals and signal systems as part of the project TTC, such as phasing and timing revisions, coordination revisions, pedestrian crossing time requirements, and geometric changes.

Non-signalized intersections may be similarly impacted by a project's proposed TTC. Operational changes may necessitate revisions to existing intersections as part of the project's TTC, such as adding or revising traffic control, including TTC signals and geometric changes.

9.7.3 – Interchanges

Interchanges may be impacted or have impacts as part of a project's proposed TTC. Some items that need to be considered when there are interchanges within the project area or surrounding network area include:

- Off-ramp queuing and backups on to a mainline.
- On-ramp queuing and backups on to a secondary road.
- Mainline off-ramp access/egress within the work zone.
- Mainline on-ramp access/ingress into the work zone.

9.7.4 – Roundabouts and Complex Intersections/Interchanges

There are several potential design alternatives to manage congestion at major roadway junctions. The alternatives include intersection treatments (such as roundabouts) and interchange treatments (such as the diverging diamond interchange).

When installing these options at existing intersections or interchanges, traffic control phasing and staging can become complex, as considerations of maintenance of all modes of traffic, staging of materials, construction methods, and available right-of-way lead to several considerations when developing the TCP.

Exhibit 9.7.1 illustrates an example roundabout TTC. A summary of potential design issues on roundabout and interchange projects is depicted in **Exhibit 9.7.2.**

Exhibit 9.7.1 Example Roundabout TTC Layout

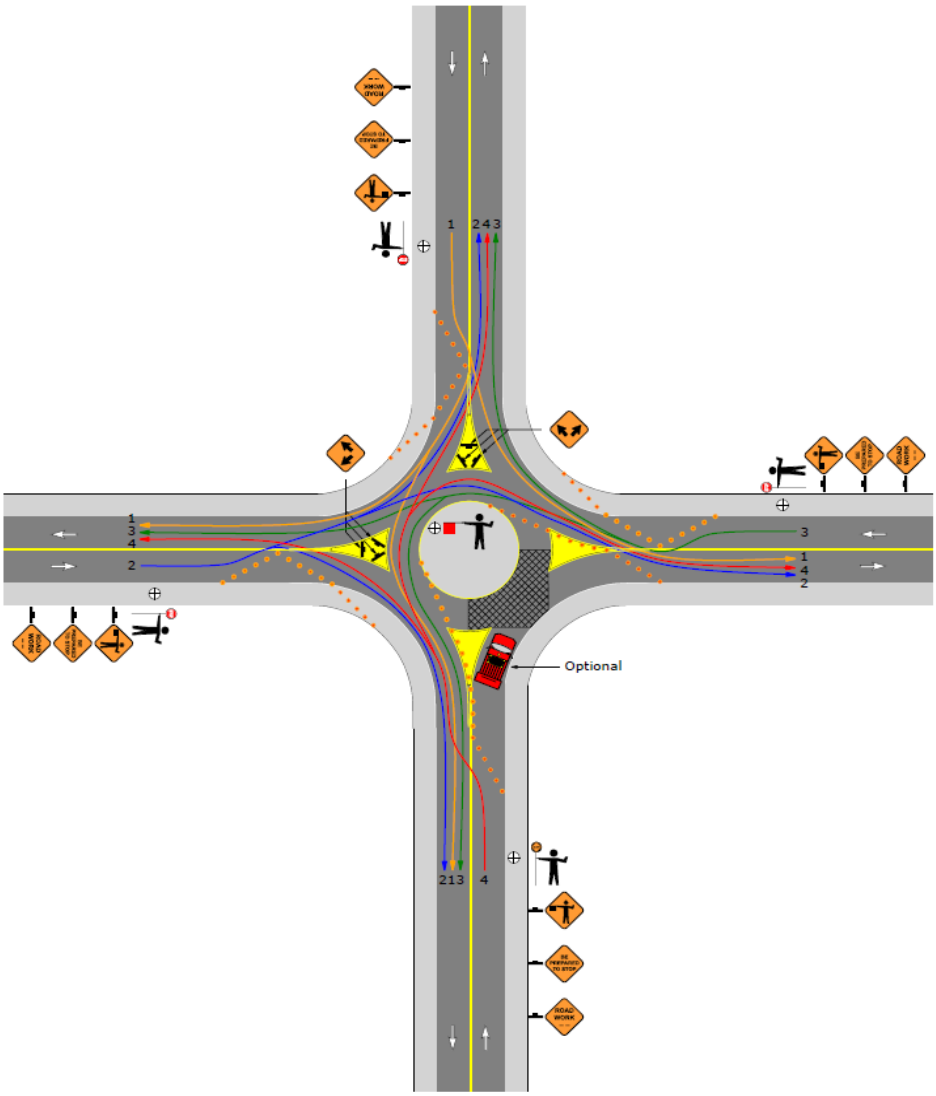






Exhibit 9.7.2 Interchange and Roundabout TTC Design Considerations

Traffic Control Aspect	Questions to Consider
Contractor working room	• Can the proposed project be built with active traffic adjacent? • Is there enough room to feasibly build the project if traffic is maintained? • Will phasing cause undue exposure to site workers?
Construction cost	• Can the construction be accommodated without undue cost to the contractor? • Will maintaining traffic adjacent to areas with open excavation or significant elevation differences create the need for significant construction measures (e.g., shoring or other support systems)?
Off roadway/temporary roadways	• Should off-roadway construction or temporary roadways be considered to allow for feasible construction? • Can this work be accommodated within right-of-way, or can easements be realistically obtained?
Construction phasing	• Should closures to through traffic on one or multiple approaches be considered? • Will phasing and partial-width construction leave a disjointed final product?
Time-of-day restrictions	• Can work be completed during off-peak periods in a manner that leaves the area traversable during construction?

For guidance on short-term operations in and near roundabouts and signalized intersections, refer to Publication 213. While not intended for long-term application, this guidance can serve as a framework for developing a staging and phasing plan and how traffic can be maintained adjacent to the work area.

For complex interchanges, the designer should consider the following:

- Detours of major interchanges and their ramps should be avoided if at all possible.
- Detouring major traffic volumes onto lower-volume roadways can create safety and congestion issues throughout the adjacent roadway network.
- Temporary ramp and structure operations should be coordinated with the final project to minimize redundant excavation and allow for proposed shoulders and excess roadway width to be utilized during construction.

9.7.5 – Driveways/Curbside Access

Driveways and highway openings within a project area can present a challenge when designing TTC phases. It is important that these open-access points are inventoried and addressed so that traffic flow and operational conflicts are avoided within the work zone. See Publication 213 for guidance and details on TTC in driveway areas.

9.7.6 – Parking Considerations

Operations for TTC will often impact lanes typically provided for parking, loading zones, or other stopping and standing operations most commonly found in rural towns and urban areas. As part of designing a TTC phase, consideration for providing these parking and loading zone areas will assist in maintaining the community businesses and context.

9.7.6.a – Short-Term Impacts

Temporary parking prohibitions can be instituted in coordination with local stakeholder agencies. This may be present with resurfacing operations, pavement marking installation, or minor curb and drainage repairs adjacent to the curb.



In cases where parking will be prohibited during working hours, signage clearly denoting the restriction and time period should be included as part of the TCP. However, for long-term traffic control impacts, coordination should be made with the local stakeholder to coordinate alternate parking arrangements.

9.7.6.b – Accessibility Guidelines for Parallel and Angle Parking

When permanent accessible parking spaces, as required by the Americans with Disabilities Act (ADA), are removed due to work zone activity, alternate temporary accessible parking spaces must be provided. The parking space must be clearly signed and marked, so it is easily identified. Refer to Chapter 19, *Parking*, for accessibility parking guidelines.

9.7.6.c – Loading Zones

For parking and loading zone areas, efforts should be made to ensure that access to businesses is maintained. When construction will potentially impact a loading zone or parking, the business owner should be contacted to assist in determining appropriate alternate measures to mitigate the impacts as part of traffic control phase design.

9.7.7 – Pedestrian/Bicyclist Accommodations

A properly designed TCP should seek to properly accommodate motorists, pedestrians, and bicyclists around or through the work area. These users have vastly different operational and exposure concerns compared with motorists.



9.7.7.a – Pedestrian Access

When pedestrian pathways are closed or disrupted due to construction, maintenance, or utility work, pedestrian traffic controls are required. These controls shall include signs, channelizing devices, etc. to clearly direct pedestrians through or around the work site. Advanced notification of sidewalk closures shall be provided. Adequate provisions shall be made for persons with disabilities. Access to businesses, residences, and crosswalks must be maintained. Adverse economic consequences to businesses within the work zone area should be avoided by maintaining proper access.

Some major considerations in planning for pedestrian safety in work zones include:

- Pedestrians should not be led into conflicts with work site vehicles, equipment, and operations.
- Pedestrians should be provided with a safe, convenient path that replicates as nearly as practical the most desirable characteristics of the existing sidewalk(s).
- Covered walkways should be provided when pedestrians are exposed to potential injury from falling objects.

It must be recognized that pedestrians are reluctant to retrace their steps to a prior intersection for a crossing or to add distance or out-of-the-way travel to a destination. Adequate provisions should be made for persons with disabilities. A pedestrian route should not be severed and/or moved for non-construction activities such as parking for vehicles and equipment. Consideration should be made to separate pedestrian movements from both worksite activity and motor vehicle traffic. Pedestrians should be appropriately directed with advance signing that encourages them to cross to the opposite side of the roadway. In urban and suburban areas, these signs should be placed at intersections so that pedestrians are not confronted with midblock work sites that will induce them to attempt skirting the work site or making a midblock crossing.

The following items must be considered when creating a TCP:

- Impact on pedestrian generators (Schools, Senior Centers, transit stops, etc.).
- Impact on existing pedestrian flow.
- Pedestrian information needs – advance, transition, work area, and exit information.

- Pedestrian Facilities – walkway width, surface, boundaries, transitions, and channelization.
- Intersections – crosswalk placement, additional signing/marking, and traffic signals modification (timing, pedestrian signals, push button, etc.).
- Adequate pedestrian protection – physical separation from work space and vehicular traffic, overhead protection, etc.
- Construction staging to maintain pedestrian access throughout all construction phases.
- Temporary nighttime lighting.
- Requirements of the Americans with Disabilities Act (ADA) of 1990.
- Location/access to business, residences, etc.

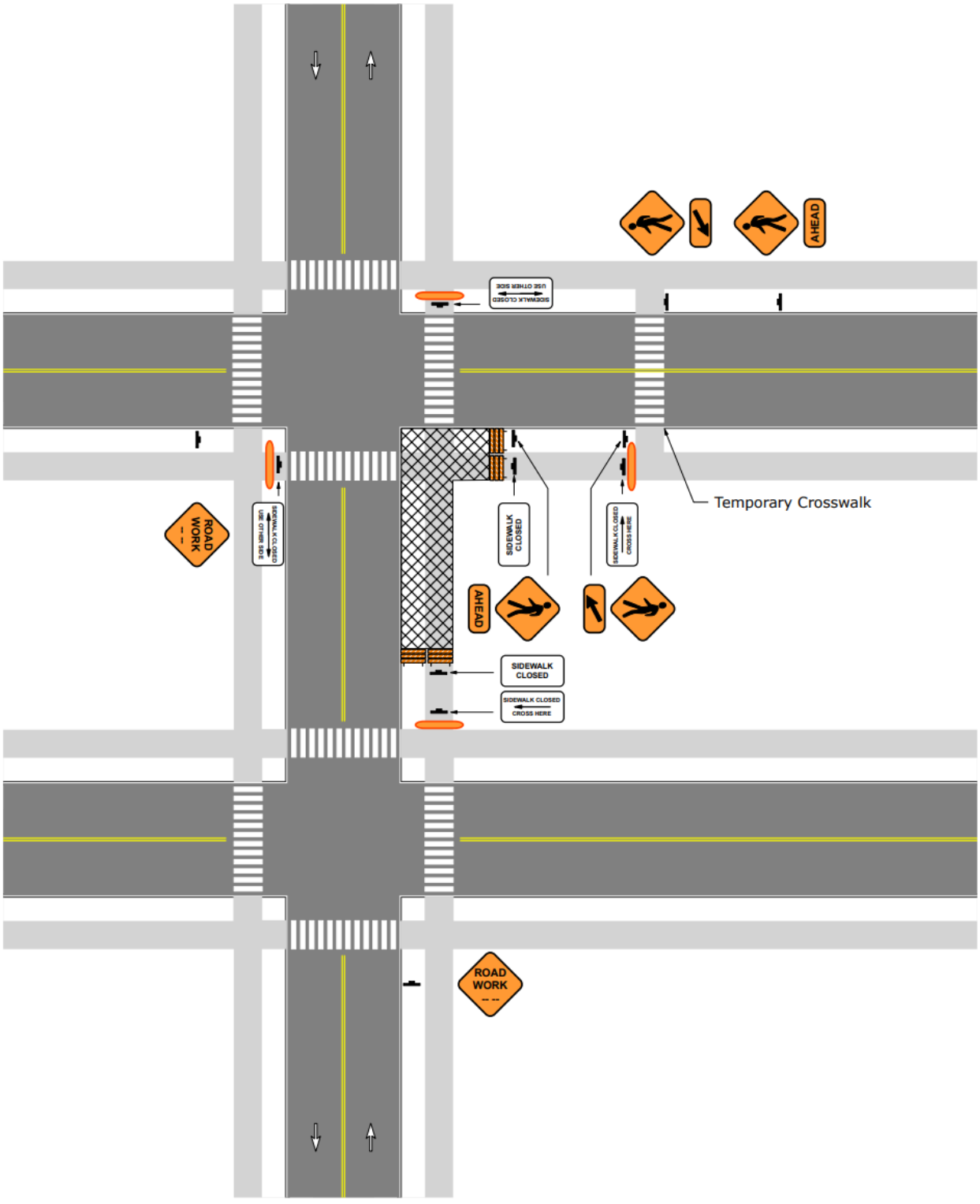
When pedestrian movement through or around a work site is necessary, a separate usable footpath without abrupt changes in grade or terrain should be provided. Whenever it is feasible, closing off the work site from pedestrian intrusion may be preferable to channelizing pedestrian traffic along the site with temporary traffic control devices such as barricades and drums. The extent of pedestrian needs should be determined through engineering judgment for each work zone situation. **Exhibit 9.7.3** provides an example sidewalk closure layout.

9.7.7.b – Guidance for Pedestrian Paths

Pedestrians should be provided with a safe, accessible, and convenient path that replicates nearly as practical the most desirable characteristics of the existing sidewalks.

- The alternate route should have a minimum width required by accessibility guidelines. Chapter 13, *Pedestrian Facilities*, provides additional information on accessibility guidelines.
- Signage related to construction activities must be placed in a location that does not obstruct the path of bicyclists or pedestrians, including bicycle lanes, wide-curb lanes, or sidewalks.
- In urban areas, access to businesses and residences should be maintained using temporary access ramps even during sidewalk closures.
- Adequate protection must be provided to ensure pedestrians are separated from and do not enter the work area; appropriate barriers should separate pedestrians and traffic.
- The path should have a level surface to allow for wheelchair and blind-user access without tripping hazards.
- There must be access to transit or clear directions to relocated transit access.
- There must be positive guidance, by way of barrier placement and signage, to the intended path.

Exhibit 9.7.3 Example Sidewalk Closure Layout

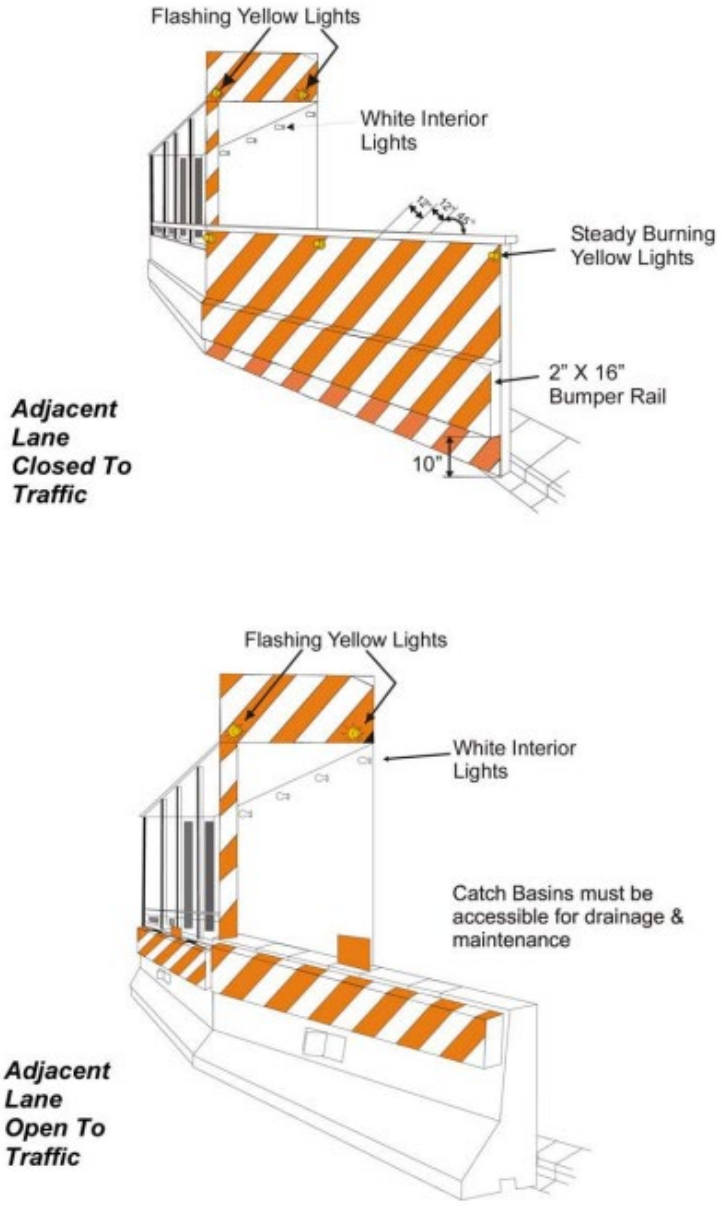


9.7.7.c – Covered Walkways and Walkways Adjacent to Work Areas

An additional concern in many urban areas is building/bridge or roadway construction scaffolding that encroaches on sidewalk widths or accommodation of pedestrian traffic immediately adjacent to a work zone.

While working within the pedestrian path, minimum horizontal and vertical clearances in accordance with ADA standards should be maintained. A temporary covered walkway must be used to protect pedestrians from falling debris and to provide a covered passage for pedestrians. Refer to **Exhibit 9.7.4.**

Exhibit 9.7.4 – Temporary Covered Walkway at Mid-Block



Temporary covered walkways are subject to the following criteria:

- The structural design and construction of covered pedestrian pathways shall be approved by Bureau of Design and Delivery.
- Covered walkways shall be sturdily constructed and adequately lighted for nighttime use with vandal-resistant fixtures mounted on 30-ft centers near the roof line.
- Under no circumstance shall work equipment or any other objects associated with work zone operations be placed on top of the roof of the covered walkway.

9.7.7.d – Bicycle Traffic Accommodation

With the growth of trail access and urban bike lanes within the commonwealth, bicyclists are making up a larger share of facility users. When construction impacts either their exclusive facility or an adjacent roadway that might serve as a shared route, provisions must be provided to ensure the safe travel of cyclists around or through the work area.

These impacts and provisions can take several different forms, as outlined below.

9.7.7.d.i – Bike Lane Closure with Detour

When an existing bike lane is closed as part of a construction project, an adequate detour route should be provided and signed accordingly. If available, local bike maps should be consulted to determine the closest comparable bike route. The bike detour route should follow the motor vehicle route if practical. Bicycle detour routes can be separate from motor vehicle routes.

If directing bicyclists into a vehicular lane, a SHARING THE ROAD sign should supplement the detour signage. The lane must have adequate width to function as a shared facility.

When closing the bike lane, ensure that visibility of the closure is adequate to clearly delineate the closure, using delineators, drums, and flashing devices.

Elements of an effective bicycle detour include:

- Traffic signals or bicycle signals to permit protected crossing of arterial streets.
- Flat surfaces free of obstacles.
- Exclusive bicycle paths/lanes or, if shared with motor vehicles, low traffic volumes.
- Appropriate detour signage with easily navigable path.

9.7.7.d.ii – Bike Lane Adjacent to Work Area

Any bike lanes adjacent to the work area should have minimum widths, as defined in Chapter 14, *Bicycle Facilities*. Deviations in surface should be clearly marked and signed. Excavations within the bike lane need to be secured and plated.

9.7.7.d.iii – Short Distance Closure of Bike Lane

If directing cyclists to use the sidewalk, signs directing bicyclists to dismount must be provided in advance of the transition to the sidewalk. Additionally, the end of the work area must be signed to denote when cyclists may remount their vehicles.

Refer to Chapter 14 for further information on bicycle facilities.

9.7.8 – Adjacent Projects

When designing project TTC, determine whether there are any adjacent projects. The effect that each project's TTC can have upon the other must be analyzed, considering:

- Overlapping TTC.
- Network disruptions from multiple projects.
- Overloading detour routes for volumes and type of vehicles.
- Traffic signals phasing, timing, and coordination.

Coordination should be made between adjacent or overlapping projects to check that duplicate signing is not used and to check compatibility of traffic control between adjacent or overlapping projects. Traffic control planning should be completed for all highway construction, utility work, maintenance operations, and incident management including minor maintenance and utility projects prior to occupying the temporary traffic control zone. Planning for all road users should be included in the process.

9.8 – Worker Safety Considerations

Equally as important as the safety of road users traveling through the temporary traffic control zone is the safety of workers. Temporary traffic control zones present temporary and constantly changing conditions that are unexpected by the road user. This creates an even higher degree of vulnerability for workers on or near the roadway. Maintaining temporary traffic control zones with road user flow inhibited as little as possible and using temporary traffic control devices that get the road user's attention and provide positive direction are of particular importance.

The following are the key elements of temporary traffic control management that should be considered to improve worker safety:

- **Temporary Traffic Barriers.** Temporary traffic barriers should be placed along the work space based on an engineering study considering factors such as lateral clearance of workers from adjacent traffic, speed of traffic, duration and type of operations, time of day, and volume of traffic.
- **Speed Reduction.** Reducing the speed of motor vehicle traffic, mainly through regulatory speed zoning, funneling, use of law enforcement officials, lane reduction, or flaggers should be considered.
- **Activity Area.** Planning the internal work activity area to minimize backing maneuvers of construction vehicles should be considered to minimize the inherent risk to workers on foot.

The following are additional elements of temporary traffic control management that may be considered to improve worker safety:

- **Road Closure.** If alternate routes are available to handle road users, the road may be closed temporarily. This may also facilitate project completion and thus further reduce worker vulnerability.
- **Police Use.** In highly vulnerable work situations, particularly those of relatively short duration, police units may be stationed to heighten the awareness of passing vehicular traffic and to improve safety through the temporary traffic control zone.
- **Lighting.** For nighttime work, the temporary traffic control zone and approaches may be lighted.
- **Special Devices.** These include rumble strips, portable changeable message signs, hazard identification beacons, flags, and warning lights. Intrusion warning devices may be used to alert workers to the approach of errant vehicles. Judicious use of the special devices might be helpful for certain difficult temporary traffic control situations, but misuse or overuse of special devices or techniques might lessen their effectiveness.

9.9 – Traffic Control Strategies

The designer has a wide variety of options in selecting appropriate traffic-control strategies for each project. Based on the scope and size of the project, multiple strategies may be applied in different areas or within different phases of the project.

Design related traffic control strategies pertain to how the TTC will be physically implemented on a project work area. **Exhibit 9.9.1** provides a summary table showing the relationship of available Publication 213 PATA series typical applications, based upon the type of project work zone activities.

Exhibit 9.9.1 Work Zone Activities Table (Publication 213 PATA References)

Work Zone Activities (Publication 213 PATA References)	Conventional Highways			Freeways and Expressways		
	Stationary		Mobile	Stationary		Mobile
	Short Term	Long Term		Short Term	Long Term	
	PATA 100 Series	PATA 200 Series	PATA 300 Series	PATA 400 Series	PATA 500 Series	PATA 600 Series
Work on or beyond the shoulder	X	X	X	X	X	X
Work on a single-lane approach	X	X	X			
Work on a multi-lane approach	X	X	X			

Work Zone Activities (Publication 213 PATA References)	Conventional Highways			Freeways and Expressways		
	Stationary		Mobile	Stationary		Mobile
	Short Term	Long Term		Short Term	Long Term	
	PATA 100 Series	PATA 200 Series	PATA 300 Series	PATA 400 Series	PATA 500 Series	PATA 600 Series
Work on two-lane approach				X	X	X
Work on three-lane approach				X	X	X
Work near interchange ramps				X	X	
Road closure with detour	X	X				
Freeway closure				X		
Work space located on sidewalks	X	X				
Lane closure ending at a T-intersection	X					
Lane closure beginning at a T-intersection	X					
Lane closure ending at a 4-way intersection	X					
Lane closure beginning at a 4-way intersection	X					
Flagger control with automated flagger-assistance devices	X					

9.9.1 – Do Nothing (Sustain Normal Traffic Operations)

Some projects or select work zone activities within a project may not need special traffic control to safely manage traffic. For example, tree trimming outside the clear zone may have no impact on the normal flow of traffic; therefore, setting up TTC may unnecessarily disrupt traffic. In addition, early phases of major roadway projects, such as earth moving or utility relocation, may have little to no impact on existing roadway operations.

In these particular situations, the best design strategy may be maintaining traffic with existing traffic control and not providing any special TTC measures.

9.9.2 – Full Lane Restrictions and Control

TTC for construction work may require restrictions and control to existing lanes, including temporary closures, shifts, or vehicle restrictions. Lane shifts or closures can last for varying durations based on construction operations, contractor access, or project restrictions. These lane restrictions can take on several forms:

- **Intermittent.** Often in the form of short-term closures (e.g., 15 minutes) to allow for contractor operations, switching of TTC, or other operations requiring heavy impact to facilities for a very short-term period.
- **Off-Peak and Night.** Projects on high-traffic facilities often only permit traffic restrictions during off-peak periods to avoid heavy congestion and significant traffic impacts to the adjacent roadway network.
- **Weekend.** Weekend lane restrictions may allow the contractor more opportunity for longer (i.e., 16 to 48 hours) construction operations while minimizing impact to peak hour operations.
- **Continuous.** For a single project phase or continuous for the duration of the project.

Exhibit 9.9.2 lists various lane restriction traffic-control strategies.

Exhibit 9.9.2 Lane Restriction Strategies

Strategy	Typical Uses	Advantages	Concerns
Reduced lane widths	• Shoulder repair. • Guide rail replacement. • Other operations that result in minor encroachment on the roadway.	Provides only minor capacity reductions while not compromising the number of lanes.	Need to be managed in conjunction with: • Emergency responders. • Heavy vehicles. • Transit vehicles.
Lane closure	• Full depth reconstruction. • Shoulder work. • Inspection operations.	• Contractor flexibility. • Ability to combine with other temporal restrictions to avoid roadway closures.	• Capacity analyses should be considered. • May require implementation of lane rental fees.

Strategy	Typical Uses	Advantages	Concerns
Reduced shoulder widths and shoulder closures	• Clearing and grubbing. • Wall installation. • Other off-roadway work that may require encroachment on to or closure of the shoulder.	• Maintains the existing number of lanes. • Allows access for the work activities to take place.	May require closure of clear area.
Use of shoulder or median	Full depth reconstruction.	Allows use of existing roadway infrastructure to maintain some capacity through: • Shift of the regular travel lanes. • Conversion of the shoulder/median to a travel lane. • Use of the median to crossover traffic.	A pavement analysis should be completed to ensure that the shoulder has sufficient structure.
One-lane or two-way operation	• Half-width reconstruction. • Emergency slide repair.	Typically, can be effective for lower volume roadways while avoiding total closure.	• Typically, only applicable for lower volume roadways. • Sight distance must be met. • May require signalization or use of flaggers to maintain efficient operation.
Reversible lanes	Areas with definitive reversible peak-hour behavior.	Allows for more efficient usage of unused capacity in non-peak direction of travel.	• Limited applicability, due to requirements of flexible barrier types or adjacent lane guidance indications. • Can be confusing to road users.

A key goal of any selected traffic-control strategy should be to minimize construction-related user delays and impacts. To minimize these impacts:

- Recognize that the length of lane closures should be as short as possible.
- Whenever possible, use a short “rolling work zone,” with movement of the closure as the project progresses to minimize the length of the capacity reduction.

- If possible, avoid recurrent congestion (i.e., LOS E) by maintaining all travel lanes or by specifying the work hours for times when congestion will be minimal.

TCP design may involve application of several of the lane restriction strategies listed above, in conjunction with other traffic-control strategies discussed in this chapter. Different facilities and traffic demands will require different treatments to help mitigate construction-related impacts.

On limited access highways (freeways and expressways):

- If feasible, the first consideration should be to maintain all travel lanes, particularly if a capacity analysis indicates significant congestion will occur over several consecutive hours due to lane restrictions. Generally, assume 1,200 to 1,600 passenger car equivalents per hour per lane, but the actual value should be refined based on local conditions.
- Consider maximum length lane closures of 3 to 5 miles with a minimum of 2 miles between adjacent work areas, unless documentation shows that a longer length minimizes road user costs or substantially shortens the overall duration of a lane closure. This should be evaluated on a case-by-case basis, as different construction operations may permit different lane arrangements.
- Accumulated queues over peak demand can lead to significant congestion on the constrained facility, as well as potential spillover effects onto adjacent arterials and other local roadways. Any capacity analysis should seek to quantify these impacts in addition to those on the primary facility.
- For projects where data is available, the FREEVAL software tool should be utilized to determine impacts from different capacity reductions resulting from the traffic control.

9.9.3 – Temporary Roadways and Bridges

In some situations, it may be appropriate to consider installation of a temporary roadway (i.e., runaround) or bridge that would allow for maintenance of traffic adjacent to the project area without requiring installation of a detour.

This is common on projects that necessitate a total closure of the facility but where a detour is not feasible, due to high traffic volumes, excessive detour length, high heavy vehicle traffic, or infeasible impact on emergency service providers.



9.9.3.a – Single-Lane and Two-Lane Temporary Roadways

Temporary roads can be single-lane or two-lane. See **Exhibits 9.9.3**, **9.9.4**, and **9.9.5** for example layouts. **Exhibit 9.9.6** provides details on temporary roadway standards (e.g., appropriate traffic control method and pavement widths).

Single-lane temporary roads can be considered when a study/capacity analysis indicates that any resultant traffic backup will be acceptable. When a single-lane temporary road cannot adequately handle the traffic, two-lane temporary roads will be used.

Traffic on single-lane temporary roads can be controlled by stop signs or traffic signals.

Obtain peak hour traffic counts to use with the *Highway Capacity Manual* to perform capacity analyses, when necessary.

Exhibit 9.9.3 Example Traffic Control Setups for Temporary Runaround

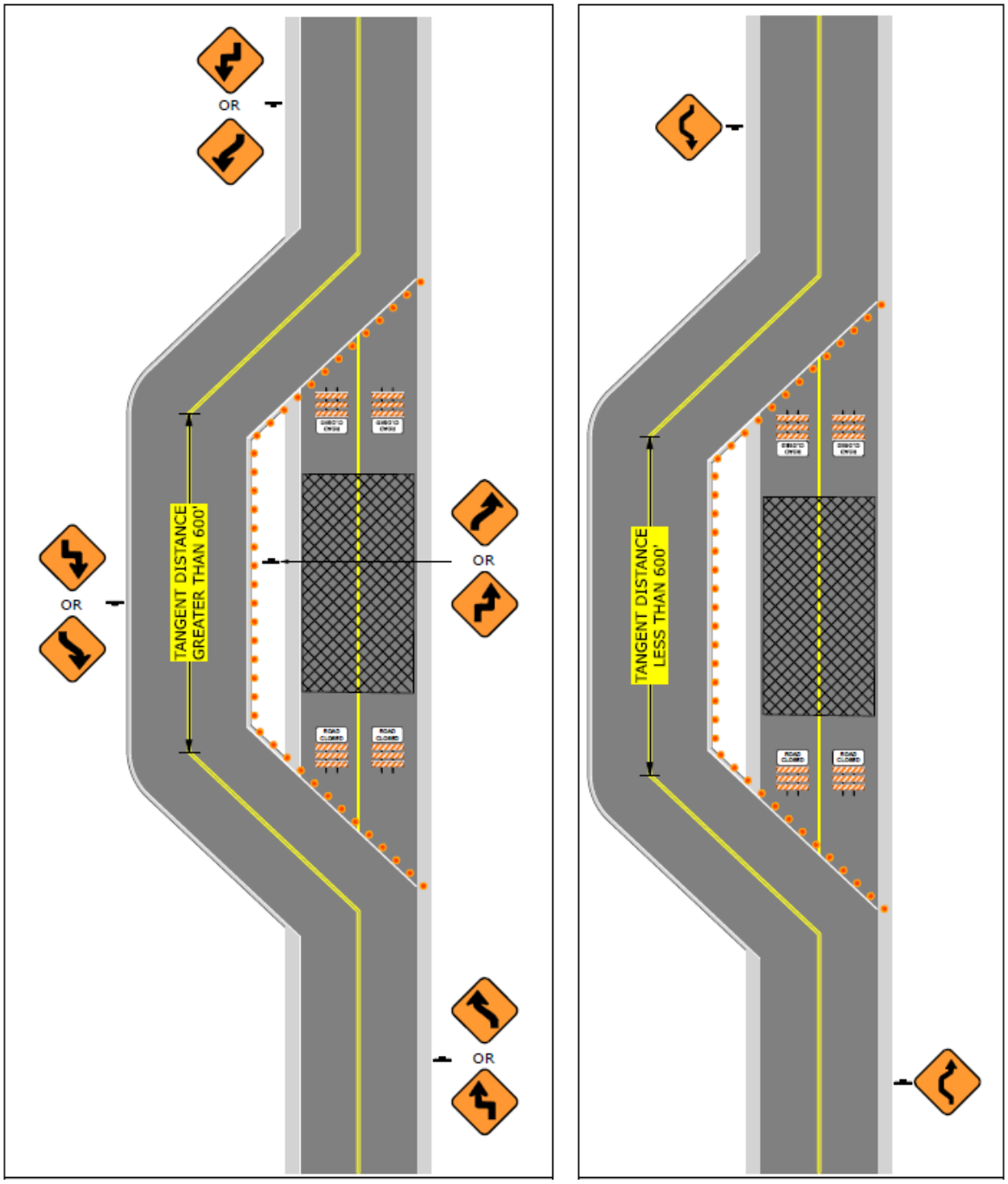


Exhibit 9.9.4 Example of Signal-Controlled Single-Lane Temporary Roadway

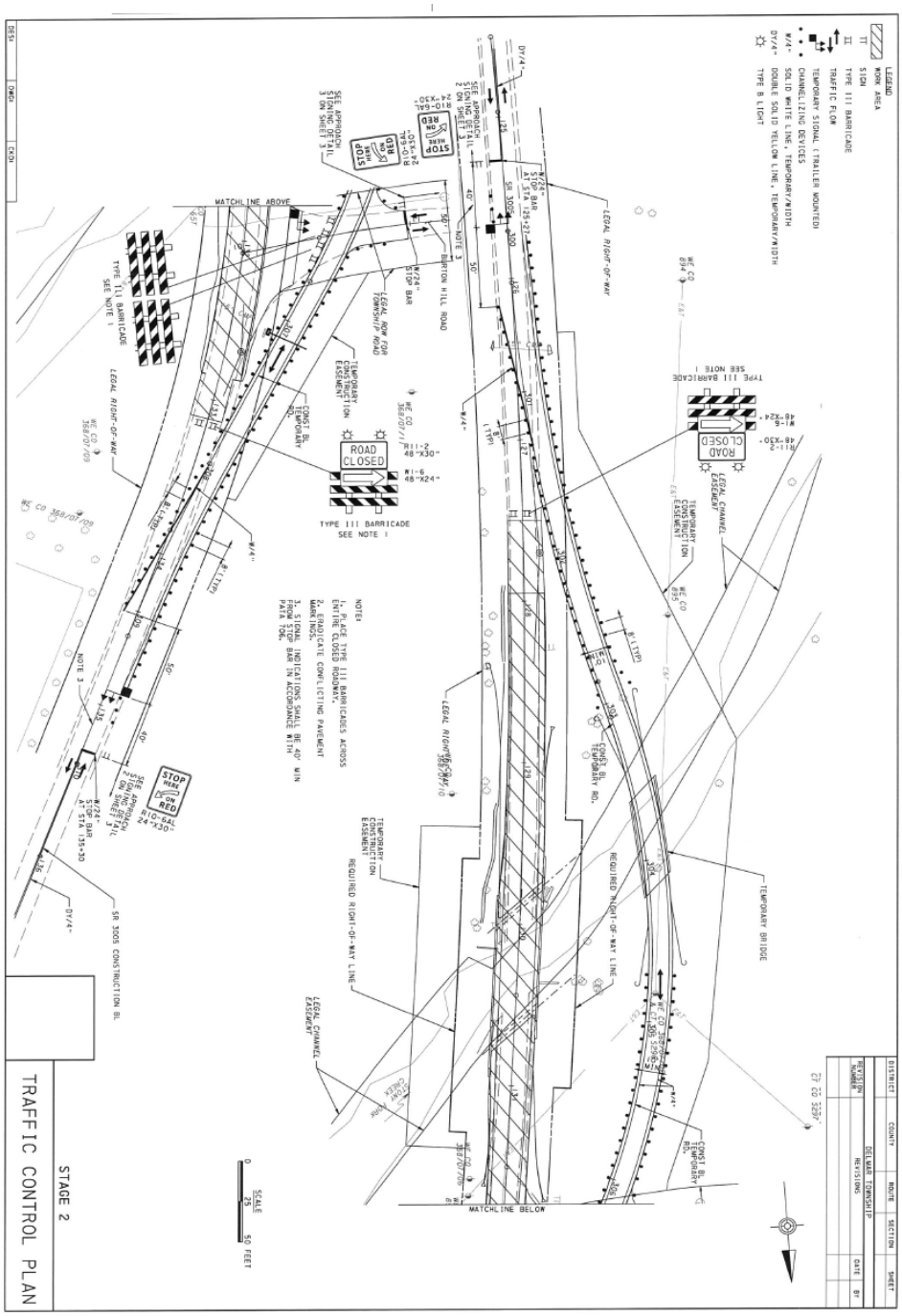


Exhibit 9.9.5 Example of Stop-Controlled Single Lane Temporary Roadway

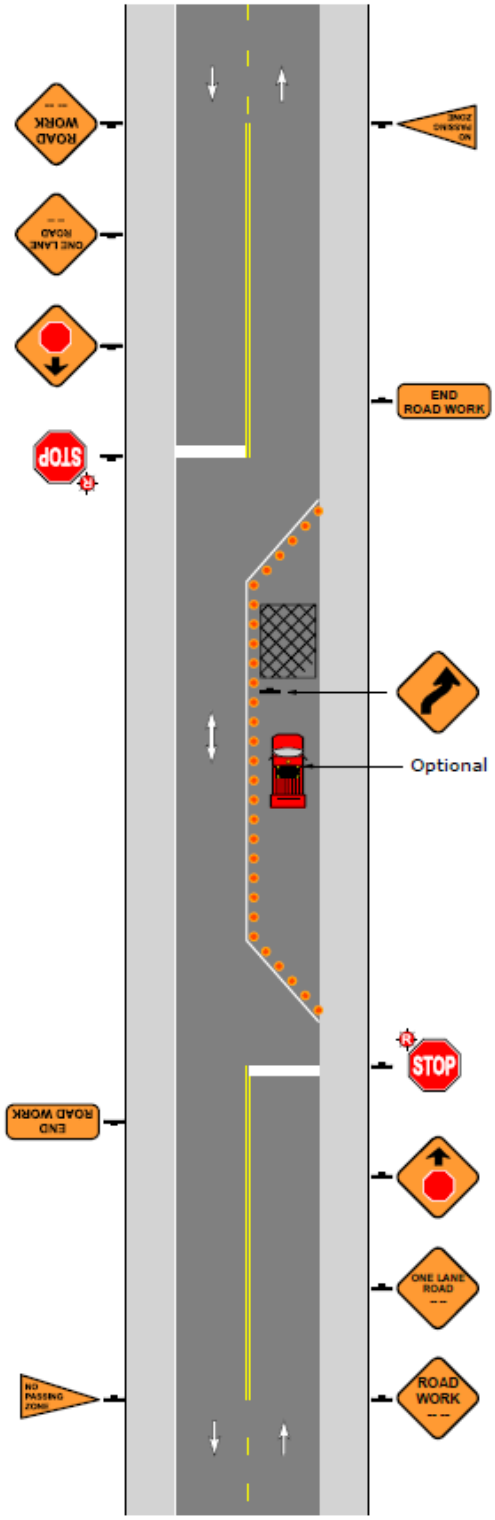


Exhibit 9.9.6 Temporary Roadway Lane and Shoulder Widths for Non-Interstate Roadways

Lane Arrangement	Traffic Volume	Length	Traffic Control		Traffic Volume	Minimum Lane Width	Minimum Shoulder Width
Single Lane	ADT<1,500	<150 ft	Stop Sign		ADT<500	10 ft (Paved)[4]	2 ft
						14 ft (SMS)[3]	N/A
	1,350< ADT< 1,650	>150 ft	*See Note 1		ADT>500	12 ft (Paved)[4]	2 ft
	ADT>1,650	N/A	Traffic Signal[2]			16 ft (SMS)[3]	N/A
Two-Lane					ADT<8,000	20 ft (Paved)[4]	2 ft
					ADT>8,000	22 ft (Paved)[4]	2 ft
					All ADTs	24 ft (SMS)[3]	N/A

(1) For ADTs of 1,350 and 1,650 vehicles per day and/or temporary road lengths greater than 150 ft, perform a study/capacity analysis to determine if traffic queues will be acceptable.

(2) Consider using traffic signals for traffic control of single lanes where stop sign control is not acceptable. Perform a study/capacity analysis, using hourly volumes, to determine if traffic queues will be acceptable. If traffic signal control cannot be used, provide a two-lane temporary road.

(3) When selected material surfacing (SMS) is specified, provide for paving the entire pavement and shoulder width.

(4) When higher-type pavement material is specified, consider paving the entire pavement and shoulder width if this is more economical than constructing separate shoulders of different material.

9.9.3.b – Temporary Bridges

Temporary bridges are designed using the current Department bridge design methodology found in Publication 15M, Design Manual Part 4, *Structures* (DM-4), Volume 1, Part A, Section 5.5.3.4, including consideration of geometric constraints (e.g., truck turning patterns).

9.9.3.c – Temporary Lighting

Often, TTC creates unfamiliar or modified lane arrangements and geometry for drivers. Appropriate use of temporary highway lighting may serve to promote:

- Safer operation through the work zone.

- Increased visibility of the traveled way, barriers, and other appurtenances.
- Increased visibility of construction workers during night work.

In single-lane, bidirectional traffic control with TTC signals, luminaires are not required but may serve to increase visibility of the temporary signal and better delineate the path.

On freeway temporary crossovers and/or at temporary exit ramp gores with significant geometric constraints or change in original exit location resulting in driver uncertainty, consider installing pole-mounted “cobra head” luminaries. Cobra head streetlights illuminate a larger area than floodlights and are not as distracting to the driver. Avoid floodlights, as they only illuminate a small area with a bright light that may blind drivers or cause them to lose their night sight.

9.9.4 – Full Roadway Closures and Detours

Due to construction requirements, space limitations, traffic conflicts, or desire to accelerate construction work, TTC may require the use of a full roadway or bridge closure with a signed detour**.** In addition to vehicular detours, provisions also need to be made for non-motorized users. As a design consideration, account for planned detours (e.g., emergency detours, colored detoured routes).

These full closures and detours may be:

- **Brief.** Intermittent or off-peak, typically less than 15 minutes.
- **Short term.** Night or weekend, typically up to 72 hours.
- **Long term.** Continuous for the duration of the project, greater than 72 hours.

9.9.4.a – Detour Design Considerations

When considering a strategy to close the roadway to traffic and detour versus other options which permit traffic, refer to WZSM policy guidance, located in Publication 46, for aspects to be considered. The guidelines require an analysis of overall contract and public costs, as well as safety aspects, before a decision is made. On some projects, an alternative to closing to traffic may be easily dismissed as being non-feasible; on other projects, it may be the best alternative.

The guidance box in Section 9.9.4.c provides a checklist of additional detour considerations that need to be addressed before deciding upon a full road closure and detour.

9.9.4.a.i – Consideration of a Roadway as Potential Detour Route

When considering a specific roadway for use as a detour route, the following items need to be determined:

- Ownership of the route (state, local, or other)

- It is preferrable to utilize state routes for detouring traffic from the closure of a state road.
- Consider the pre-existing condition of the proposed route (both local owned AND state owned) and if upgrades to this route will be required to safely convey the increased traffic volumes.
- There may be situations where a local roadway is preferred for the detour, due to excessive detour length with using a state road or other factors.
- Prior to implementation of any detour of a state roadway using local roadways, coordination should be undertaken with the local roadway owner. Agreements with local municipalities, businesses, and residences regarding the proposed detour routes need to be obtained as part of the design process.
- Further information on this is included in Publication 46, Chapter 6, Section 6.14, and Publication 23, Chapter 15, Section 15.3. Forms M-4902L18, *Roadway Detour – Relief of User Maintenance Responsibilities*, and M-4902L19, *Re-establishment of Roadway Posting*, detail requirements when using a posted or local highway. While not directly the responsibility of the designer, the need to complete this must be communicated to the contractor through the design package to enable consideration of the cost in the contractor's bid.

- Accommodations and condition of the proposed route:
  - Detour routes must be able to accommodate height, width, weight, length, off tracking, and other physical characteristics of the design vehicle (i.e., largest vehicle expected to use the detour). The designer should take into consideration weight and height restricted roadways.
  - If a local roadway is considered, it must be in adequate condition to accommodate the state highway traffic. If not, any required improvements and associated costs should be identified.

9.9.4.b – Freeway and Interstate Construction Ramp Closures

Detour of a ramp may be an appropriate option in situations where mainline work affects the ability of users to access the established ramp connections or where work may create elevation differences or potential safety hazards.

Where construction phasing, work access, or improved mainline traffic flow are needed, detour of one or more ramps in or near the work zone may be the appropriate option for specific time periods or construction phases.

In establishing the detour, considerations need to be made as to the capacity of adjacent ramp interchanges and any adjustments that may be required to provide additional capacity. The schedule of the ramp closures (e.g., nighttime, weekend) may be staggered or managed to minimize traffic impacts.

9.9.4.c – Detour Signing

Appropriate and adequate detour signing must be provided for the entire route in both directions. The design should:

- Provide roundabout detour signs using a curved stem arrow in accordance with the MUTCD.
- Use multiple portable changeable message signs to provide real-time advance warnings or notifications for conditional or periodic detours.
- Consider adding street name signs when detouring four-digit state routes or local routes. Street name signs may also be added to the required route number signs when detouring numbered traffic routes.

Overlapping detour routes create unique signage challenges to ensure clarity, particularly where multiple higher-volume routes are detoured at the same time and utilize similar detour routes. As mentioned, supplemental use of local roadway names on the detour signage may serve to help clear confusion. Clarity in message and routing is also critical to ensure that vehicle users receive clear and simple direction.

Guidance

- Do emergency conditions require closing of the bridge?
- Moderate and tolerable impact on:
  - The local economy
  - Emergency services
  - School bus routes
  - Other local services providers
- The route is NOT a critical route.
- The detour length is less than approximately 10 miles.
  - Local conditions may dictate a different length.
- The detour does not generate any major public concerns.
- A temporary crossing would cause:
  - Significant environmental impacts (e.g., archaeological studies, wetland, 4(f) items)
  - Right-of-way clearance conflicts
- Major river crossings:
  - New structure has to be at the existing location.
  - Half-width construction is not possible.
- Is the cost of improving and/or maintaining the designated detour less than the cost of the half-width construction or temporary crossing options?

Refer to Publication 213 for detailed guidance on appropriate detour signage relative to the type of roadway closed.

9.9.4.c.i – Temporary Business Signs in Work Zones

When a highway or street is under construction, or when a detour is established directing motorists onto different routes, temporary business signs should be installed to guide motorists to the affected businesses.

Do not automatically assume that the locations of the business, office complex, shopping center, or their entrances are intuitively obvious. The general rule is to sign for drivers who are not familiar with the area.

Consider temporary business signs when:

- **Road closed with detour established.** Install signs for major shopping centers, offices, industrial sites, and general street locations (e.g., Locust Street businesses) with directional arrows in advance of locations where a left or right turn is required to direct drivers along the proper route to the location. Sign individual businesses if there is a possibility of a problem in locating them. A ROAD OPEN TO _____ sign may also be necessary.
- **Road closed but traversable.** Install sign at the road closure saying, ROAD OPEN TO _____, using the name of the farthest office complex, shopping district, plaza or mall, street, or geographic location.
- **Road under construction.** If the access to a business is changed, moved, or not easily identified, then place a sign with the business name, as needed, and a directional arrow at the business entrance.



- Use other appropriate sign phases to fit unique conditions.

9.9.4.c.ii – General Sign Guidelines

Due to the numerous variables involved (e.g., type of business or office, number of businesses, length of words in the business name, number of locations), it is not possible to specify a single standard that would be correct for every signing situation. However, the following general guidelines are provided:

- Use black legend on an orange background.
- Do not install business logos.

- On multilane roadways and all roadways with travel speeds 40 mph or higher, use a 6-in legend on 72-in wide sign panels, when possible.
- Show the business-sign layouts and locations on the TCP.

9.9.5 – Detours Along Signalized Corridors

Often, existing signalized corridors will be designated for use as part of a project's detour plans. Detoured construction traffic onto these existing signalized corridors will probably necessitate temporary signal-timing adjustments and/or modifications to properly accommodate the additional traffic demand.

Publication 408, Section 958, contains specifications for the following types of work on existing permanent signals that may be needed as part of TTC design for the detour routes:

- Temporary timing adjustments to existing permanent traffic-signal controller.
- Temporary modifications to existing permanent traffic signal.

Additionally, modern adaptive signal technology can allow for signal timings to adjust, based on variable demand, and to collect data on changing volumes. As part of the TTC design, upgrades to existing signals systems on detour routes can often be completed with minor equipment upgrades and communication systems.

9.10 – TTC Plan Development

A Temporary Traffic Control Plan describes temporary traffic control measures to be used for facilitating road users through a work zone. These plans play a vital role in providing continuity of safe and efficient road user flow when in a work zone, or other events that temporarily disrupt normal road user flow. Important auxiliary provisions that cannot conveniently be specified on project plans can easily be incorporated into special provisions within the temporary traffic control plan. Plans should refer to special provisions to avoid conflicting language. Verify TCP and E&S sequencing are aligned. Temporary traffic control plans range in scope from being very detailed to simply referencing typical drawings contained in this chapter, Publication 213, standard approved highway agency drawings and manuals, or specific drawings contained in the contract documents. The degree of detail in the temporary traffic control plan depends entirely on the nature and complexity of the situation.

The design, selection, and placement of temporary traffic control devices for a temporary traffic control plan should be based on engineering judgment.

9.10.1 – Construction Phasing

Phasing refers to the sequencing of all project activities, for completing portions of the project one part at a time. Key considerations for phasing include:

- Traffic maintenance needs.
- Elevation differences between proposed and existing facilities.
- Working room for the contractor.
- Business and residence access.
- Other factors.

Phasing plans are heavily project specific and should be developed through feedback from the public, the Department, and other critical stakeholders. The impacts of a work zone may be minimized by using operationally sensitive phasing and staging throughout the life of the project.

9.10.1.a – Staging

Staging refers to how the contractor will position the equipment and materials. Adequate room must be provided for equipment operations (e.g., crane swings, curb forms, excavators) and material and equipment storage. TCDs, particularly barriers, should be placed with some consideration of potential contractor operations.

9.10.1.b – Contractor Access

In developing the phasing and staging for the project, some attention should be paid to:

- The contractor's ability to physically access work-site locations.
- The safety of accessing work-site locations for both workers and highway users.
- The ability for construction equipment to develop the final roadway surface.
- The vehicles involved in excavation operations, structure erection, and other heavy construction functions. This equipment operates differently than other heavy vehicles and their operational characteristics should be considered in determining potential access locations.

9.10.1.c – Construction Schedule and Time Restrictions

A construction schedule provides a general overview of the project, including the timeline, project tasks, dependencies, and resource requirements. By outlining all the high-level details and components of the project, TTC can be evaluated taking into consideration required construction seasons for particular activities and the desired completion date.

Designers should give consideration for proposed scope of work, material types, and environmental time restrictions. Cure times (concrete strength gaining for application of load, primer cure times for Class B Faying Surfaces) are often neglected in working time considerations.

Work schedule restrictions may also dictate allowable times to restrict lanes or times when work is not permitted, such as nighttime work near residential communities. **Exhibit 9.9.7** provides a summary of the different types of schedule restrictions.

Exhibit 9.9.7 Schedule Restrictions

Type of Restriction	Description	Advantages and Usage
Working hour	Limits work hours such that work does not occur during specific time periods of peak travel demand and congestion.	• Can be applied to limit construction work during non-desirable time periods. • Use adjacent to residential communities where construction noise at night is not desirable.
Peak hour	Limits work hours such that work that impacts traffic does not occur during peak travel demand and congestion.	Limits lane restrictions and worker exposure at periods of highest demand on roadway facilities.
Weekly restrictions	Limits weekend work and traffic restrictions.	Can be applied in areas where traffic has significant peaking behavior during the weekend, such as: • Metro urban areas with large events. • Recreational areas with significant weekend activity.
Seasonal restrictions	Specified for limitations in the type of work being performed at certain times of calendar year.	Can be used to limit: • Type of work being performed (concrete and paving work in colder weather). • Impacts to tourist demand in certain areas.
Night work	Work (all or individual phases) is performed at night (end of evening peak period to beginning of morning peak period) to minimize work zone impacts on traffic and adjacent businesses.	• Night work minimizes work zone impacts on traffic and adjacent businesses. • Noise impacts from the operations need to be considered in conjunction with the surrounding land use.
Weekend work	Work (all or individual phases) is restricted to weekend periods from the end of the Friday afternoon peak period to the beginning of the Monday morning peak period.	• Provides multiple days of consecutive availability for the contractor to adjust operations without impacting the traditional weekday peak hours of traffic demand. • Often, weekend closures can be utilized to provide more working room for the contractor and allow for accelerated delivery of certain facility aspects (e.g., paving operations, prefabricated structures).

In evaluating different combinations of working schedules and restrictions, several factors should be considered in determining the most appropriate working phase:

- Avoidance of recurring congestion (LOS E or worse).
- Worker safety.
- Construction noise impacts.
- Emergency vehicle access and response times.
- Driveway impacts.
- Local business access.

Projects with accelerated construction delivery schedules may result in more extensive traffic-control impacts, with longer workdays, night work, and larger spatial requirements for contractor operations.

9.10.2 – Emergency Management

An emergency may consist of a short duration, simple, static, and singular incident; or it may be prolonged, complex, and dynamic, impacting multiple fronts and requiring deployment of extensive assets and resources. An incident is an occurrence, regardless of cause, which requires response actions to prevent or minimize loss of life and damage to property and the environment.

9.10.2.a – Emergency Pull-Off Areas

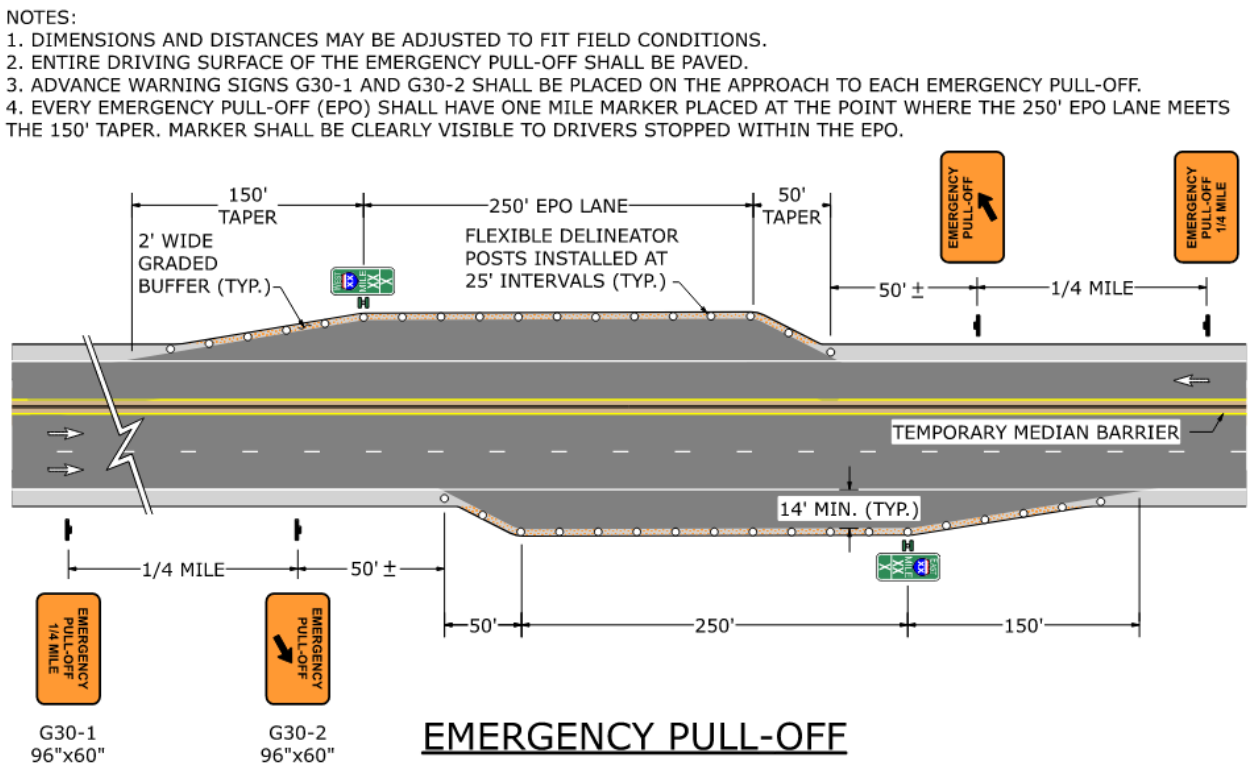
Emergency pull-off areas within work zones provide an operational and safety improvement to freeway and expressway facilities. These areas provide space for disabled vehicles or those requiring a stop to be safely removed outside of the traveled lanes. They also limit delay from non-recurring events by providing a refuge for vehicles and limiting queue development behind the incident. The designer should consider incorporating emergency pull-off areas on freeway and expressway construction areas where the shoulder width is less than 10 ft (i.e., where shoulders would not be wide enough for a vehicle to be parked safely) or when both the right and left shoulders are simultaneously closed for a distance greater than half a mile. Refer to Pub 46 for more information on emergency pull-off areas.

Emergency pull-off areas should be designed:

- To meet field conditions at nominal one-half mile intervals.
- Using standard dimensions for the pull-off areas as depicted in **Exhibit 9.10.1**.
- Using paved areas, since gravel pull-offs are more difficult to maintain and provide poor traction for acceleration and deceleration.

- Using flexible delineator posts or other channelizing devices at 25- to 40-ft intervals to highlight the area.
- Using recommended EMERGENCY PULL-OFF AREA signs instead of EMERGENCY PARKING AREA signs, since “parking” connotes that the area can be used for non-emergencies.

Exhibit 9.10.1 Emergency Pull-Off Area Schematic



9.10.2.b – Incident Management

As part of the development of TTC, planned and unplanned responses to incidents should be addressed as a design consideration. For phased construction, operating room for emergency vehicles and room for removal of disabled vehicles (among other design considerations) should be coordinated through the design process with local emergency responders. Detour plans should be discussed to determine if the length or geometry of the routing will create operational issues or longer response times.

For Significant Projects, the IMP is part of the TMP and lays out appropriate communication protocols, impacted emergency responders, and procedures for response to incidents. For incident response and management, consider the following as part of the design:

- Proactive coordination with emergency responders.

- Emergency vehicle requirements.
- Anticipated incidents and response operations.
- Impact of TTC and construction on standard incident response.

For details on the components of an IMP, see Publication 46 and Publication 911.

9.10.3 – TTC Geometry and Roadway Features

In the transition area from the existing highway to the temporary road, the designer should:

- Avoid abrupt, sharp curvature.
- Design the horizontal curvature so that the operating speed of a vehicle will match the existing speed limit to the maximum extent feasible.
- If required, complete Form TE-162 for any speed limit reduction. If the regulatory speed limit is not reduced, advisory speed plaques should be provided to aid in safe operation.

Design for sight distances:

- Provide clear sight distances on approaches to stop signs or traffic signals.
- Provide adequate sight distance and roadway length to allow a vehicle to come to a complete stop from its operating speed.
- Consider the placement of guide rails, barriers, or temporary signing, while being cognizant of how placement may affect clear sight distance.
- During design, confirm stopping sight distance to any installed TCD (e.g., stop sign, traffic signal).
- Provide headlight stopping sight distance on vertical curves.
- For temporary roads controlled by STOP signs, ensure that the entire length of the temporary road between the STOP signs is visible to a stopped driver.
- Recognize that pavement widths may have to be widened through horizontal curves to provide adequate turning radii for trucks.
- Provide appropriate superelevation for the operating speed within the transition curvature.

Where traffic signals are used, a study should be performed (in coordination with the District Traffic Unit) to determine the acceptable operating speed through the temporary road area. It is recommended that a minimum operating speed of 15 mph be provided.

9.10.3.a – Guide Rails/Barriers

Provide guide rails on temporary roads when required for shielding:

- Embankments.
- Roadside obstacles, especially where the obstacles are potentially hazardous because of roadway geometry.
- Non-traversable hazards, such as permanent bodies of water.

Also provide guide rails for proper connection to bridge railings of temporary bridges, with appropriate runout of the guide rail when site conditions allow.

Temporary barriers may be used in place of guide rails on temporary roads and approaches, especially if temporary stream crossings have a minimum fill (cover) over the pipes which would cause interference with driving guide rail posts. If a concrete barrier is used, the effect on sight distance must be carefully checked to ensure that it is acceptable. Ensure that the temporary road is designed to carry the temporary barrier.

Refer to Chapter 12, *Roadside Design*, for additional information related to guide rail, barrier, and other roadside safety devices.

9.10.3.b – Side Slopes

Side slopes, in cut or fill sections on temporary roads, are to be as steep as feasible, based on the stability of the soil and rock involved. Slopes of 1V:1H are considered maximum, with flatter slopes to be used if necessary, based on the stability of the soil and rock involved. Gabions may be specified to retain slopes but not as a bridge abutment. The geotechnical designer is to be consulted regarding the stability of the temporary side slopes. Refer to Publication 293, Chapter 6, Section 6.4.4, *Temporary Slope Conditions*, for more information.

9.10.3.c – Pavement Type and Shoulder Type

Pavement and shoulders on temporary roads are to be maintained in a smooth condition during use. Special provisions for adequate maintenance and dust control must be included in the PS&E.

The guidelines below provide additional information on temporary roadway pavements:

- SMS is recommended as the pavement material for temporary roads with low average daily traffic (ADT) and/or low speeds.
- Consideration can be given to using adequately compacted milled asphalt as the pavement material to control potholes and dust and for medium ADT.
- For higher ADT, consideration should be given to using asphalt as the pavement material. An asphalt concrete base course, without a top material, will normally be adequate for the short period of time the temporary road will be in use.
- Selected material shoulders are recommended as a minimum. Compacted milled asphalt material and higher type shoulders should be considered if a high-type pavement is used.

- Pavement and shoulder thicknesses should be determined based on ADT, percent of trucks, expected life of the temporary road, and stability of the subgrade, in consultation with the District Materials Manager, Geotechnical Engineer, and Pavement Engineer.

9.10.4 – Operational TTC Considerations

Within work areas, installation of operational improvements may serve to mitigate some of the expected impacts of work zone operations. If considered and developed early enough in the design process, potential conflicts (due to right-of-way, utilities, or public involvement) may be identified and resolved to allow implementation of these operational improvements.

Some (but not all) of these potential improvements include:

- Signal timing and coordination improvements
- Temporary traffic signals at currently unsignalized locations.
- Street or intersection improvements (e.g., temporary widening, use of shoulders).
- Bus turnouts.
- Turn restrictions.
- Provision for emergency pull-offs.
- Parking restrictions.
- Heavy vehicle restrictions.
- Separate heavy vehicle facilities.
- Ramp closures.
- Late or zipper merges.



Recognizing that some of these items may not be applicable on certain projects, these potential improvements should be considered if they are relevant to the subject project.

9.10.4.a – Operational Strategies

Work zone operational strategies should be considered and analyzed (in conjunction with the goals of the WZSM policy presented in Publication 46). These strategies include:

- WZSM:
    - Speed limit reductions.
    - Temporary traffic barriers.
    - Installation of work zone safety enhancements (impact attenuators, rumble strips).
    - Queue warning systems.

  - Intrusion alarms for construction vehicles.
  - Automated flagger-assistance devices.
  - On-site safety groups and inspection.
  - Work zone speed safety cameras.
  - Truck/buses USE LEFT LANE ONLY signage.
- Police enforcement:
  - See Publication 46, Chapter 6, for information on PSP cooperation in work zones.
- Demand management:
  - Transit improvements and incentives.
  - Shuttles and carpools.
  - Park and ride promotion.
  - High occupancy vehicle lanes.
  - Teleworking and flexible working hours.
- Traffic/incident management:
  - CCTV.
  - Travel-time notification.
  - Portable changeable message sign communication.
  - Enhanced milepost markings.
  - Towing services.
  - Development of incident detours.
  - Inclusion of support services for incident management in construction contract.
  - IMP.
  - Virtual highway advisory radio (linked to 511PA and the Advanced Traffic Management System).
- Public information:
  - Brochures and mailers.
  - Press releases/media alerts.
  - Project websites.
  - Public meetings and hearings.
  - Coordination with local stakeholders and public agencies.
  - Public education campaigns.

- Public communications coordinator.
- Freight travel information.
- Social media outreach.

9.10.4.a.i – Late-Merge Concept

One consideration to mitigate potential capacity reductions on major interstate and arterial projects involves use of the late-merge concept, a unique traffic control setup used when it is necessary to close a travel lane.

Instead of encouraging motorists to form a single lane a mile or more before the lane closure, this setup encourages motorists to use both travel lanes up to the merge point.



(Source: inc.com)

Using this traffic control setup may eliminate backups through nearby interchanges, reducing delays for entering and exiting traffic. With the shift of the merge point closer to the lane restriction, queued vehicles can stack in two lanes, making the length of any queue shorter relative to the work area.

The use of the late merge may reduce road rage caused by motorists passing the queue and butting in line. This allows motorists to drive at a more relaxed and uniform speed.

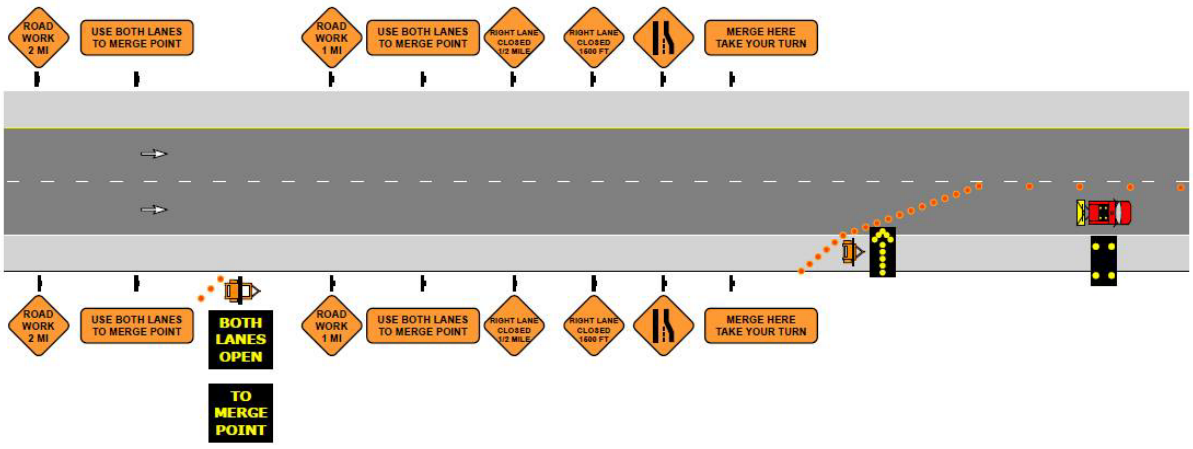
Studies performed by a consultant and the University of Nebraska suggest that the capacity of a lane reduction may be up to 15 percent greater by using the late-merge concept, as opposed to conventional traffic control. The late merge should subsequently provide a significant reduction to any queues resulting from the lane closure, potentially to less than 50 percent of the queue length in a normal lane closure.

Field experience in Pennsylvania has shown mixed results with the late-merge concept. There does not seem to be any apparent pattern as to the success of implementing the late merge. It has been tried in both urban and rural settings, as well as in different geographical regions of the state. However, experience demonstrates that a late merge is not as beneficial in areas with typical free-flow conditions.

It is still encouraged to consider this approach wherever the throughput capacity may be an issue, while at the same time understanding where the late-merge concept has worked and where it has not.

Exhibit 9.10.2 provides an example for signing of a late merge.

Exhibit 9.10.2 Example for Signing of a Late Merge



9.10.4.a.ii – The Smarter Work Zones (SWZ) Concept

The use of SWZ should primarily focus on major roadway (freeway/expressway and comparable facilities) and bridge projects where:

- Heavy traffic volumes are impacted by the work area.
- Dissemination of work zone travel information can provide some benefit in encouraging adjustments in route or modal choice.

With advances in SWZ technology and the use of common equipment applications, better and more timely information can be made available to drivers approaching work zones (thus enabling better driver decisions). These technologies and equipment include items such as the following:

- Portable changeable message signs.
- Queue and traffic detection technologies.
- Signal communication and coordination systems.
- Traffic monitoring systems.
- Speed detection.
- Variable speed limits.
- Tying into existing ITS applications such as, permanent messaging sign system, existing traffic cameras, and traveler information smart phone applications.

Refer to Section 9.4.4.b for information on work zone ITS systems.

Some potential benefits that can be expected from the SWZ include:

- Sign message alerts of slowed/stopped downstream traffic.
- Travel-time estimates to reach the end of the work zone or some other landmark.
- Traffic restrictions.
- Incident reduction.
- Display of pre-programmed legal speed reductions during peak work activity.
- Collection of traffic volumes and speeds (in multiple lanes/multiple directions) for traffic analysis during and post-project.

9.10.4.a.ii.1 – SWZ Data Points

In considering implementation of SWZ technologies, numerous potential data points should be considered:



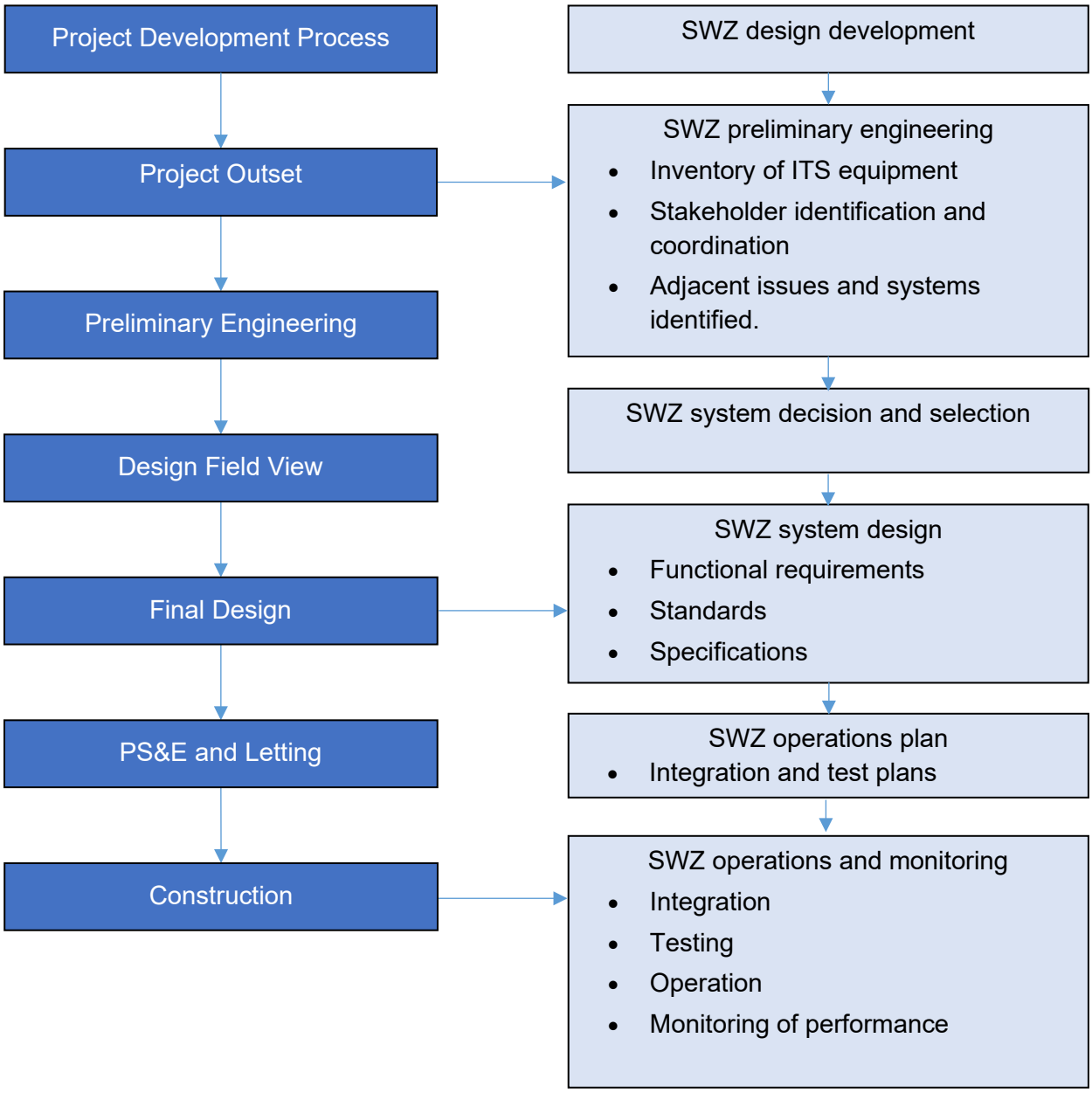
- Length or duration of the work zone.
- Adjacent traffic generators.
- Estimated queue lengths and sight distance.
- Existing traffic issues and surrounding alternate routes.
- Complex traffic-control layouts and potential merge conflicts.
- Emergency response operations.
- Speeding and speed variations.
- Other projects in the area.
- Presence of existing ITS infrastructure and/or connected vehicles.

9.10.4.a.ii.2 – SWZ Development Process

SWZ considerations are a part of each design phase within the design process. The decision on whether to implement a SWZ as an operational strategy should be made when the project is advanced from Preliminary Engineering into Final Design. This will help ensure that adequate room for placement of detection devices and coordination of power and communication utilities are addressed.

Exhibit 9.10.3 provides a flow chart outlining key phases in the project delivery process and SWZ design.

Exhibit 9.10.3 Integration of Project Development and SWZ



9.10.4.a.iii – PennDOT Traffic Management Center (TMC) Coordination and Tie-In

With any considerable traffic-control impact, monitoring and public information efforts can notify users of congestion, incidents, or shifts in traffic control that may impact operations. Where feasible, monitoring should be tied back to a PennDOT TMC.

Connection to a TMC will allow for more robust public information sharing, from video monitoring and distribution of congestion and incident information through existing dynamic messaging signs. Consideration of this type of ITS application should be started once TTC is selected, as design efforts will require consideration of communications infrastructure needs, temporary device placement, operation concepts, and potential right-of-way and utility impacts.

For coordination details and regional TMC locations, contacts, and boundaries, refer to Publication 213, Section A, *General Notes*.

9.10.4.b – Flagging

In the design of TTC plans, the use of flagging operations may be an appropriate and useful tool to provide:

- Road users traversing the TTC zone with positive guidance that may otherwise be difficult to convey without the use of flagging operations.
- Drivers with positive guidance in areas where signing and markings are not feasible (due to the short-term nature of work).
- Drivers with positive guidance in areas with specific traffic control requirements (intersections, curb ramp construction, tie-ins for phasing, traffic control transitions).
- Contractors with the ability to perform operations that may require additional working width and result in additional travel restrictions.
- Contractor with flexibility for maintaining traffic through the work zone.

When flagging operations are used, it is important that the design documents include any necessary requirements that the contractor must follow to ensure the proficiency of the flaggers and their safety. For the designer, some coordination with the construction schedule is required regarding length of time a flagger may be needed and the subsequent additional construction cost that must be communicated to the contractor in the construction documents.

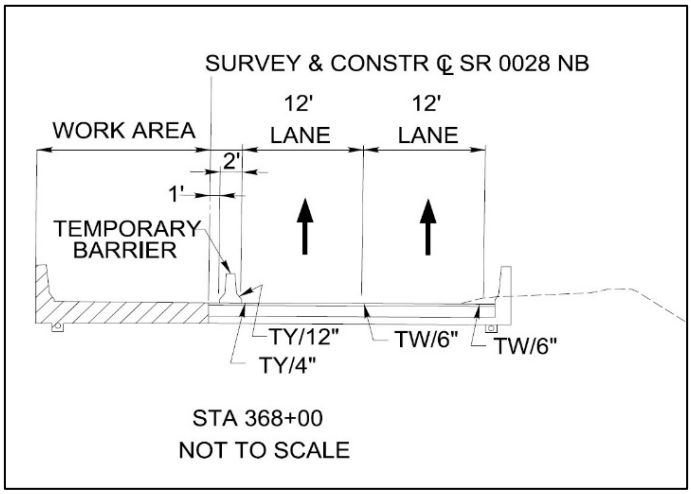
Publication 213 provides details for typical flagging applications, such as guidance on device requirements, automated flagging systems, locations, and supplemental signage. Automated flagger assistance devices (AFAD) should be considered as a substitute for standard flagging.

Publication 234, *Flagging Handbook,* can also be referenced as a resource in the TCP plan notes.

9.10.5 – TCP Typical Sections

TCP typical sections are a graphical representation of the work within the project limits at a specific station or within a station range. They include construction components being built, removed, moved, or otherwise incorporated into the project at a specific location during a particular time in the contract.

Exhibit 9.10.4 Example Typical Section



The TCP designer used typical sections to present the contractor with a clear picture of the available working area and minimum requirements for maintenance of different types of traffic.

The phasing for the construction and maintenance of traffic around the work area is detailed within the typical section when performing phased or partial-width construction. An example typical section is provided in **Exhibit 9.10.4**.

The typical section can provide additional details on work zone widths, barrier placement, drop-offs, and other information not immediately observed from the TCP view. Critical components to the traffic control typical section include (at a minimum):

- Width and direction of travel lanes.
- Type and location of barriers and other appurtenances, including device width.
- Work areas and clearances from traffic and other devices. All required ROW and easements necessary to maintain traffic, access to businesses, and provide adequate work areas must be included.
- Location of drop-offs and key elevation changes within the cross section. Verify old and new drainage elevations are compatible. Provide adequate room for equipment and excavation to tie in drainage.
- Proposed and existing roadway elevations in locations with phased construction as traffic switches from riding on temporary, milled, reconstructed, and resurfaced pavements throughout the project.
- Locations of required widening for traffic-control purposes.
- Barrier deflection distance criteria.

When designing TCP and work zone typical sections, it is desirable to follow design standards that are provided elsewhere in DM-2 for minimum lane and shoulder widths, pavement cross slopes, barrier criteria, and other standards for the type of highway on which the work zone is located.

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 chapters 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

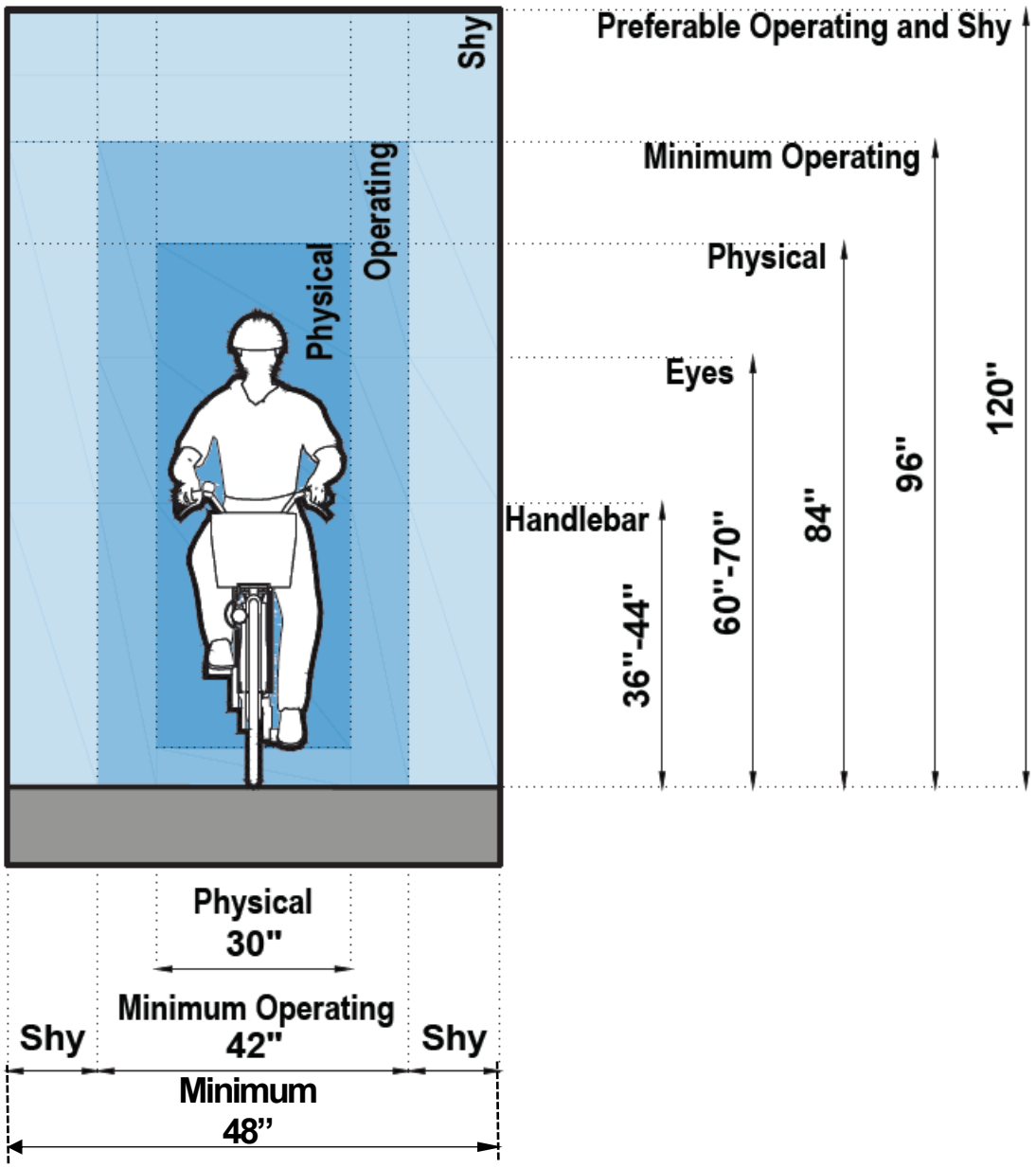
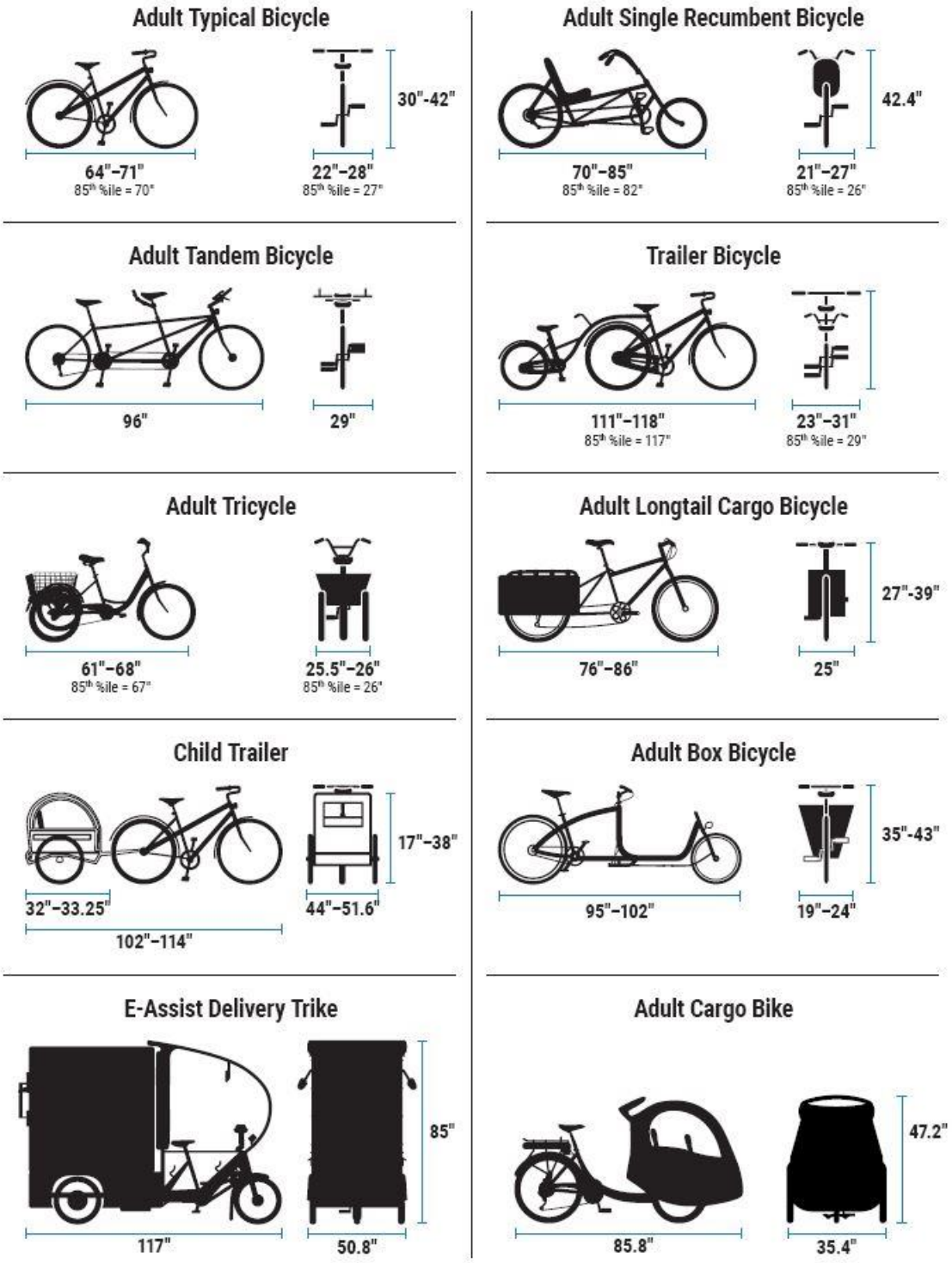


Exhibit 14.1.2 – Typical Bicycle Dimensions



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.

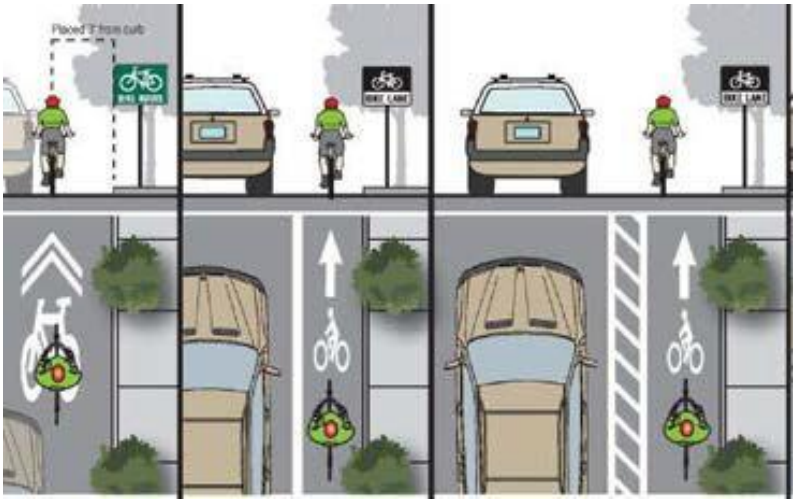
Exhibit 14.1.3 – Bicycle Design Speed Expectations

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.





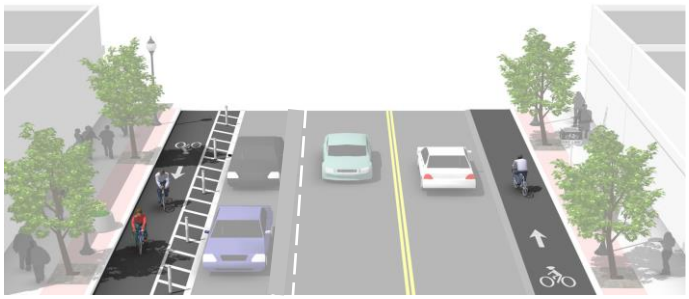
  Except where prohibited, all roadways are shared roadways. Certain circumstances/constraints may warrant the consideration of shared lane signing/markings. The most basic type of bikeway is a shared roadway. This facility provides continuity with other bicycle facilities (usually bike lanes) or designates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



- **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.

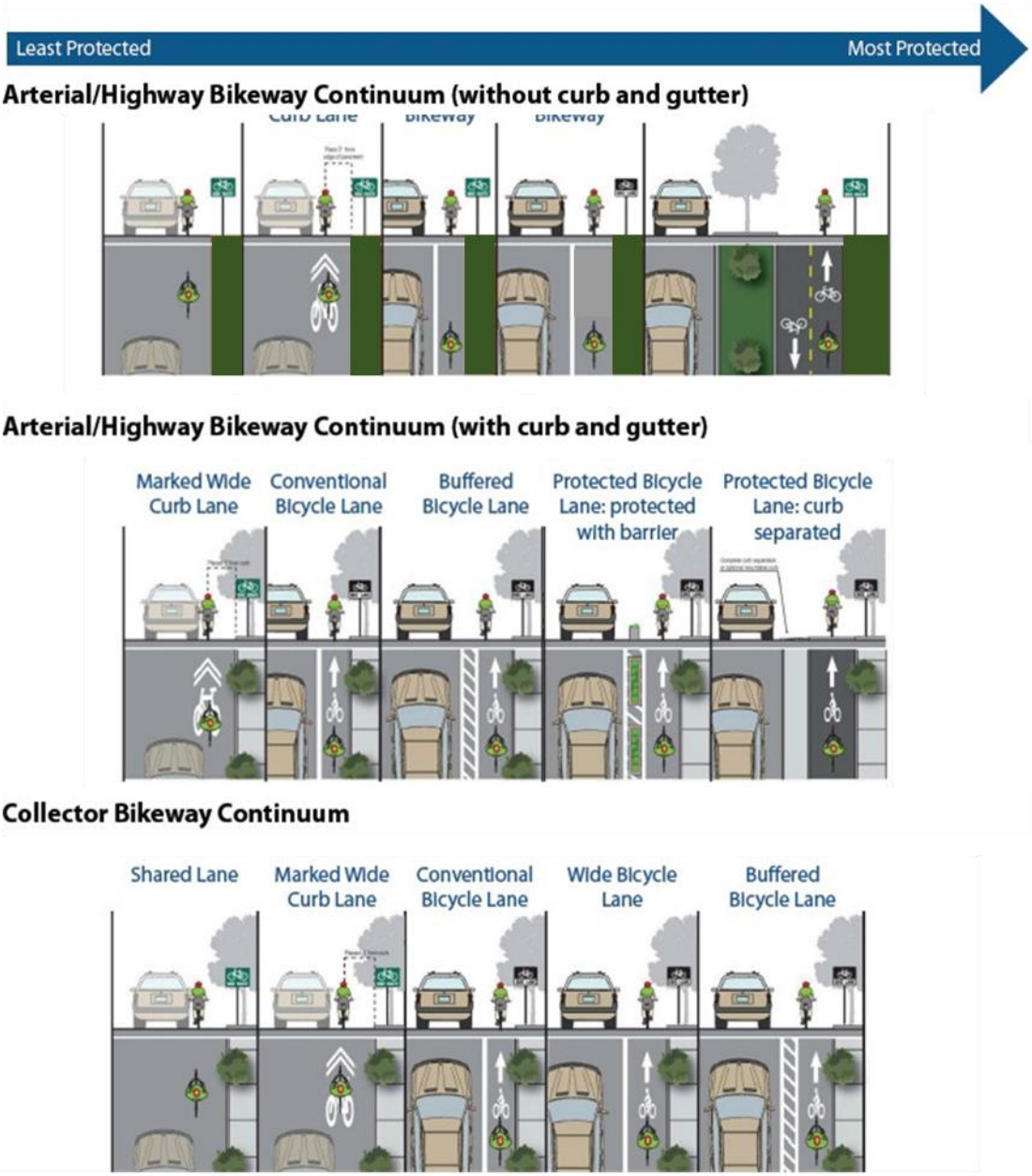


14.2.2 – Bikeway Treatments for Various Roadway Environments

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

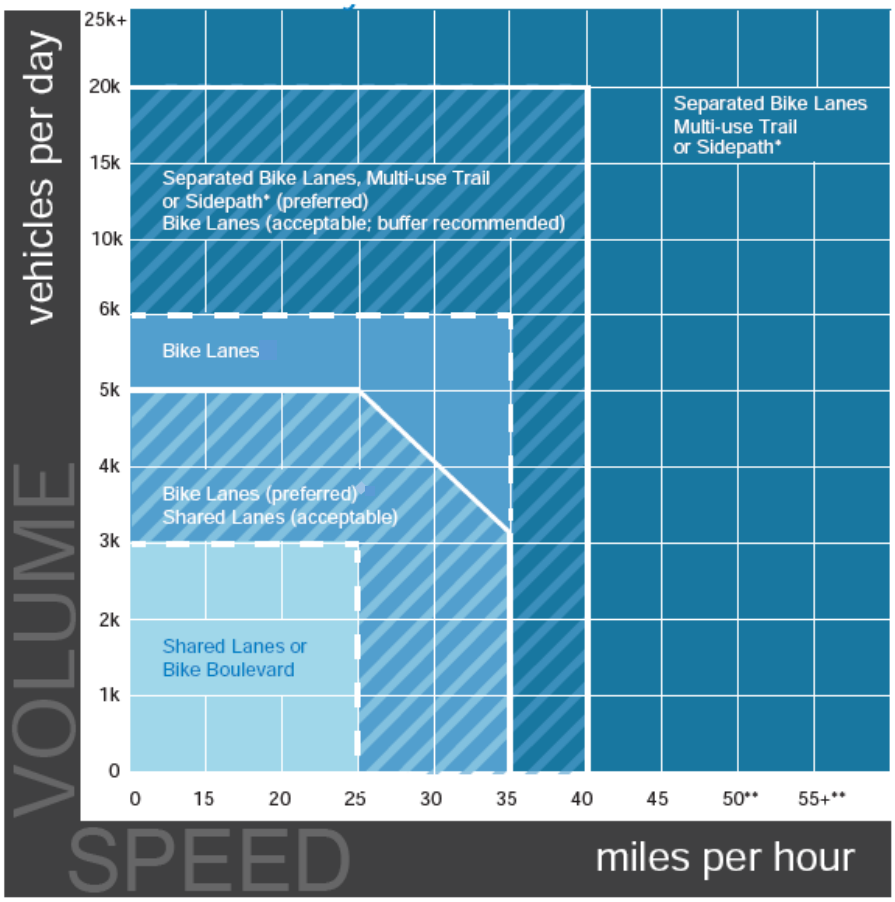
Selecting the best bikeway facility type for a given roadway can be challenging. This is due in part to factors that influence bicycle users' comfort and safety, such as when the speed differential between bicyclists and motor vehicle traffic is high and/or separation is low.

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*.



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.

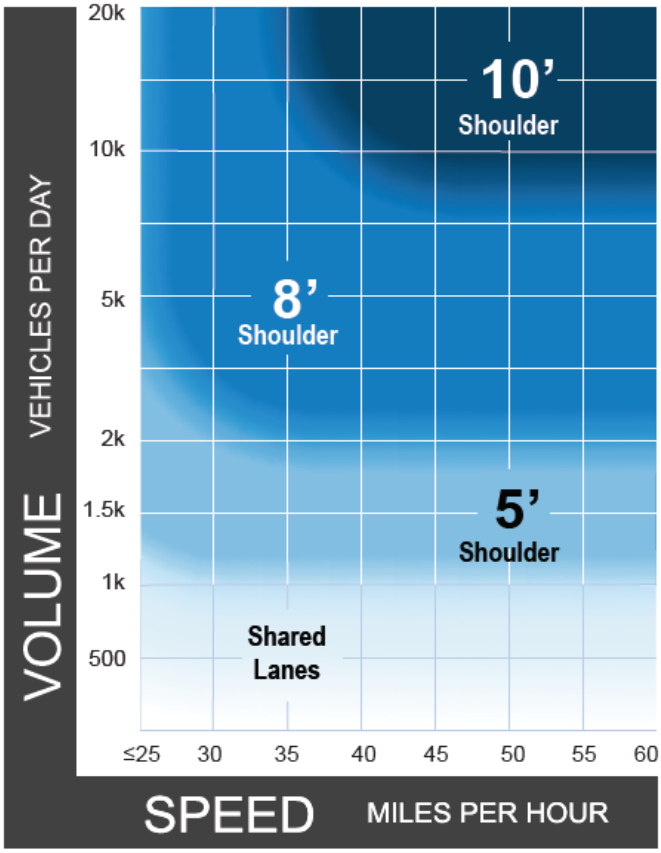
Shared roadways employ a variety of treatments from simple (e.g., no signage or markings or simple signage and shared-lane markings) to complex (e.g., use of directional signage, traffic diverters, chicanes, chokers, and/or other traffic calming devices to reduce vehicle speeds or volumes).

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.

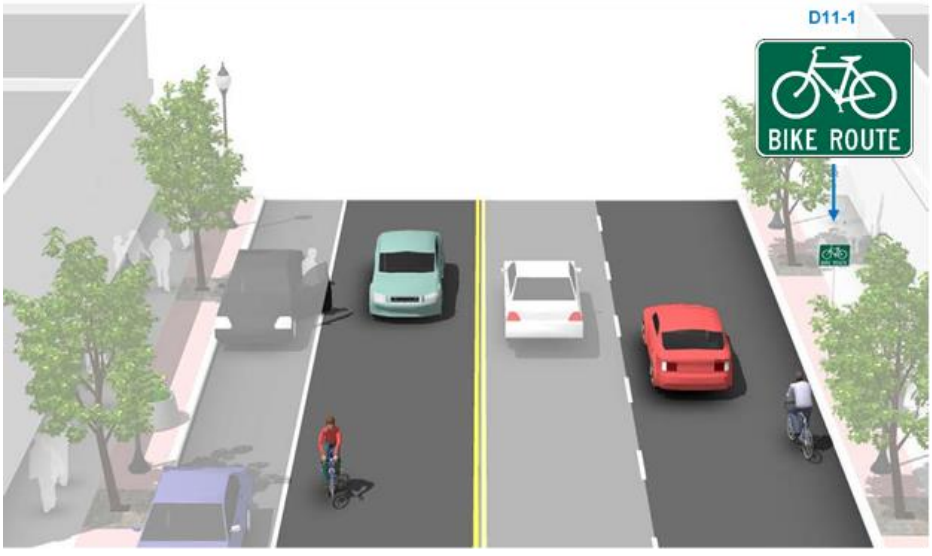
Usually, a motorist will have to cross into the adjacent travel lane to pass a bicyclist, unless a wide outside lane or shoulder is provided.

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.

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.



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.

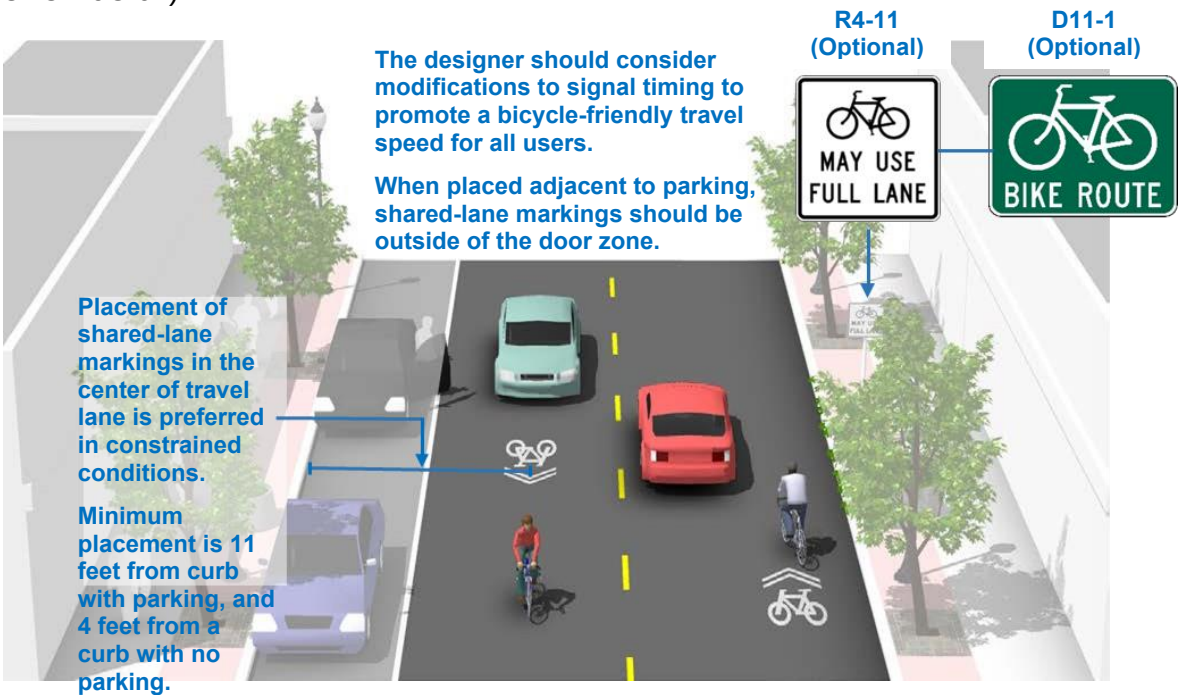
On a collector or arterial roadway, shared-lane markings should not be a substitute for dedicated bicycle facilities if space is available.

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)



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.

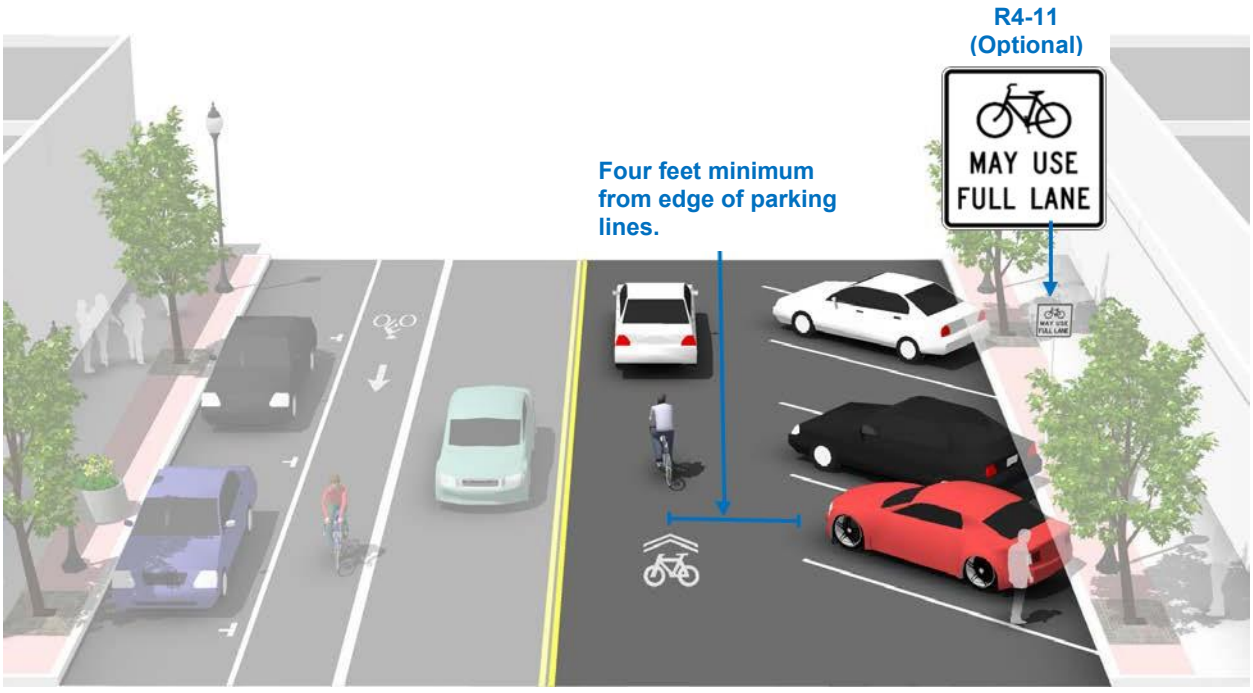
When compared to conventional front-in diagonal parking, front-out diagonal parking improves sight distances between drivers and bicyclists. Front-out diagonal parking also provides additional benefits, including loading and unloading of the trunk at the curb rather than in the street.

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.

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.



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.



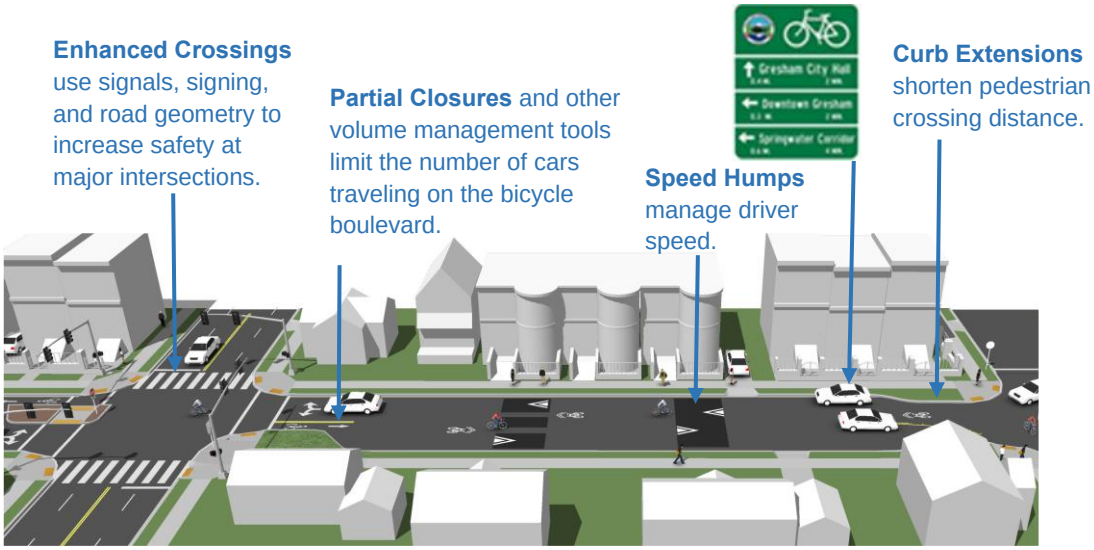
Some local streets may already provide optimal traffic conditions for a bicycle boulevard, requiring little more than signage and pavement markings to create the bikeway. Other streets, particularly roadways used frequently by motorists for through-trips, require features that reduce motor vehicle speeds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

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.

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.


Temporary Curb Extension



Choker or Neckdown


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.



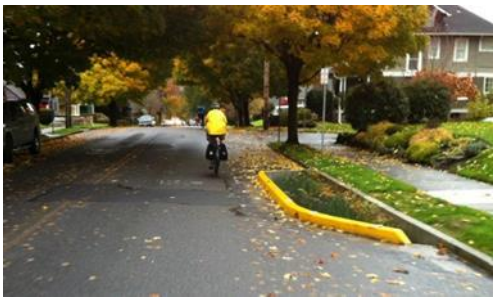
However, stop sign removal should be carefully evaluated beforehand. The warrants for stops signs should be re-evaluated to determine possible removal.











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.











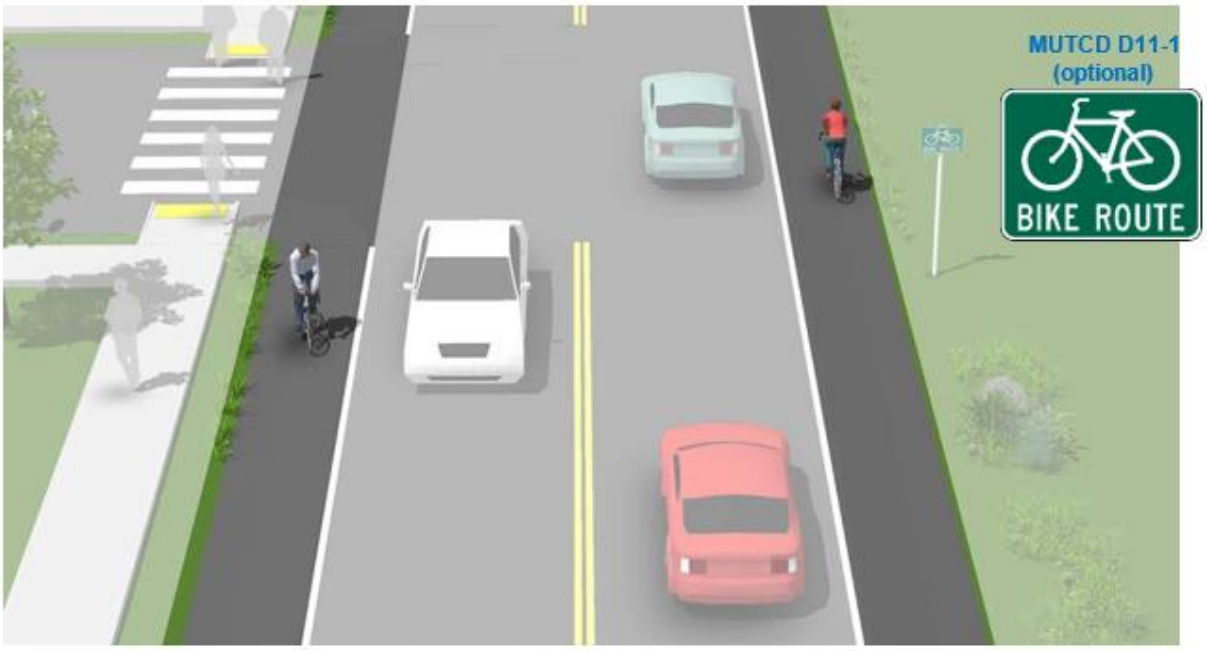
14.3.3.a – Shoulder Bikeways/Bike Lanes

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).

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).

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.



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.

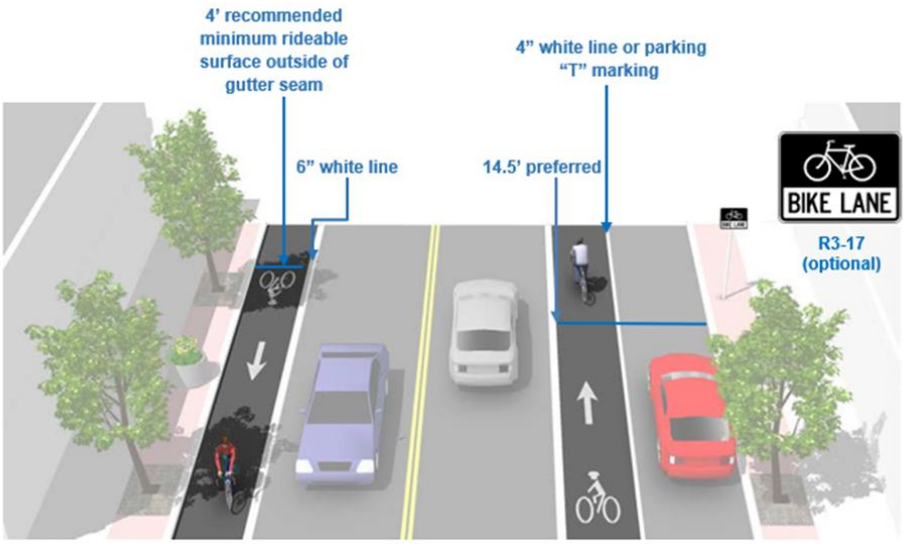
Many bicyclists, particularly less experienced riders, are more comfortable riding on a busy street if it has a striped, signed, and physically separated bikeway.

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

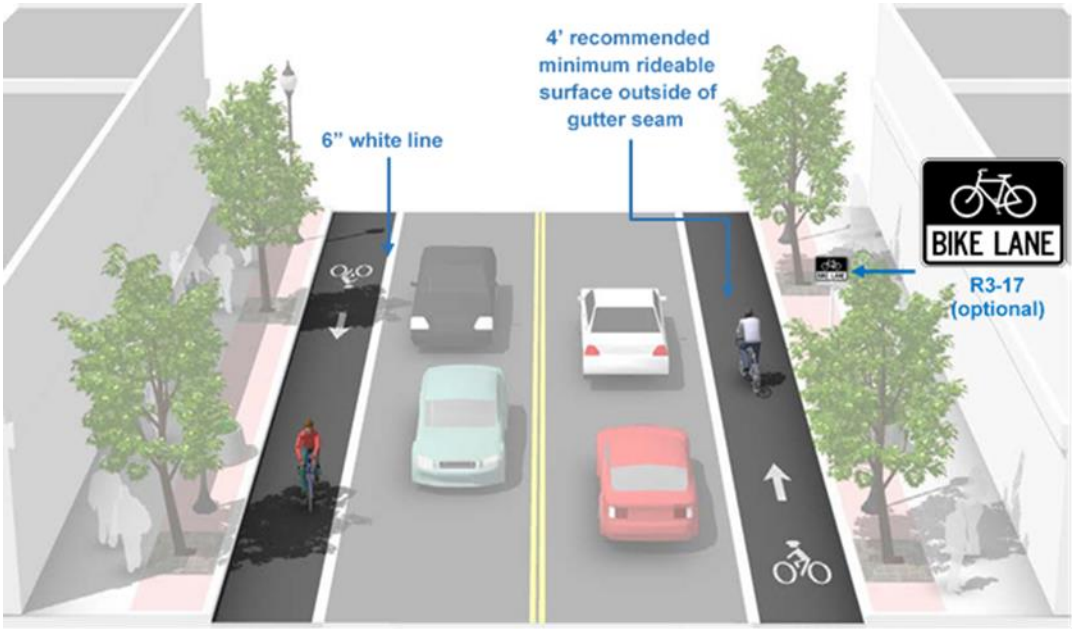
- The minimum bike lane width should be 4 feet when no curb is present or 5 feet if there is curb without gutter.
- When adjacent to a vertical curb and gutter, the width of bike lane shall be a minimum of four feet and will not include the gutter seam.
- The minimum width from the curb face to the edge 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.

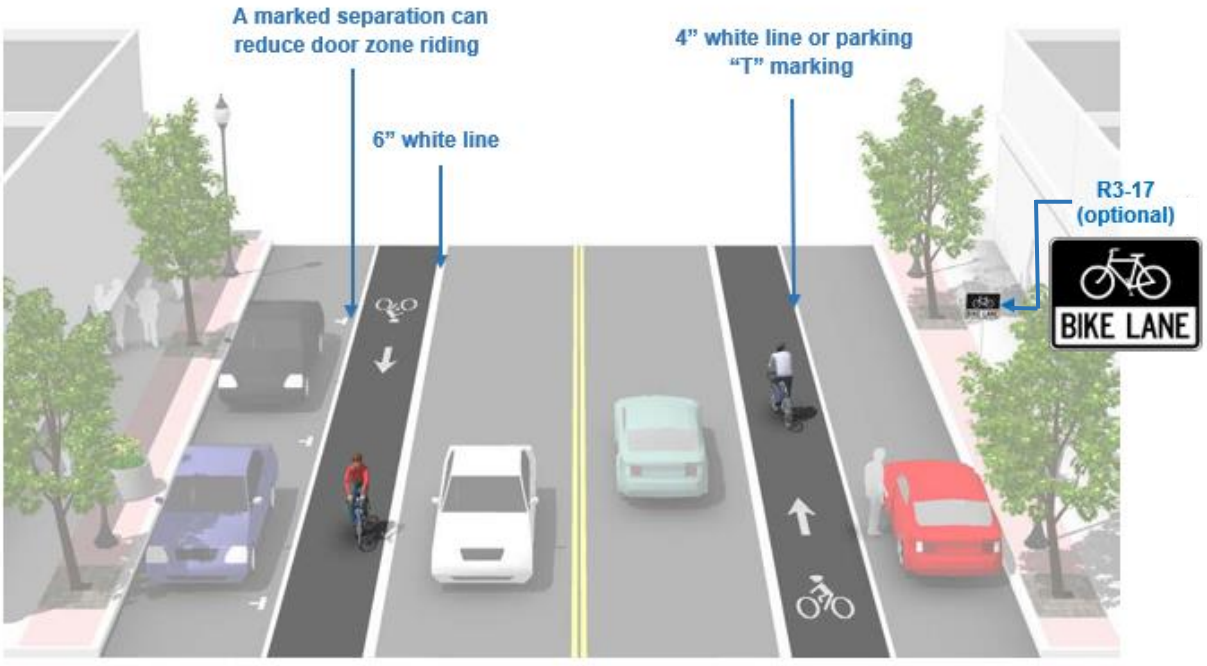


14.3.3.d – Bike Lane Adjacent to On-Street Parallel Parking

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.

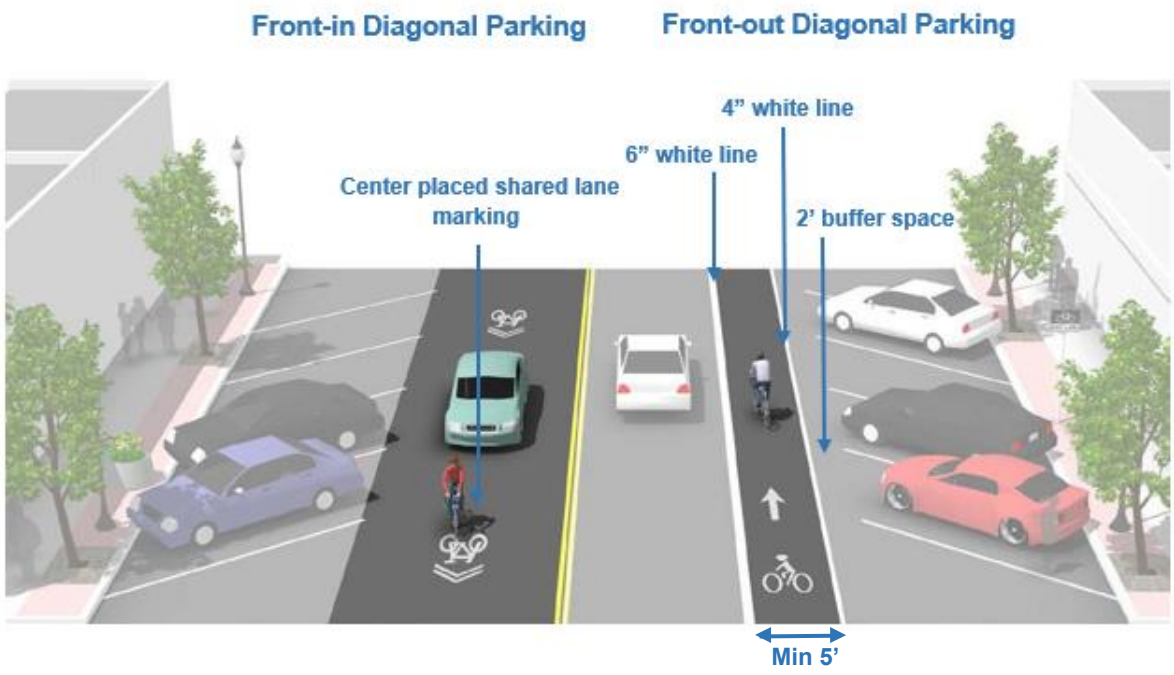
Guidance

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).



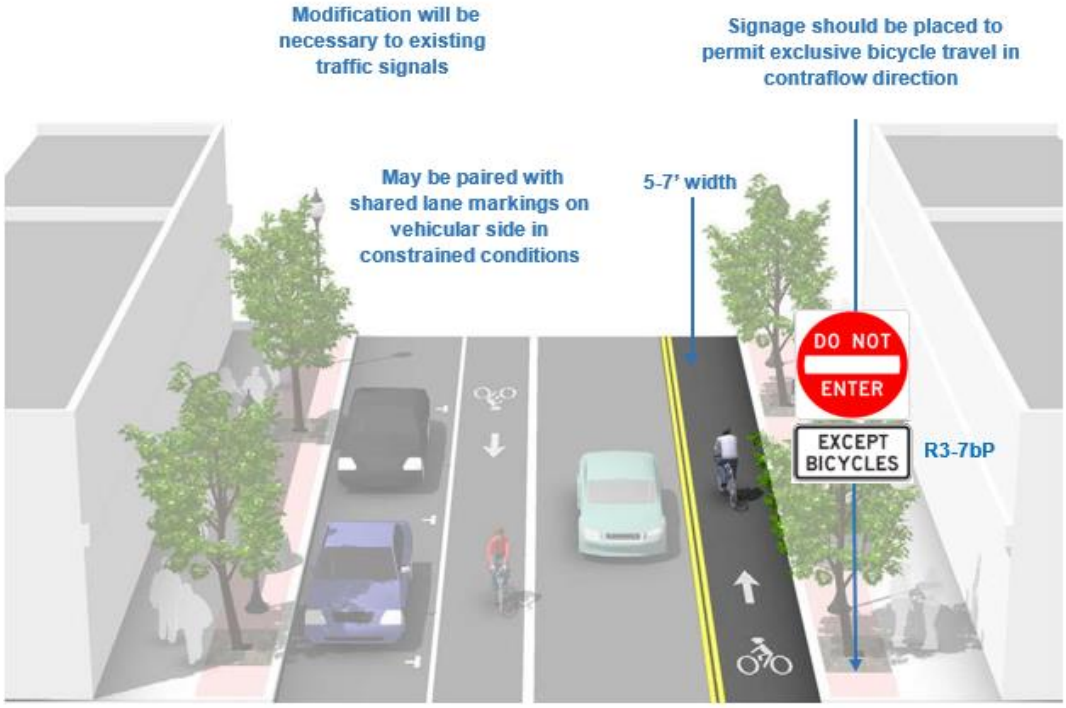
14.3.3.f – Contraflow Bike Lanes

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.

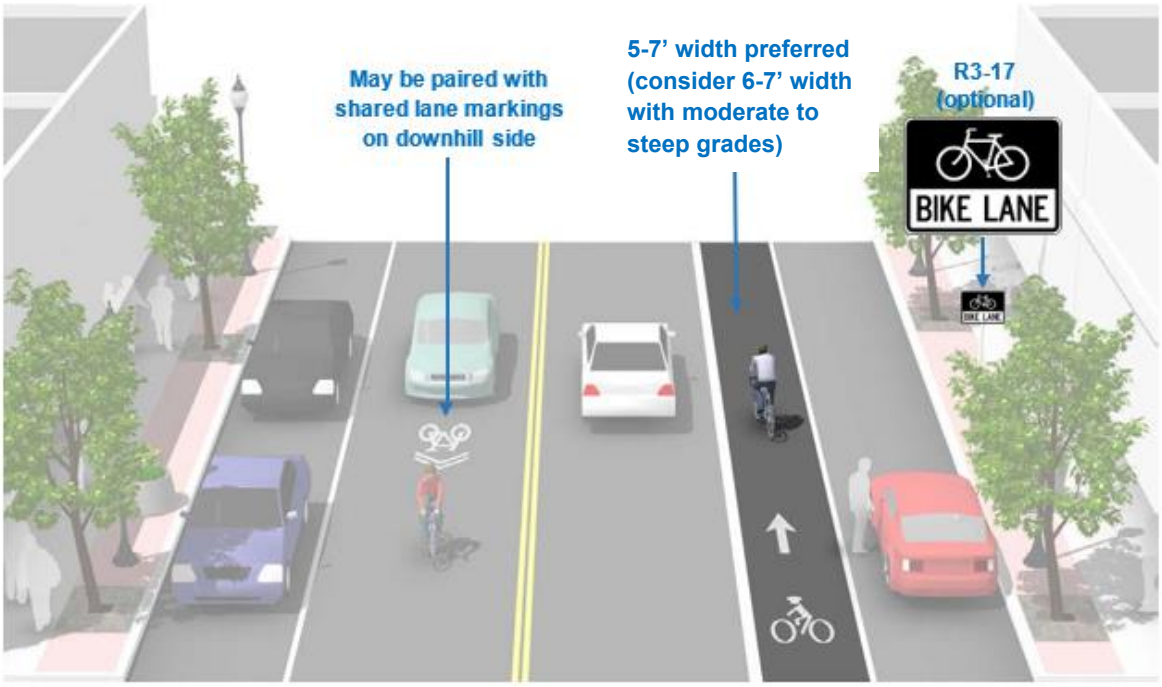
Because of the opposing direction of travel, contraflow bike lanes increase the speed differential between bicyclists and motor vehicles in the adjacent travel lane. If space permits, the designer should consider a buffered bike lane or protected bike lane configuration to provide additional separation.



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

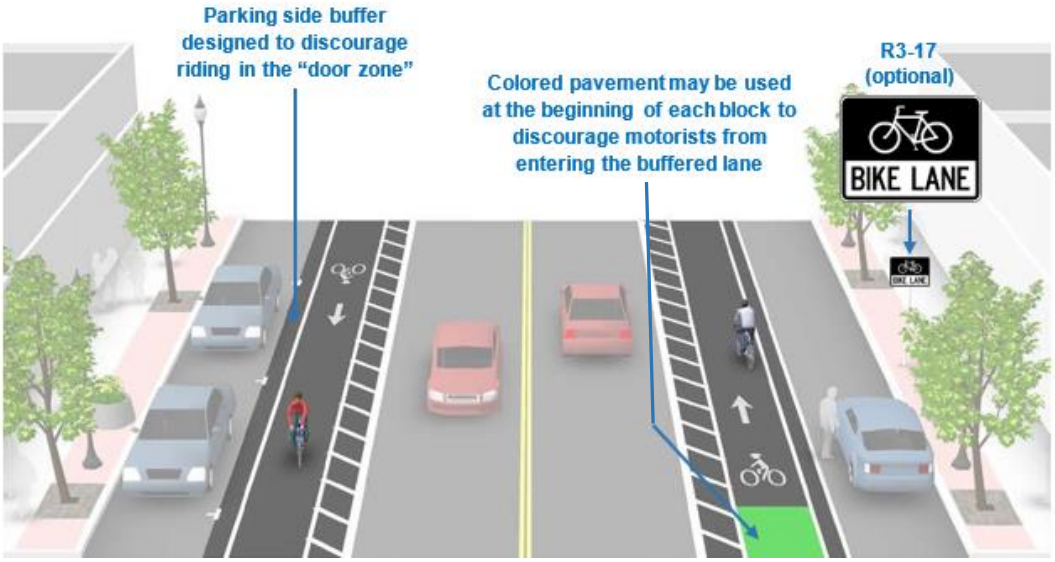
Buffered bike lanes are conventional bicycle lanes paired with a designated buffer space, separating the bicycle lane from the adjacent motor vehicle travel lane and/or parking lane. Buffered bike lanes follow general guidance for buffered preferential vehicle lanes as per MUTCD guidelines.

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

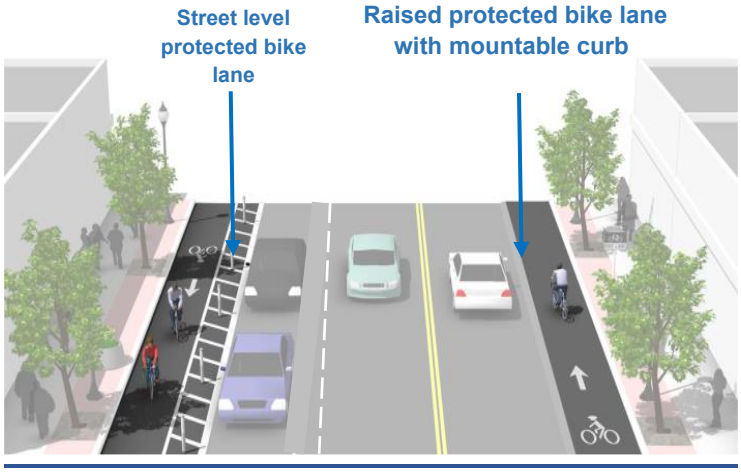
One-way separated bike lanes are physically separated/protected from motor vehicle traffic and distinct from the sidewalk. Protected bike lanes are either raised or at street level and use a variety of elements for physical protection from passing traffic.

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.

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.

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.

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.

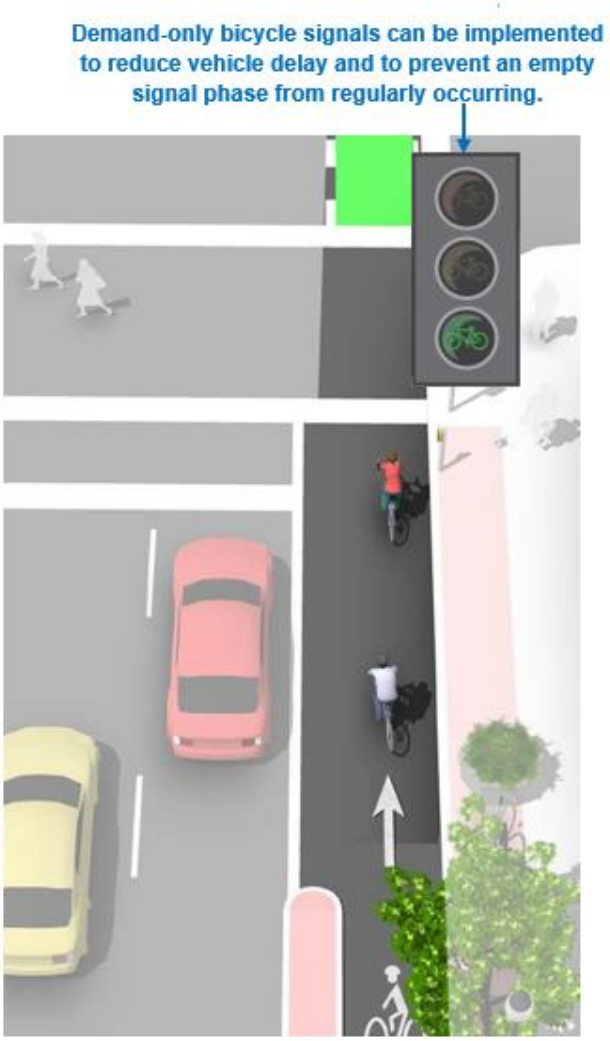
However, bicyclist visibility is important at these locations, as a buffer of parked cars or vegetation can reduce the visibility of a bicyclist traveling in the protected bike lane. Markings and signage should be present, alerting all travelers to where bicyclists and pedestrians should be travelling.

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.

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.

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.



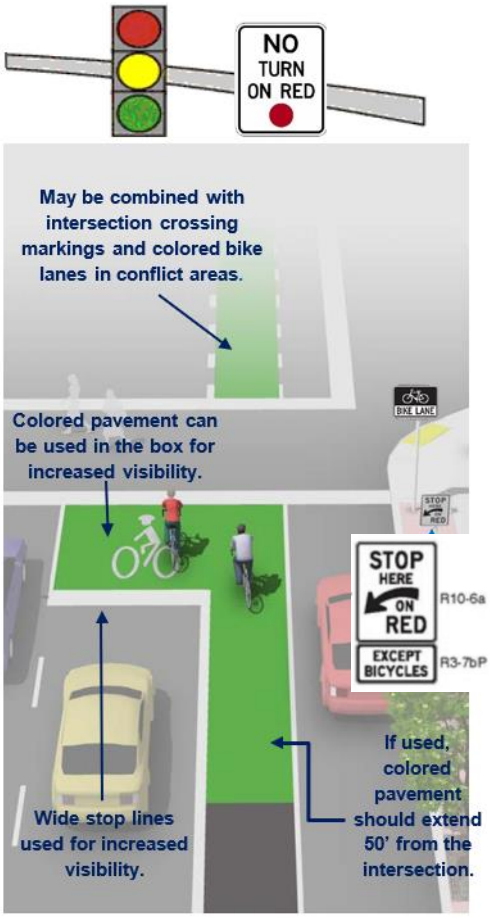
Details pertaining to these treatments are provided in AASHTO's *Guide for the Development of Bicycle Facilities*, the MUTCD, and NACTO's *Urban Bikeway Design Guide*.

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.

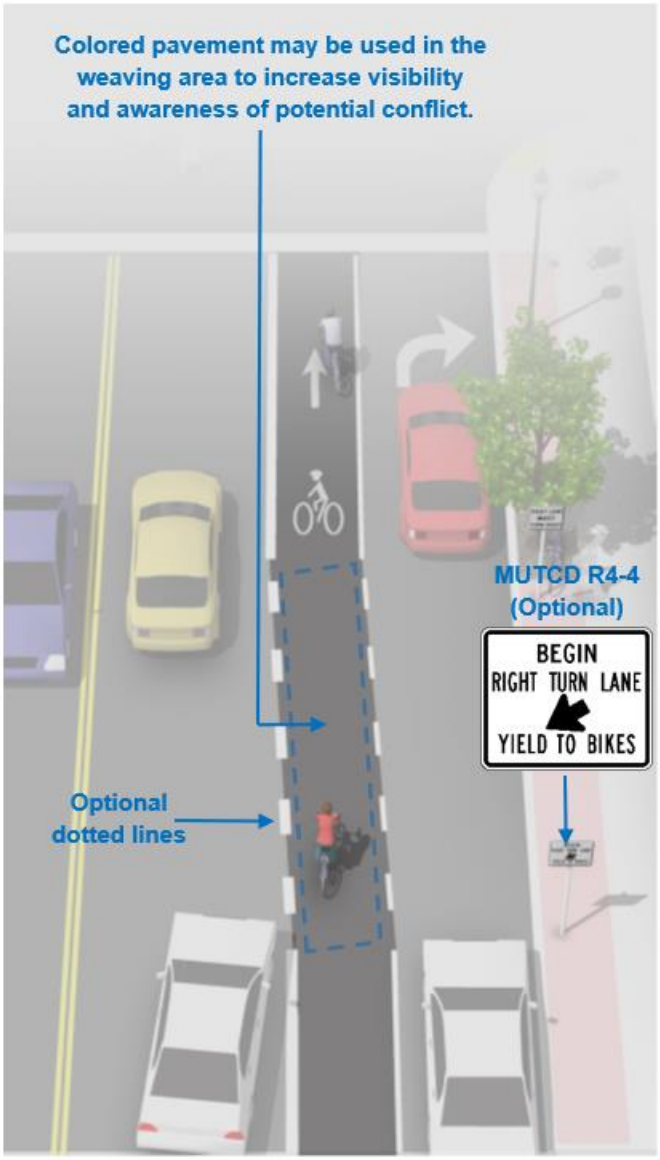
Bicycle boxes should be placed only at signalized intersections, and right turns on red shall be prohibited for motor vehicles. Prohibiting right turns on red improves safety for bicyclists yet does not significantly impede motor vehicle travel. Details about bicycle boxes are provided in the FHWA Interim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

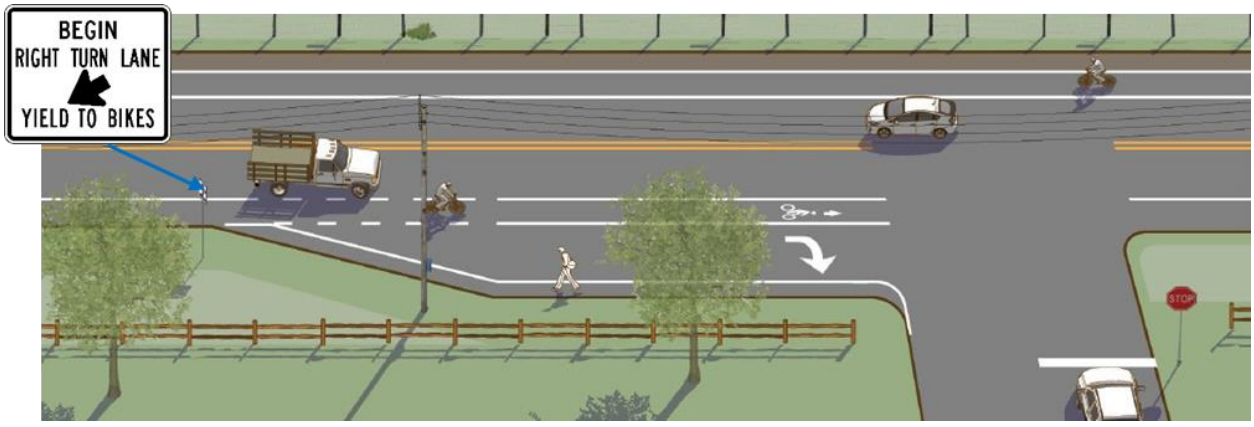
Guidance

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

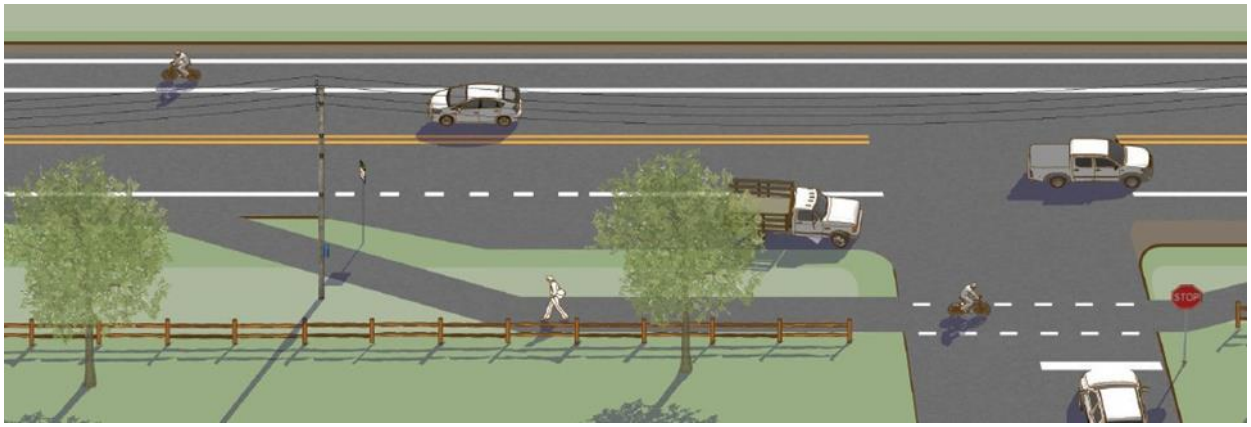
- A dotted-line merging path for bicyclists should not be defined.
- The bicycle lane should be dropped in advance of the merge area.
- Shared-lane markings should be used to indicate shared use of the lane in the merging zone.



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

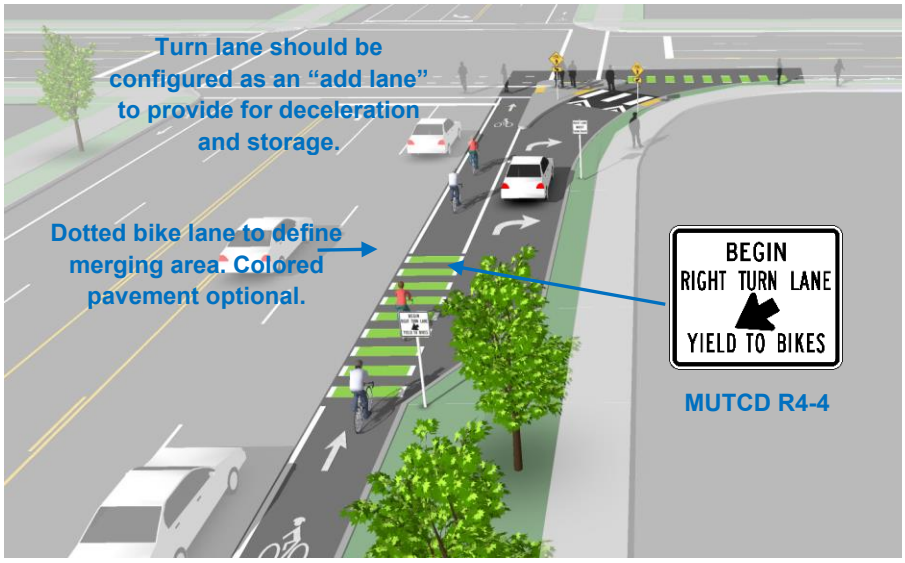
14.4.3 – Channelized Right-Turn Lanes

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.

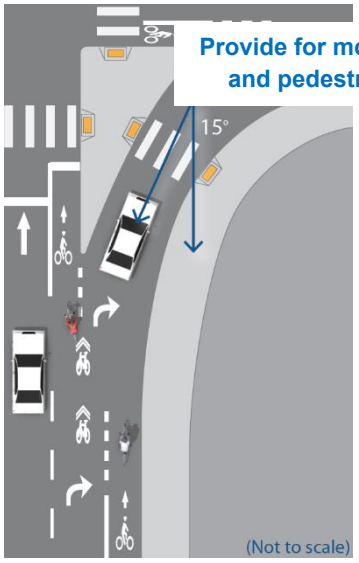
As an alternative, the designer should avoid using the channelized free right turn and instead require queuing in stop or signal-controlled intersection before making a turn into the receiving lanes. The designs can include features that support traffic calming features that direct merging of all vehicles 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.

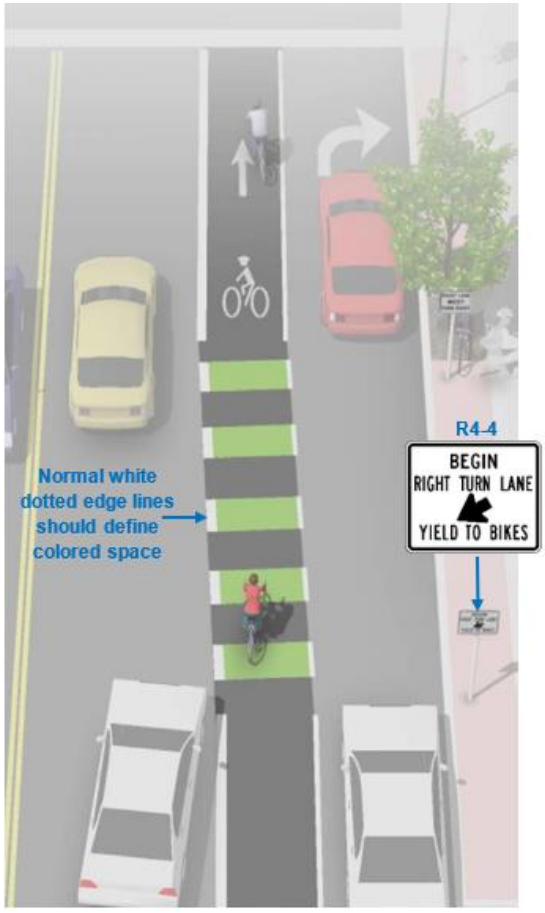


Add Lane Configuration Option



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.

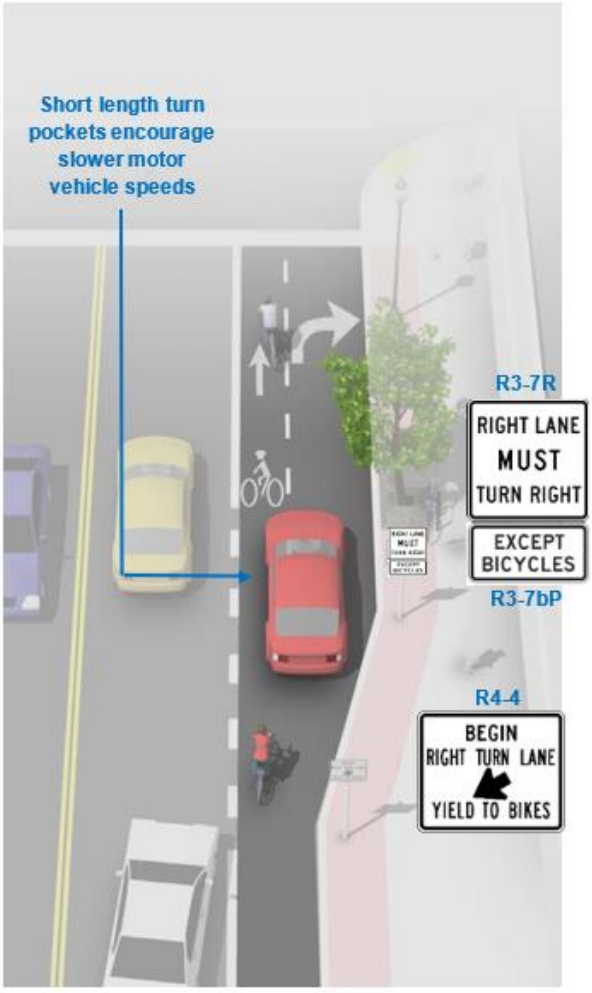
14.4.5 – Combined Bike Lanes/Turn Lanes

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.

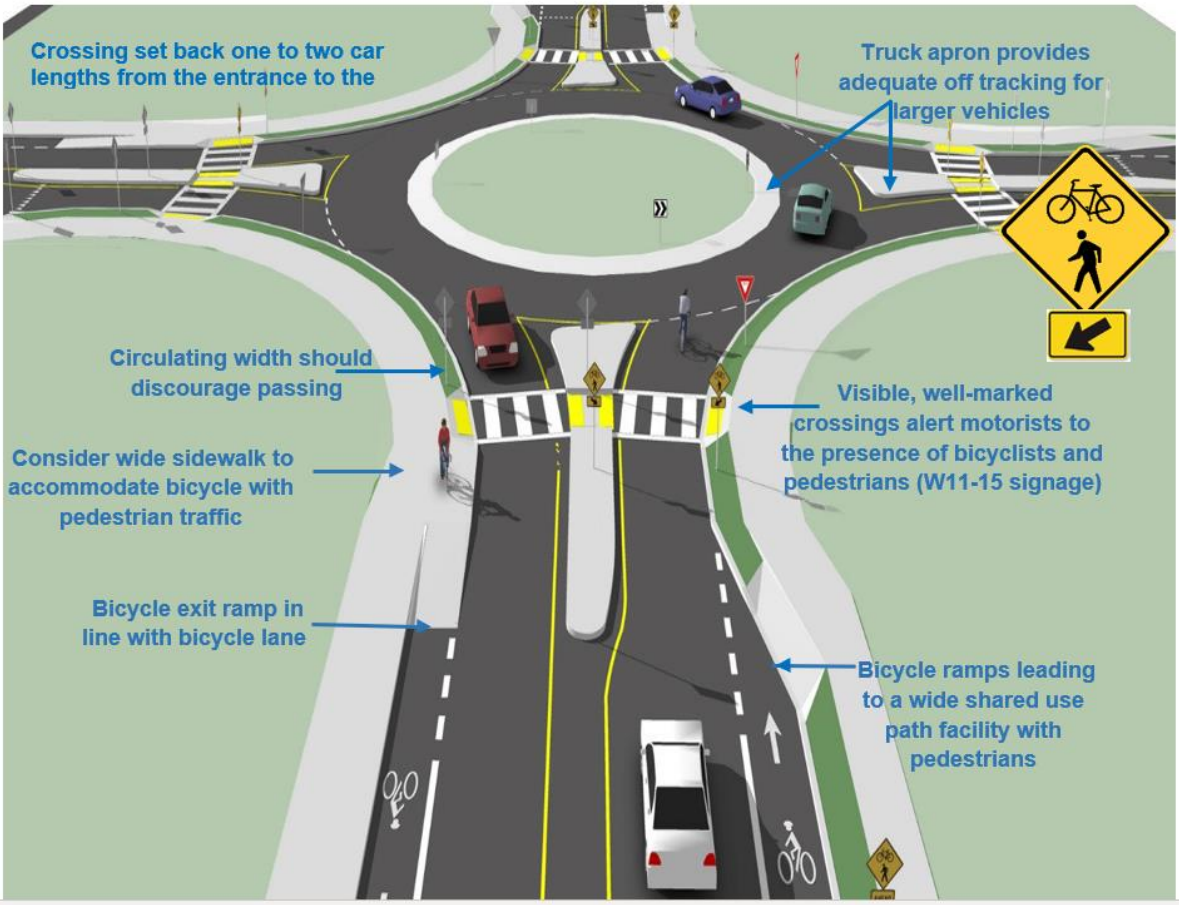
14.4.6 – Bicyclists at Roundabouts

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.

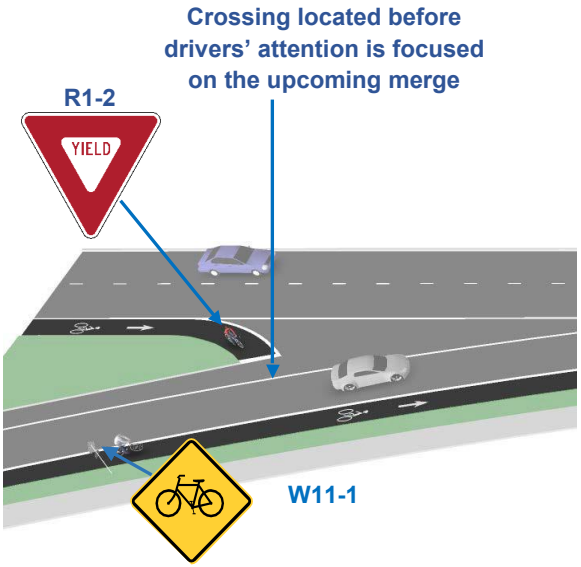
Exit Ramps

- 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.

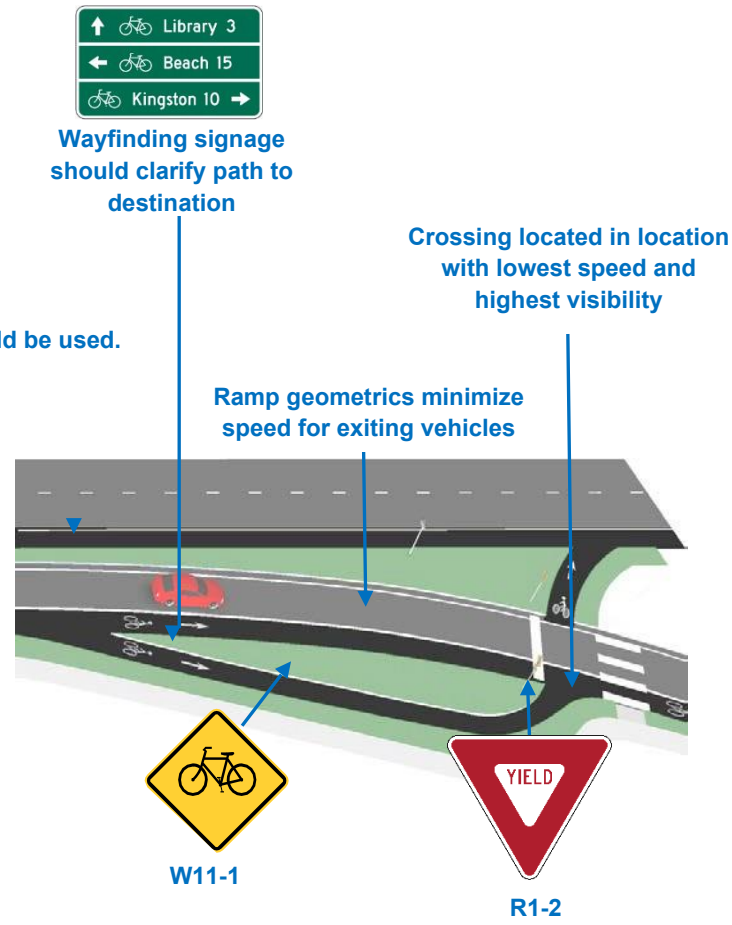
Example Entrance Ramp Layout

Note: Appropriate yield or stop bar should be used.



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.



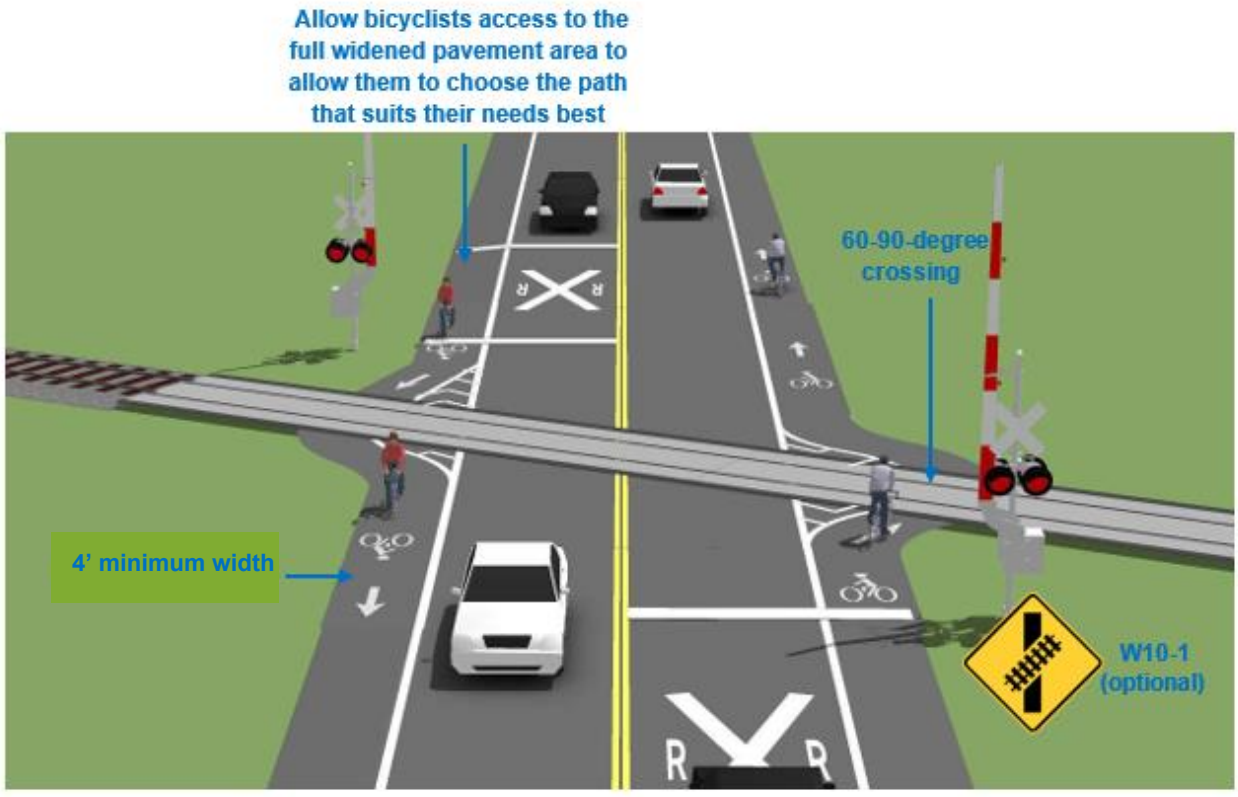
14.5.1 – Bicycle Lanes at Railroad Grade Crossings

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.



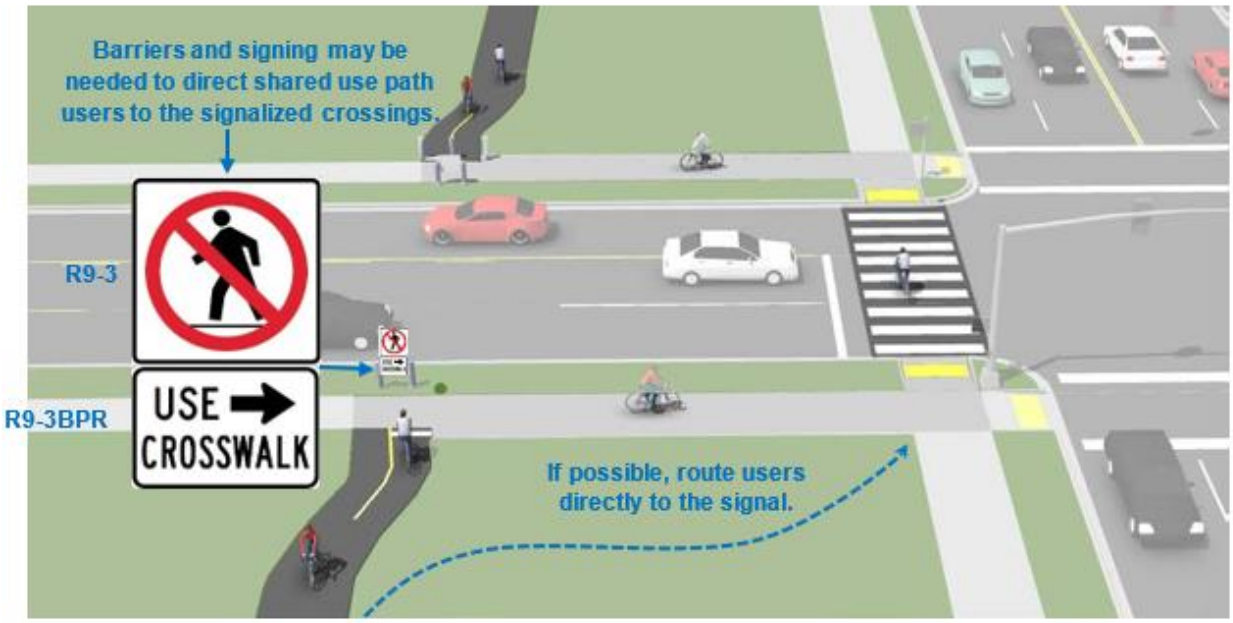
14.5.2 – Routing Users to Signalized Crossings

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.

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.

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."



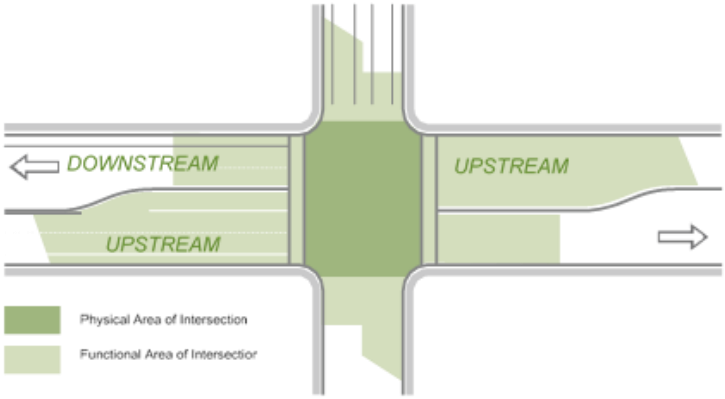
The functional area of an intersection, as illustrated in **Exhibit 14.5.1**, is the area beyond the physical intersection of two roadways (or roadway and path) that includes decision and maneuvering distance, plus any required vehicle storage length.

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

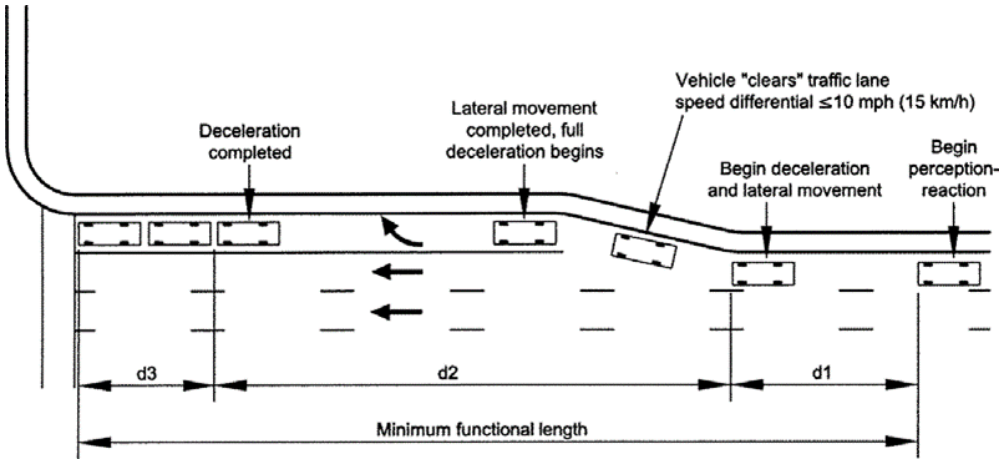


Exhibit 14.5.2 illustrates:

- **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:

$$d1 = 1.47Vt$$ [Stopping Sight Distance Chapter of AASHTO Green Book]

$V =$ design speed, mph

$t =$ brake reaction time, s

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

$$d1 = 1.47Vt = (1.47) * (35) * (1.5)$$

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

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/s²

G = roadway grade ft/ft

Given: V = 35 mph; a = 11.2 ft/s² (from AASHTO Green Book); G = -0.02

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

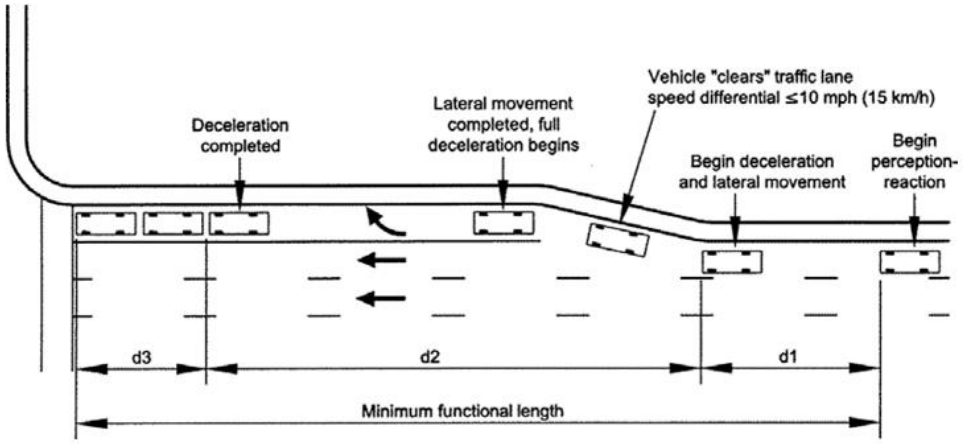
$$d2 = 124.559 \approx 125 \text{ ft}$$

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.

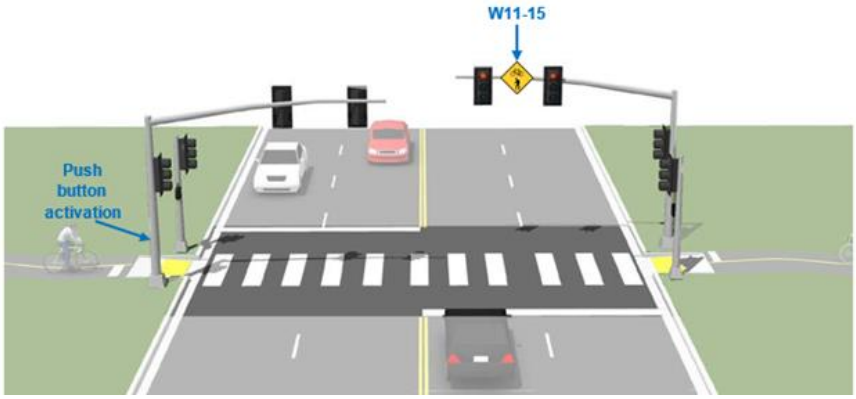
$$d3 = Q = 150 \text{ ft}$$



Minimum Functional Length = d1 + d2 + d3 = 77ft. +125ft. +150ft.

Minimum Functional Length = 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

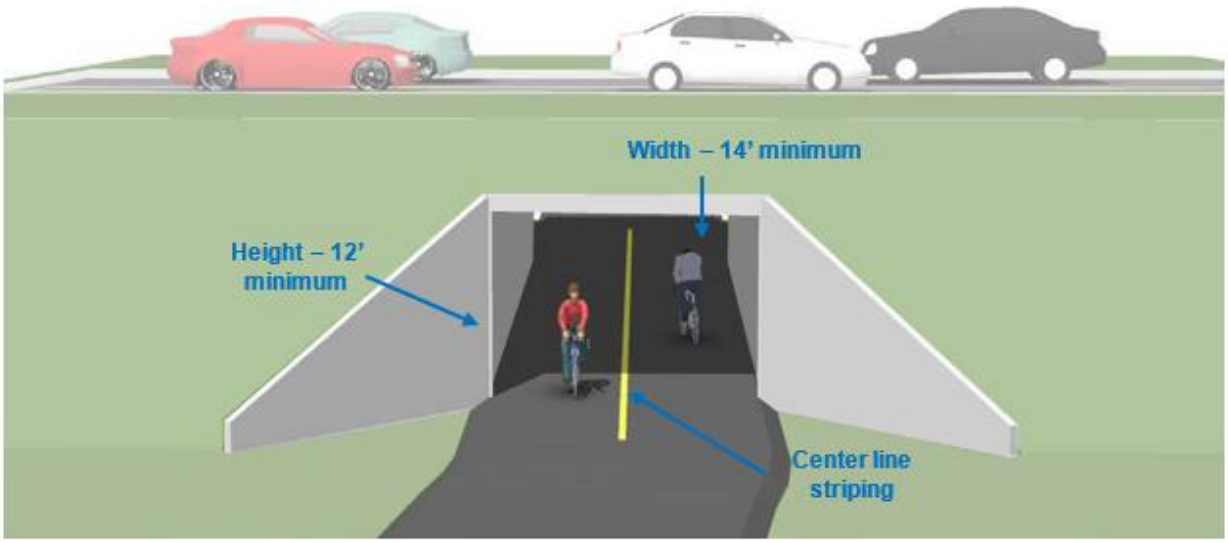
Bicycle/pedestrian undercrossings provide critical non-motorized system links by joining areas separated by barriers, such as railroads and highway corridors. In most cases, these structures are built in response to user demand for safe crossings.

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.

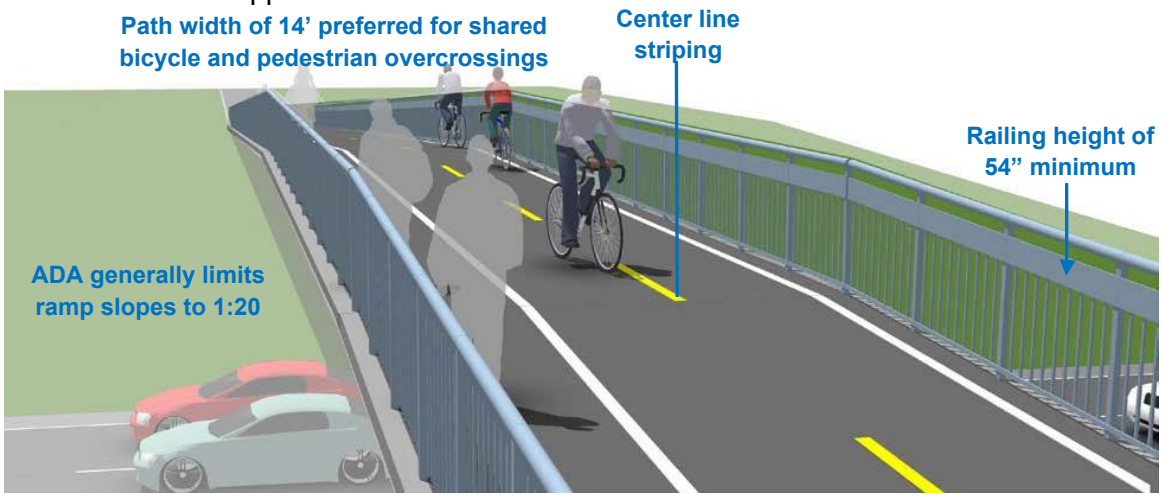
For new construction and reconstruction projects, the vertical clearance is 1 foot greater than the vertical clearance required for the highway over which the structure is located.

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.



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.

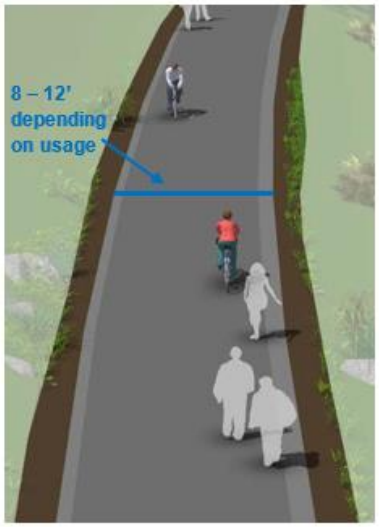
Directing the active attention of motorists to roadway signs may require additional alerting devices, such as roadway striping or changes in pavement texture. Signing for path users may include a standard STOP or YIELD sign and pavement markings, possibly combined with other features, such as bollards 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.

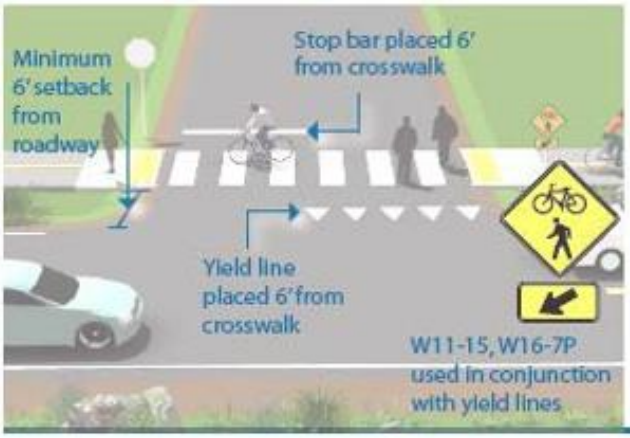
AASHTO's *Guide for the Development of Bicycle Facilities* also cautions practitioners about the use of two-way side paths on urban or suburban streets with many driveways and street crossings.

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.



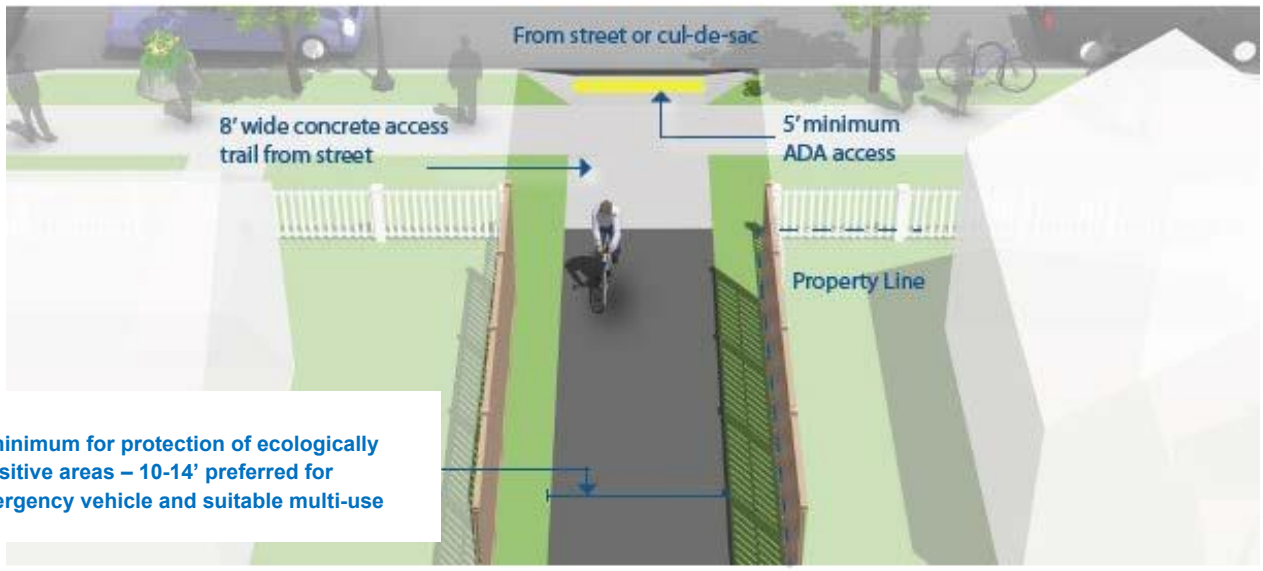
14.6.3 – Local Neighborhood Accessways

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.

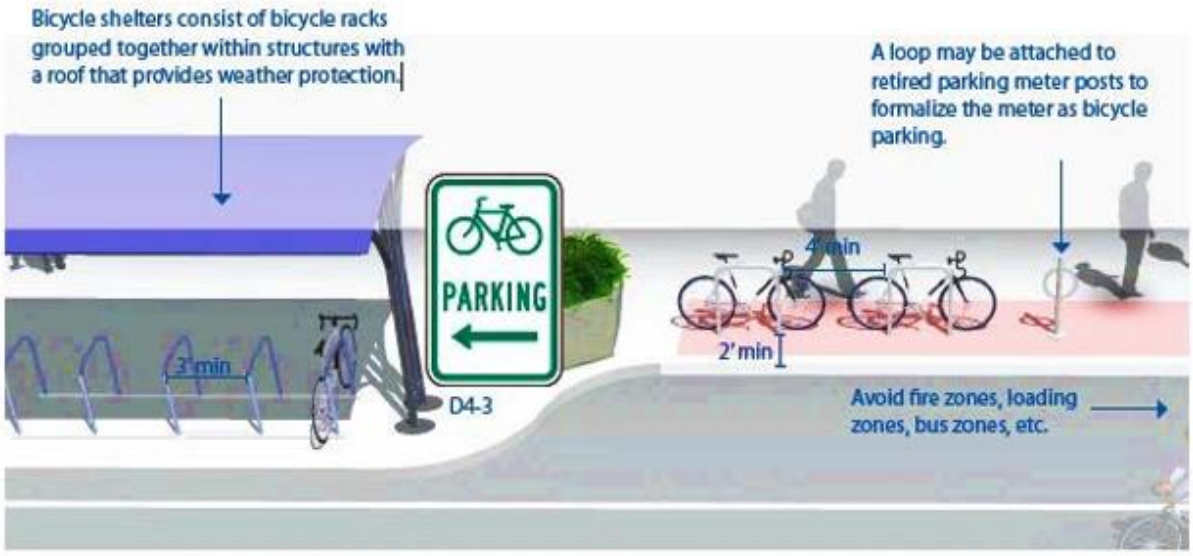
The Association for Pedestrian and Bicycle Professionals (APBP) recommends selecting a bicycle rack that:

- 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.



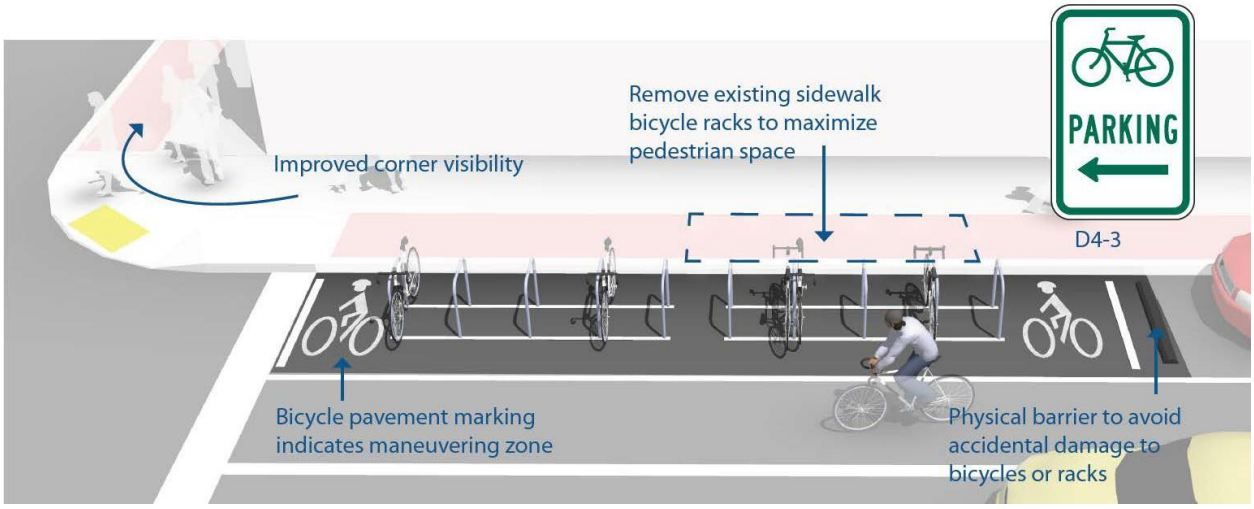
14.7.2 – On-Street Bicycle Corrals

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.

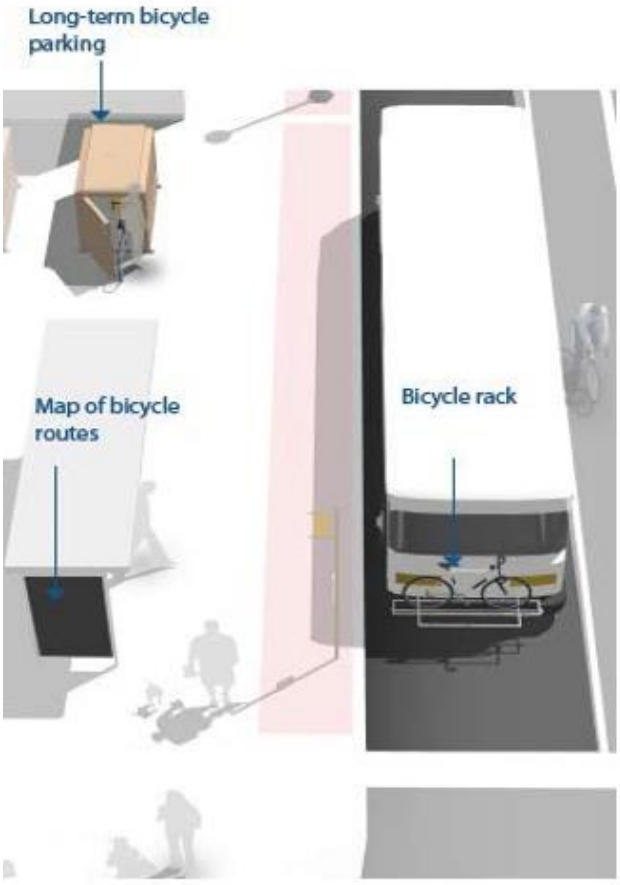
Bicycle corrals (which require a Highway Occupancy Permit and possible maintenance agreement) move bicycles off the sidewalks, leaving more space for pedestrian and sidewalk activities. Because bicycle parking does not block sight lines (as large motor vehicles do), it may be possible to locate bicycle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



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

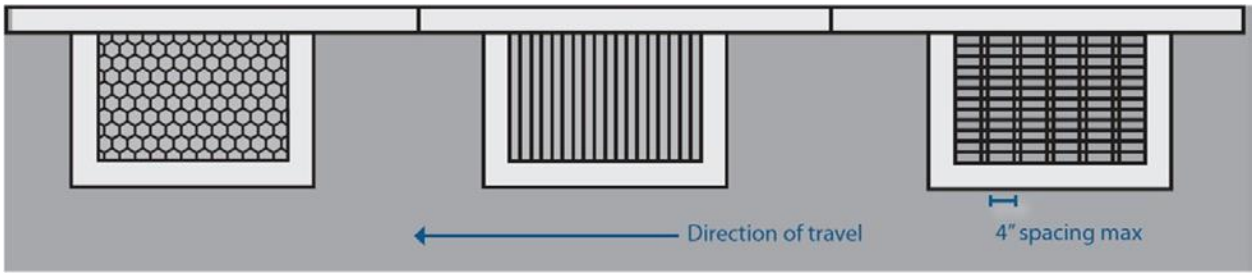
Drainage grates are typically located in the gutter area near the curb of a roadway. They contain slots through which water drains into the municipal storm sewer system.

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.

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.

- 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.

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

In this chapter there are references to future chapters 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 15 – Transit Facilities

15.0 – Introduction



Transit is broadly defined as public and private services including on-demand van transport, buses, and passenger rail systems. The incorporation of transit facilities within PennDOT projects should be context-based as required and provide transit patrons with waiting areas that are outside pedestrian flows yet connected to pedestrian infrastructure and separated and secured from automobile traffic. This chapter focuses on the integration and accommodation of transit operations within the street and highway system.

The designer of transit facilities should ask these important context questions:

- Is this project in an urban or rural area, and what types of transit serve this area (e.g., buses, vans, trains, public, and private)?
- Are stops, stations, and center locations coordinated with other supporting elements of the transportation system (e.g., sidewalks, crossings, parking, trails, and ramps)?
- What can be done to improve the safety and security of transit users (e.g., in arrival, waiting, and departure areas)?
- How easy is it to transition between all modes of transportation at various locations (e.g., automobile passenger or bus drop-offs/pick-ups at rail service locations, bicycle-to-bus, or bicycle-to-rail services, accommodate bus-to-bus transfers)? Will the proposed transit facility be able to be maintained? Poorly maintained facilities present both safety and tort liability issues and designing a facility that will be difficult to maintain may exacerbate these issues.

Key design components include:

- **Coordination of Stop Locations.** In general, transit agencies determine the general locations of stops. Too few of the appropriate types of service locations may mean that transit riders are unaware of the services in their area, are forced to walk too far, or to wait too long to board (often without shelter). Conversely, too many locations, even of the right type, may increase overall trip times for transit riders and cause delays for motorists because more time is needed for acceleration, deceleration, and dwell times at each stop. As the transit agency determines the locations of stops, coordination with them is required to determine the appropriate improvements.

Sidewalks, clear crossing locations, and other supporting features (such as shelters and bike racks) should be in place or added near transit stops, stations, and centers whenever possible to meet the needs of transit users.

- **Giving Transit Vehicles Adequate Space.** In some cases, it is desirable to allow buses to stop in the roadway, as opposed to requiring the driver to use a bus bay/bus pullout. Stopping in the roadway avoids delay in trying to re-enter traffic. However, providing this accommodation may cause delays for motorists on congested roadways. Exclusive bus lanes, typically used in highly urbanized areas, increase the reliability and speed of transit service.

  Incorporating bus bay/bus pullouts into a project requires ensuring adequate space. For example, many buses provide bicycle racks, typically located on the front of the bus. If bus bay/bus pullouts or other transit facilities are included in a project, the design should provide adequate space for cyclists to place their bikes on and remove them from the rack safely. Additionally, the design should allow sidewalk space to accommodate transit users with disabilities when they board and depart the bus.

- **Providing a Clean, Well-Lit Place to Wait.** Good signage and lighting are important for the safety of transit users and motorists, but they can inconvenience nearby residents and businesses. Uniform signs (determined by the transit agency) let passengers know where they need to be and where the bus will be taking them.

- **Ensuring Easy Transitions Between Modes.** Many transit users are also carpoolers, pedestrians, and bicycle riders. Comprehensive planning is necessary to ensure that the transit system is well connected to areas of high pedestrian activity and distribution points for other transportation modes. Bicyclists will be more enthusiastic about riding transit if bikes can be carried on the bus, bicycle racks are provided at transit stops, and if the system is connected to bicycle routes. Further, the public will be more attracted to transit if there is ease of transition and a sense of continuity between the bus and other modes of transportation, whether it be a car, ferry, airport, or train.

Many transit agencies have developed their own transit design guidelines or best practices. Therefore, the designer should always contact the transit agency that serves the project area to identify its common practices for consistent system design.

15.0.1 – Resources and References

- AASHTO, *Guide for Geometric Design of Transit Facilities on Highway and Streets,* 2014.
- Florida DOT, *Accessing Transit: Design Handbook for Florida Bus Passenger Facilities,* 2017.
- National Association of City Traffic Officials (NACTO), *Transit Street Design Guide* 2016.
- Northwest Commission, *Northwest Commission Bus Stop Guidelines*, 2018.
- Palm Tran, *Transit Design Manual*, 2004.
- Pennsylvania Public Transportation Agency, *Building Better Bus Stops Resource Guide,* 2020.
- Port Authority of Allegheny County, *Port Authority of Allegheny County Bus Stop and Street Design Guidelines*, 2019.
- Southeastern Pennsylvania Transportation Authority and the Delaware Valley Regional Planning Commission, *SEPTA Bus Stop Design Guidelines*, 2019.
- United States Access Board*, Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way,* 2011.
- United States Department of Justice*, ADA Standards for Accessible Design,* 2010.

15.1 – Required Agency Coordination

Coordination with the local transit agency is essential in any transit-related planning or design. This stipulation is important on several levels. The local transit agency knows the existing and future transit needs of its service area. Without coordination, the designer may not know the transit intentions in the highway project area. For example, a corridor may not have transit service, but the transit agency is planning to expand service to the area. Once the project is completed, the transit agency will use the facility daily; therefore, features such as stop locations, signal priority, and park-and-rides lots, need to be coordinated early on with transit agency operations.

Consideration

Just because there is no transit service today does not mean that there will not be a need for transit service tomorrow.

Coordination with the transit agency is required.

The design of transit operations should also be coordinated with Metropolitan Planning Organizations (MPOs) or Rural Planning Organization (RPOs), especially when there are multiple transit agencies in the project study area.

15.2 – Vehicle Characteristics

The actual dimensions of bus vehicles are used to establish minimum functional street-side standards for transit operations. Vehicle lengths, widths, heights, and operating characteristics should be considered in roadway and facility designs. Bus turning radii requirements are equally important.

Types of public agency transit buses used most often in the Commonwealth include:

- Paratransit buses, with a typical length of 29 feet.
- Standard single-unit urban transit buses, with a typical length of 40 feet (varying from 35 to 45 feet).
- Articulated buses, with a typical length of 60 feet.



Additionally, private carrier buses are used throughout the Commonwealth. These include:

- Intercity buses, such as motor coaches, with a typical length of 45 feet.
- Modern double-decker buses, with typical lengths of 42 to 45 feet and typical heights of 13.4 to 14.3 feet.



Exhibit 15.2.1 shows standard bus design characteristics. Roadway designs should, at a minimum always be evaluated against these standard bus characteristics. However, the designer shall also always perform agency coordination as discussed in Section 15.1 'Required Agency Coordination', to ascertain each transit agencies typical vehicle fleet characteristics. Regional or national bus service companies should also be consulted, to determine what their fleet vehicle characteristics are, if they provide service in or through the proposed project area. Good engineering judgement should then be made to at a minimum readily accommodate the primary bus in use through the project area.



Exhibit 15.2.1 Standard Bus Design Characteristics

Item		Standard Single-Unit and Intercity Bus		Articulated Bus
Length		40.0 ft.	45.0 ft.	60.0 ft.
Width without mirror		8.2-8.5 ft.	8.5 ft.	8.5 ft.
Width with mirrors (approx.)		10.2-10.5 ft.	10.5 ft.	10.5 ft.
Height		9.9 -11.5 ft.	12.5 ft.	11.0 ft.
Overhang				
	Front	7.2 ft.	7.9 ft.	8.8-8.9 ft.
	Rear	9.3 ft.	9.8 ft.	8.6-9.7 ft.
Wheel Base		25.0 ft.	22.9 ft.	23.3-24.5 ft.
Driver's Eye Height		7.0 ft.	7.0 ft.	7.0 ft.
Weight				
	Curb Weight	27,000-28,200 lbs.	38,150 lbs.	38,000 lbs.
	Gross Weight	36,900-40,000 lbs.	55,200 lbs.	66,600 lbs.
Passenger Capacity				
	Seats	30-50	50	76
	Standees	20	28	38
Turning Radius				
	Inside	24.5-30.0 ft.	24.5-30.0 ft.	27.3 ft.
	Outside	42.0-47.0 ft.	42.0-47.0 ft.	39.8-42.0 ft.
	Outside with Overhang	45.5-51.0 ft.	45.5-51.0 ft.	44.3 ft.

(Source: AASHTO, *Guide for Geometric Design of Transit Facilities on Highways and Streets*, 2014)

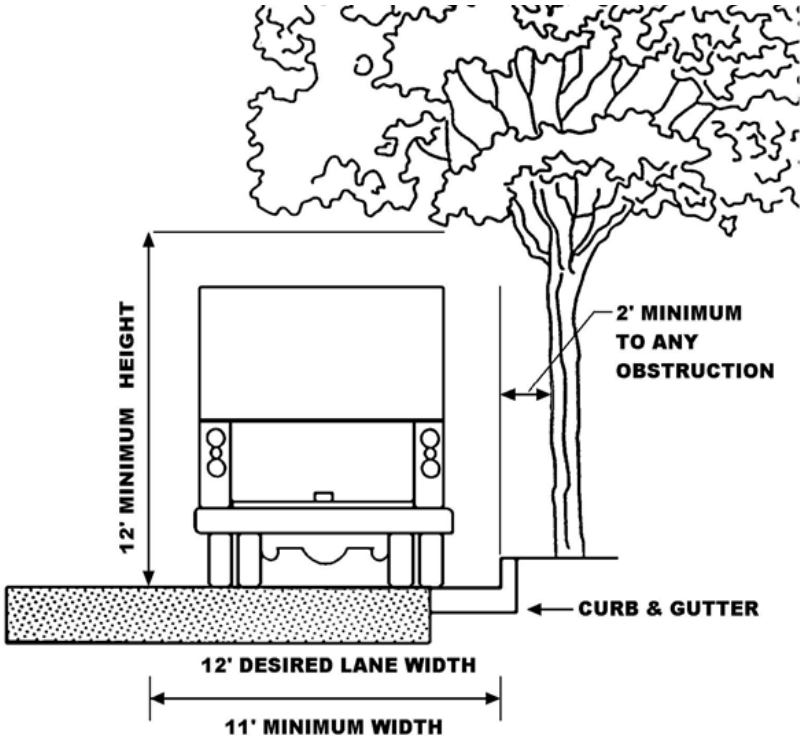
Note: Due to the variance in transit vehicles by manufacturer, a designer should confirm relevant vehicle characteristics with the appropriate transit agency.

15.3 – Clearance Guidelines

Buses typically travel along the curbside lane. As illustrated in **Exhibit 15.3.1**, when stopping for boarding and alighting (B&A), buses should be accommodated by the following minimum clearances:

- **Lane Width.** For roadways with transit route services, a minimum 11-foot travel lane should be considered because of the typical 10.5-foot width of the bus. A 12-foot lane width is preferred.
- **Curb Height.** Bus stops can be located with low curbs or an absence of curbs. However, this can make B&A difficult for riders. A 6-inch curb is preferred, with 6- to 8-inch curbs considered functional. Curbs higher than 9 inches can interfere with wheelchair lifts. On Bus Rapid Transit (BRT) and Light Rail Transit (LRT) lines, vehicles have low-level access and stations designed to be flush with the vehicle floor. Clarify vehicle dimensions with the relevant transit agency.
- **Vertical Height.** Typically, 12 feet is the minimum vertical clearance for buses, though providing 13 to 14 ft may be more appropriate in many instances due to many agencies' fleet vehicles exceeding the standard bus height dimensions shown in Exhibit 15.2.1.
- **Lateral Clearance.** A 2-foot minimum lateral clearance from the curb edge is preferred to avoid having transit mirror damage from striking objects.

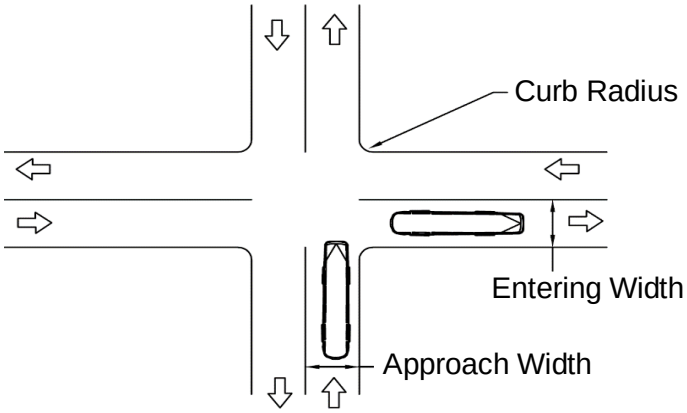
Exhibit 15.3.1 General Bus Clearances



15.4 – Roadway Design Guidelines

Exhibit 15.4.1 shows the key components of bus turning movements at intersections.

Exhibit 15.4.1 Key Components of Bus Turning Movements at Intersections



(Source: Florida DOT, *Accessing Transit: Design Handbook for Florida Bus Passenger Facilities*, 2017)

Exhibit 15.4.2 shows the desirable intersection geometry measurements for traffic lanes used by buses.

Bicycle racks on the front of buses can affect minimum turning radii, which is a consideration for roadway design construction standards. Accounting for this added dimension is particularly critical for driveways, in bus transit centers, and in neighborhoods with limited turning maneuverability.

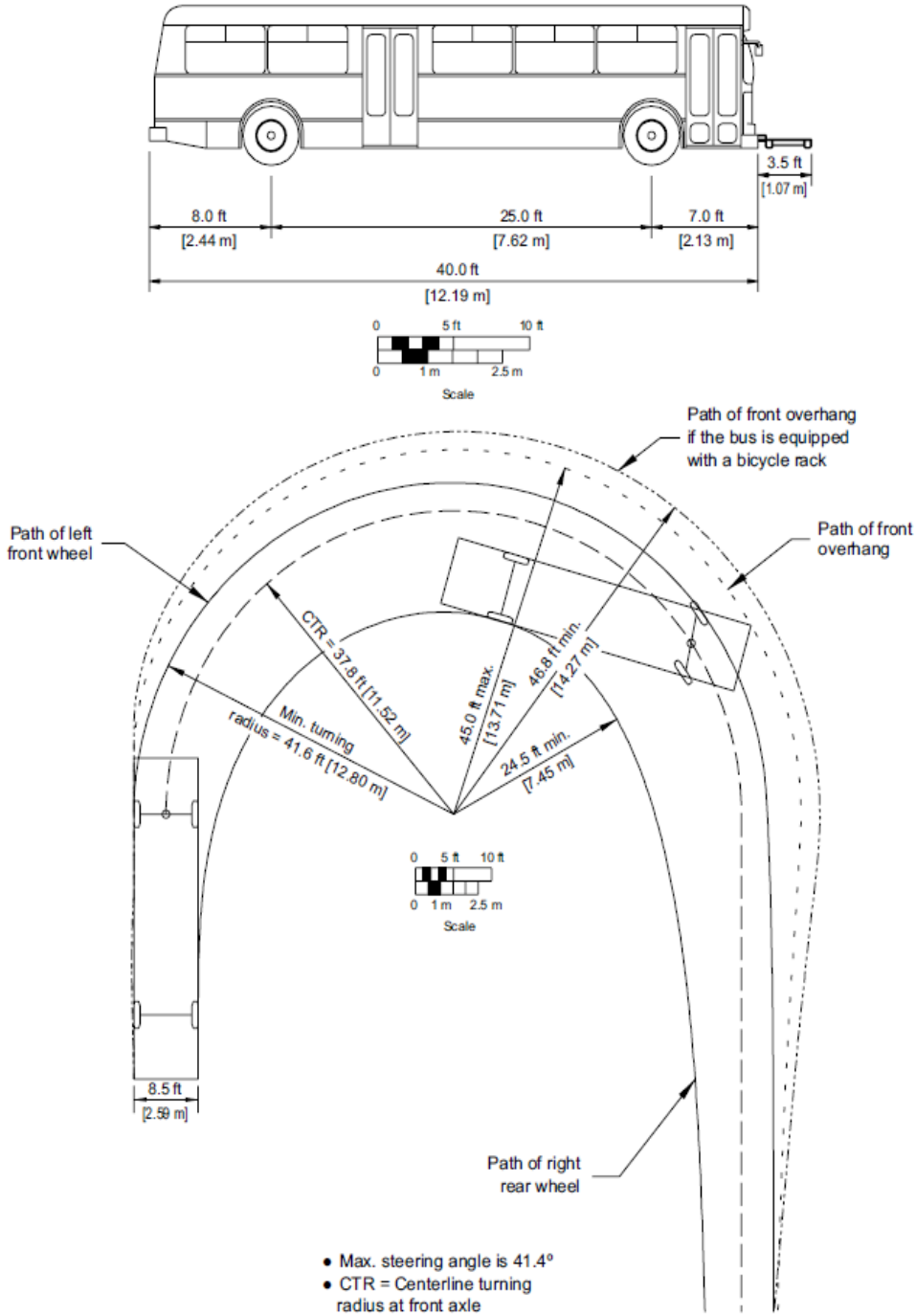
Exhibit 15.4.2 Desirable Intersection Geometry – Minimum Measurements for Transit Use

Approach Width (feet)	Entering Width (feet)	Curb Radius (feet)
12 (single lane)	12	50
	16	45
	20	40
	24	35
16 (single lane with 4' shoulder)	12	45
	16	40
	20	30
	24	25
20 (single lane with parking)	12	40
	16	35
	20	30
	24	25

(Source: Florida DOT, *Accessing Transit: Design Handbook for Florida Bus Passenger Facilities*, 2017)

Roadway dimensions must consider the minimum space in which buses can turn to ensure safe roadway turning movements. **Exhibit 15.4.3** illustrates the minimum radius required for a standard 40-foot bus.

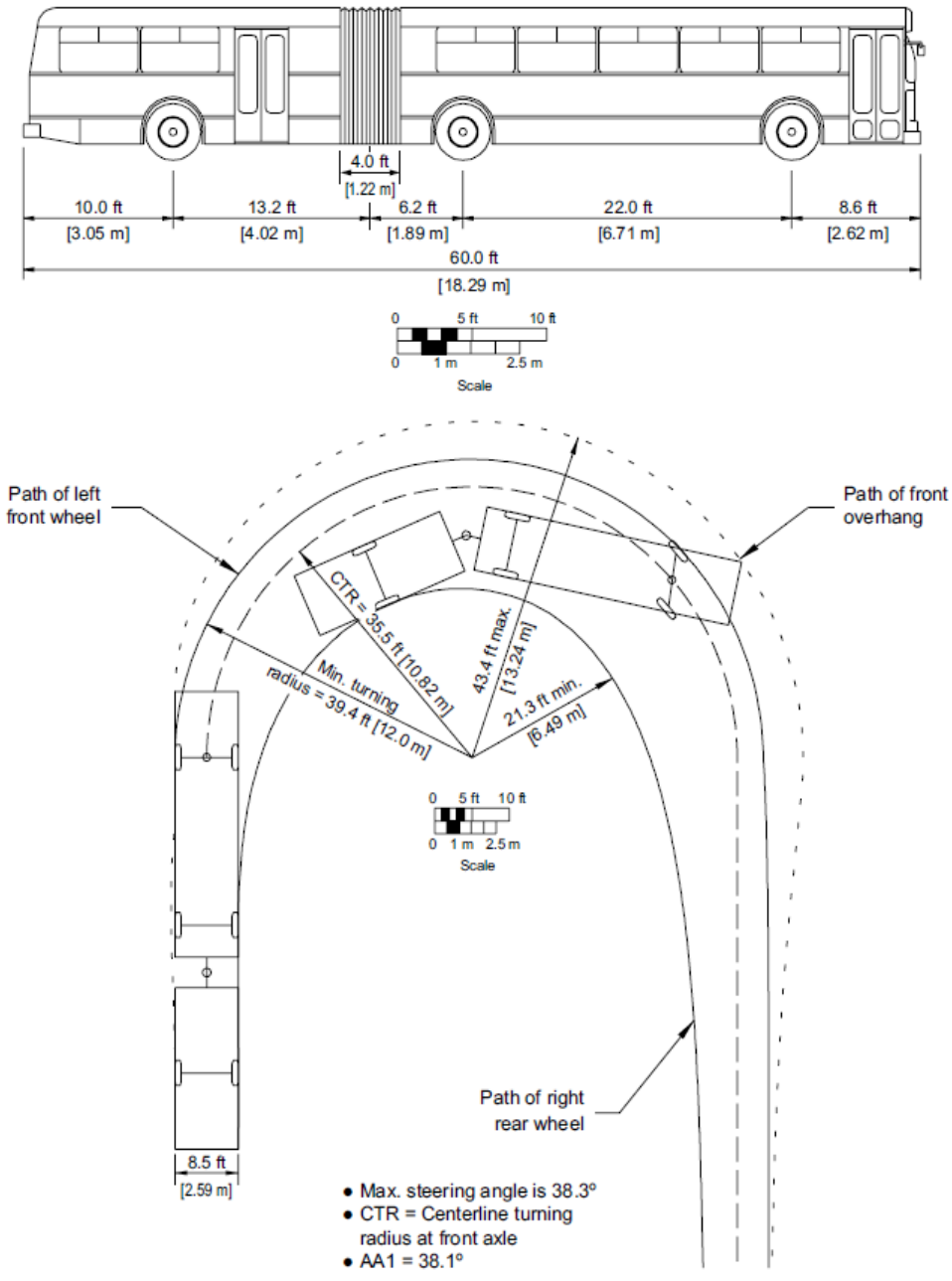
Exhibit 15.4.3 Bus Turning Movement Geometry for a 40-Foot Bus with Front Bicycle Rack



(Source: Florida DOT, *Accessing Transit: Design Handbook for Florida Bus Passenger Facilities*)

An articulated bus is an extra-long bus (i.e., 54 to 60 feet) with two connected passenger compartments. The rear body section connects to the main body by a joint mechanism that allows the vehicle to swivel for sharp turns and curves, and still maintain a continuous interior. Articulated buses are used as express buses, on high-volume routes, and for BRT services. **Exhibit 15.4.4** illustrates the 60-foot articulated turning movement.

Exhibit 15.4.4 Bus Turning Movement Geometry for a 60-Foot Articulated Bus



(Source: Florida DOT, *Accessing Transit: Design Handbook for Florida Bus Passenger Facilities*)

The AASHTO Green Book provides other bus turning radii. Additional bus-related design considerations include the following:

- The desirable minimum width for traffic lanes used by buses is 12 feet.
- Turning radii requirements for a standard 40-foot transit bus (as illustrated in Exhibit 15.4.3) are:
  - A minimum interior radius of 24.5 feet
  - A minimum outer radius of 41.6 feet
- A bus with a front-mounted bicycle rack typically requires adding at least 1.8 feet to the turning radii. This may vary by bus and rack manufacturer.
- Additional turning radii lengths are needed under the following conditions:
  - Buses turning at speeds greater than 10 mph
  - Buses making reverse turns
  - Turns in areas with sight-distance limitations
  - Turns involving changes in pavement grade
  - Turns in areas that restrict the movement of the bus overhang
- Low curbs or absent curbs make B&A more difficult for passengers. Higher curbs may interfere with wheelchair lifts.
- Articulated buses are fitted with an extra axle (i.e., set of wheels) and a joint, usually located slightly behind the midpoint of the bus behind the second axle. This makes the buses nimble enough to navigate streets safely with their increased length.
- While not always practical, there are situations where concrete pads should be incorporated into the pavement design. For example, concrete pads may be warranted in locations where transit vehicles frequently stop, and the pavement is worn.

15.5 – Transit Service Types

Prior to implementing a specific transit design, it is important to understand the various transit modes and their services. The types presented in this section are those most common throughout the Commonwealth and generally serve the transit facilities discussed throughout the rest of this chapter. As mentioned previously, coordination with the transit agency is critical in determining the types of service and the needs for service in a project area.

- **Local Bus.** Local bus service is the most basic transit mode, typically operating in mixed traffic. Local bus routes have fixed stops, and service frequency depends on the level of ridership.

  Express local bus service typically provides limited-stop or nonstop service from residential park-and-ride areas into a central business district or between two major areas or activity centers. Primarily servicing the commuter market, frequency is generally high during peak-traffic hours, with buses that operate efficiently in mixed traffic or on special/exclusive use lanes.

- **Shared Ride (Paratransit) Service.** Shared Ride is bus service that provides consolidated trips between origins and destinations that are not well served by fixed route bus service. Often referred to as “paratransit,” Shared Ride operates during limited hours, in specific travel areas, and with required application and reservation processes.

  Users may depend on Shared Ride to travel to work, medical facilities, school, or other destinations. Despite being a door-to-door service, Shared Ride does not provide taxi service or a nonstop ride for one person. Rather, riders are grouped by trip timing and origin/destination locations. Shared Ride does not provide emergency medical transportation services.

- **Bus Rapid Transit (BRT).** BRT service is a fast-frequent bus service in either mixed traffic or a dedicated or exclusive right-of-way. BRT is typically an enhanced transit service with its own branding and station design, as well as a range of premium operational elements. BRT operates in more-densely populated urban areas and has greater station spacing than a local bus service.

- **Light Rail Transit (LRT).** LRT services high-density areas with heavy transit ridership, using smaller rail cars with lower passenger capacity (compared to heavy rail and commuter rail). LRT can operate along dedicated rail lines or in a shared right-of-way. LRT stations are typically spaced closer than other rail modes, with emphasis on pedestrian access.

- **Commuter Rail.** Commuter rail services a wider region for longer, primarily work-related, trips. Typically operated through diesel train engines or overhead electrical catenary, commuter rail requires exclusive right-of-way that might be shared with an existing freight rail track. Stations are usually served by feeder bus routes and often include park-and-ride facilities. Commuter rail uses higher passenger-capacity cars and realizes operational efficiency through its larger passenger volumes.

15.6 – Transit Facility Types

Transit facilities range from simple, unsheltered bus stops to large, expensive facilities (such as intermodal centers and major transit terminals) that accommodate passengers transferring between buses and other transportation modes. Most transit systems consider development and construction of bus passenger facilities within a hierarchy based on the number of passengers, bus routes served, and overall intensity of use. This hierarchy also determines amenity placement and additional service conditions.

- **On-Line Bus Stops.** On-line bus stops provide access to transit in a variety of locations, such as rights-of-way within arterial roadways or collector streets, along local roads, and in areas adjacent to a variety of land uses. These stops connect pedestrian-ways with bus waiting areas and sidewalks, as well as to connections to nearby passenger destinations.
- **Park-and-Rides.** Park-and-rides comprise parking areas with transit connections. They allow commuters and other riders to leave their vehicles and transfer to a bus or rail system or to carpool for the remainder of the journey. Owners leave their vehicles in the car park area and retrieve them upon their return. Park-and-rides are generally located in the suburbs or the outer edges of a city. A key feature of park-and-rides is easy ingress and egress for the parking separated from the ingress and egress of the transit vehicle.

  A park-and-ride that offers parking only for meeting a carpool (and not connections to public transport) may be called a park-and-pool. The park-and-ride may also allow for passenger drop-off, also known as “kiss-and-ride” patrons. Park-and-ride facilities may offer parking for a little or no fee.
- **Stations.** Transit stations are typically transit stops located along fixed guideways, featuring more infrastructure and amenities than typical on-street stops. Stations can also serve as transfer points in the transit network and function as passenger drop-off/pick-up or park-and-ride facilities. Stations are often located within major activity centers with transit-oriented development features.

15.7 – Bus Stop Location and Design

The proper location of bus stops is critical to the safety and security of passengers and to proper transit operations. Bus stops should provide safe spaces for all users. Creation, adjustment, and replacement of bus stop locations must be coordinated with the transit agency and local jurisdictions. It is important to consider the unique circumstances at each intersection when locating and designing bus stop locations.

The designer should investigate local ordinances regarding sidewalk maintenance. If there are no local ordinances, discuss the importance of sidewalk maintenance with the municipality if sidewalks are to be incorporated into the design or serve as the primary access to the stop.

Basic considerations include:

- The need for safe, secure, and convenient service for patrons.
- Access for people with disabilities.
- Convenient passenger transfers to other intersecting bus routes or transfer points.
- Connection to nearby pedestrian circulation systems.
- Presence and width of sidewalks, crosswalks, and curb ramps.
- Pedestrian activity through intersections.
- Ability of the stop to accommodate transit dwell time and the loading/unloading of wheelchairs and bicycles.
- Adequate curb space for the number of buses expected at the stop at one time.
- Ease of re-entering the traffic stream (if a bus bay/bus pullout).
- Design characteristics and operational considerations of the highway or street.
- Presence of on-street automobile parking and truck delivery zones.
- Traffic control devices near the bus stop, such as signals or stop signs.
- Avoiding undesirable sight obstructions to other drivers that may caused by bus stop signs, shelters, and the physical bus.
- Volumes and turning movements of other traffic, including bicycles.
- Proximity and traffic volumes of nearby driveways.
- Street grade.
- Proximity to rail crossings.
- Accommodating transit priority equipment at signalized intersections.
- Transit queue bypass at signalized intersections.
- Paired stops on each side of a highway or street.

- Proximity to intersections.
- Away from storm/inlet grates as well as access points for underground utilities (water, sewer, etc.).

The design and placement of amenities at a bus stop, such as a shelter, bench, or bike rack, must comply with state and federal ADA requirements and accessibility guidelines. ADA standards require all bus stops to have a sign and sufficient space for a B&A area that has a firm, stable, and slip-resistant surface. For a bus stop designated only by a sign on a post, with no other amenities, and where complementary ADA paratransit service is provided, the B&A area is still required but may not have to include a concrete pad. If considering a concrete pad, consider the impacts of salt usage during winter operations.

The design should also incorporate any transit agency guidelines on bus stops.

Guidance

- Firm, stable surface
- Minimum clear length of 8 feet (see **Exhibit 15.7.2**)
- Minimum clear width of 5 feet (see Exhibit 15.7.2)
- Connected to streets, sidewalks, or pedestrian paths
- Slope of the pad parallel to the roadway the same as that of the roadway

Bus stops are placed at the near side or far side of an intersection or at mid-block locations. Bus stops at intersections are preferred because they provide the best pedestrian accessibility from both sides of the street and cross streets. They also provide the most convenient transfers to intersecting bus routes. In limited instances, such as where blocks are exceptionally long or where bus patrons are concentrated well away from intersections, a mid-block bus stop might be appropriate. Mid-block bus stops lessen sight distance problems for pedestrians and motorists, produce fewer pedestrian conflicts, and reduce pedestrian congestion at passenger waiting areas. However, a concern with mid-block bus stops is that they increase the walking distance for pedestrians who must cross at intersections, and, in so doing, can encourage people to cross the street mid-block (i.e., “jaywalk”). This is especially problematic on high-speed roadways.

15.7.1 – Bus Stop Location

Determining the proper location of bus stops involves choosing among far-side, near-side, and mid-block stops. The designer should consider the following factors when selecting the type of bus stop:

- Adjacent land use and activities
- Bus route (e.g., bus-turning at an intersection)
- Bus signal priority (e.g., extended green lights suggest far-side placement)
- Impact on intersection operations
- Intersecting transit routes
- Intersection geometry
- Parking restrictions and requirements
- Passenger origins and destinations
- Pedestrian access, including accessibility for users with disabilities
- Physical roadside constraints (e.g., trees, poles, and driveways)
- Potential users
- Presence of bus bypass lane
- Traffic control devices

Additionally, transportation network consistency assists with driver expectancy. The following factors should be considered in bus stop placement:

- At intersections, a consistent pattern of stops (e.g., all near-side or all far-side) enables transit riders to know where they need to board a bus.
- At intersections where more than one bus route operates and where buses operate on cross streets, consideration should be given to convenient transfer to other bus routes.
- Stops should be located close to major passenger generators. Curb space should be provided to accommodate the desired number of buses and passenger waiting areas.

Bus stops should be long enough to permit safe entry by buses without causing backups into the adjacent travel lanes or into intersections.

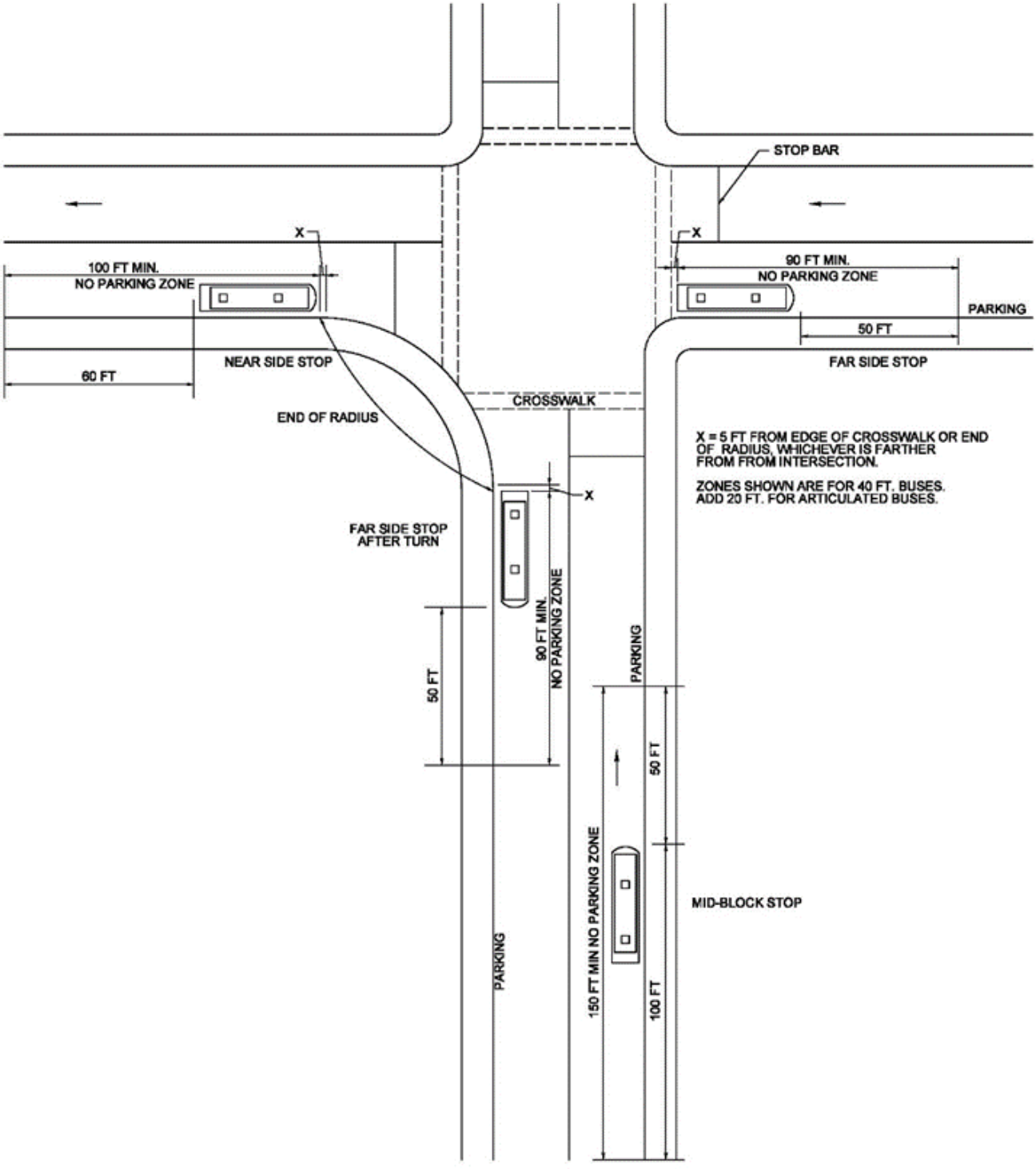
- Consideration should be given to locating stops away from stormwater inlets and grates, as well as key access points for utilities, water mains and sewers.

The remainder of this section discusses three types of bus stops:

- Far-side, with a stop located just past an intersection
- Near-side, with a stop located just prior to an intersection
- Mid-block, with a stop located away from an intersection

Exhibit 15.7.1 illustrates typical dimensions of near-side, far-side, and mid-block stops.

Exhibit 15.7.1 Bus Zone Dimensions



(Source: AASHTO, *Guide for Geometric Design of Transit Facilities on Highways and Streets*, 2014)

15.7.1.a – Far-Side Stops

Located downstream of an intersection, far-side bus stops are generally preferable to near-side stops (except on two lane roadways) because they result in fewer traffic delays, provide better vehicle and pedestrian sight distances, and cause fewer conflicts among buses, cars, pedestrians, and bicyclists. Far-side stops are recommended particularly when the street is wide enough to permit other vehicles to pass uncontrolled around the stopped bus.

The following chart lists some advantages and disadvantages of a far-side bus stop.

Advantages	Disadvantages
• Minimizes conflicts between right-turning vehicles and buses. • Provides additional right-turn capacity by making a curb lane available to traffic. • Minimizes sight distance issues on intersection approaches. • Encourages pedestrians to cross behind the bus. • Creates shorter deceleration distances because the bus can use the intersection to decelerate. • Drivers can take advantage of traffic gaps created by traffic signals.	• May result in blocked intersection, particularly due to high traffic volumes during peak periods. • May limit sight distance for vehicles and pedestrians crossing the roadway. • Can cause the bus to stop on the far side after stopping for a red light, interfering with through-traffic • May increase rear-end crashes, as vehicle drivers might not anticipate the bus stopping.

15.7.1.b – Near-Side Stops

Located upstream of an intersection, near-side stops are preferred on two-lane roadways without a bus bay/bus pullout, where vehicles are restricted from going around the bus to prevent vehicle stacking in the intersection. Near-side stops should be used where far-side stops cannot be provided. Near-side bus stops are also appropriate when street crossings and other pedestrian movements are safer on the near side rather than the far side. These stops are also appropriate when the cross street is one-way from right-to-left or when the bus route requires the bus to turn right at an intersection.

A near-side bus stop should be located in advance of the leading taper for the right-turn lane to allow sufficient distance for drivers to see and access the turn lane. The design should avoid near-side stops at intersections with dedicated right-turn lanes where right-on-red turning is permitted.

The following chart lists some advantages and disadvantages of a near-side bus stop.

Advantages	Disadvantages
• Minimizes interference when traffic is heavy on the far side of the intersection. • Allows passengers to access buses closest to a crosswalk. • Permits an intersection width that allows the driver to pull away from the curb. • Eliminates the potential for double-stopping (i.e., bus stopping twice at a stop because it is waiting for its “turn” at the stop). • Allows passengers to B&A while the bus stops at a red light. • Provides the driver with the opportunity to look for oncoming traffic.	• Increases conflicts with right-turning traffic. • May result in stopped buses obscuring curbside traffic control devices and pedestrians crossing the roadway. • May cause sight distance limitations for vehicles stopped next to the bus. • May block the through-lane, including during peak periods. • Increases sight distance limitations for pedestrians.

15.7.1.c – Mid-block Stops

Mid-block stops are desirable where traffic or physical street characteristics prohibit a near- or far-side stop adjacent to an intersection or where large factories, commercial establishments, or other bus passenger generators exist. Where possible, mid-block stops are located at the far side of an existing pedestrian crosswalk so that standing buses do not block an approaching motorist's view of pedestrians in the crosswalk.

Because of safety concerns, mid-block stops are not recommended near schools. Mid-block crossings should be well-lighted and well-marked. Additionally, on-street parking should be prohibited in advance of all mid-block crosswalks. Mid-block crossings should also be well-signed to provide proper notification to drivers to minimize rear-end crashes.

The following chart lists some advantages and disadvantages of a mid-block bus stop.

Advantages	Disadvantages
• Minimizes intersection sight distance problems for vehicles and pedestrians by moving the bus stopping location outside of the vision triangles for conflicting movements. • May result in passenger waiting areas experiencing less pedestrian congestion.	• Encourages patrons to cross street at mid-block (i.e., jaywalking). • Increases walking distances for passengers crossing at intersections. • Requires additional distance for no-parking restrictions. • Buses may have difficulty re-entering the flow of traffic. Unexpected mid-block stops may lead to rear-end crashes.

15.7.1.d – Bus Stop Placement – Special Cases

Near a Bridge.

- **Upstream.** The bus stop should be located far enough upstream from a bridge so that passengers do not have to straddle the guide rail or anchorage or be in jeopardy of falling down drop-offs or off side-fill slopes. The stop should have a flat surface large enough to accommodate an ADA-compliant B&A area.
- **Downstream.** The bus stop should be located far enough downstream from a bridge to allow the bus to make a safe stop. Consideration must also be given for adequate sight distance to permit traffic behind to see a stopped bus and safely maneuver around it.

Near Guide Rail. When considering a transit stop near guide rail, several factors may preclude installation in these areas. Often guide rail is installed in areas adjacent to steep drop offs or fixed objects which can't be moved. Additionally, if adjusting the guide rail to permit installation of a bus stop, appropriate end treatments need to be provided. Before installing transit stops at these locations, it should be confirmed these are the most appropriate locations for installation. When a guide rail runs parallel to a roadway that has or will have transit service, the bus stop should be located outside the guide rail. An opening must be provided in the guide rail to permit a B&A area.

The purpose of the guide rail may be to protect motorists from a steep slope adjacent to the roadway. If a stop is needed in these locations, the designer should review the conditions adjacent to the proposed bus stop and protect pedestrians from hazards with a handrail or fence.

Near a Driveway. Whenever possible, bus stops should be located beyond driveways to minimize conflicts between buses and other vehicles leaving or entering driveways. Ideally, transit stops should be located a minimum of 200 feet from driveways and downstream of driveway traffic. If the design cannot prevent blocking a driveway, at least one entrance and exit to a property should remain open at all times while a bus is loading or unloading passengers. Bus stop infrastructure and amenities should not block the view of traffic entering or exiting the driveway.

At a Roundabout. Transit stops are not allowed in the circulating roadway, in the approach lanes, or in the exit lanes prior to the crosswalk. Locate transit stops on the roadway before or after the roundabout, in a pullout, or where the pavement is wide enough that a stopped bus does not block the through movement of traffic or impede sight distance.

Areas of Limited Visibility. Bus stops should not be located over the crest of a hill, immediately after a road curve to the right, or at other locations that limit the visibility of oncoming traffic. If the bus stops in the travel lane or attempts to pull back into traffic from a stop in areas of limited visibility, the potential for an accident is high. If a bus stop must be placed at such a location, approaching vehicles should be warned to be prepared to stop. Signage for such conditions should be in accordance with the MUTCD.

Near Schools. When locating transit facilities near primary schools, stops should be placed in an area where they can be visually monitored by school personnel and crossing guards to increase security. Mid-block stops near schools are not recommended.

Rural Bus Stops. Rural bus stops require special considerations because of roadway design speed, right-of-way constraints, site distances, and accessibility concerns. Like all stops, they must also meet applicable ADA standards.

Near Railroad Crossings. The following requirements and limitations should be considered when locating bus stops near railway crossings:

- Bus stops should be located on the near side, in advance of the railroad crossing stop bar to avoid creating a queue that would conflict with the crossing.
- Bus stops should be placed a minimum of 25 feet in advance of railroad crossing pavement markings. Bus bays/bus pullouts should be located a minimum of 50 feet from the railroad crossing stop bar.
- Bus stops should be located so that a stopped bus does not obstruct any railroad warning signs.
- Where bus routes are parallel to railroad tracks, bus stops should be placed outside of the clear zone of the railway (which is a minimum of eight feet from the outer rail), in accordance with any specific guidance from the impacted rail agency or protected by crash walls. If possible, bus stops should be placed outside the railroad right-of-way.

Designers may refer to the MUTCD for additional requirements and guidelines on placing bus stops near a railway crossing.

15.7.2 – Bus Stop Elements and Design

Improving passenger accessibility to buses and mobility in the right-of-way is key to the safe and efficient design of bus stops. By understanding bus stop elements, a designer can lay out the space requirements within the specific context of the stop.

ADA standards require all bus stops to have sufficient space for a B&A area that has a firm, stable, and slip-resistant surface. For a bus stop designated only by a sign on a post and no other amenities (e.g., shelter, bench, and trashcan) and where complementary ADA paratransit service is provided, the B&A area is still required but it may not have to include a concrete pad. The B&A area must be clear of obstructions and located with a minimum clear length of 8 feet perpendicular to the roadway and a minimum clear width of 5 feet measured parallel to the roadway. If any bus stop amenities (in addition to a bus stop sign) are provided, the bus stop B&A area should be connected to the amenities, streets, sidewalks, and/or existing pedestrian infrastructure by an accessible route.

As part of the design, the ability to maintain the stop amenities should be considered. Stop amenities that cannot be maintained over time become safety and tort liability issues for the transit agency.

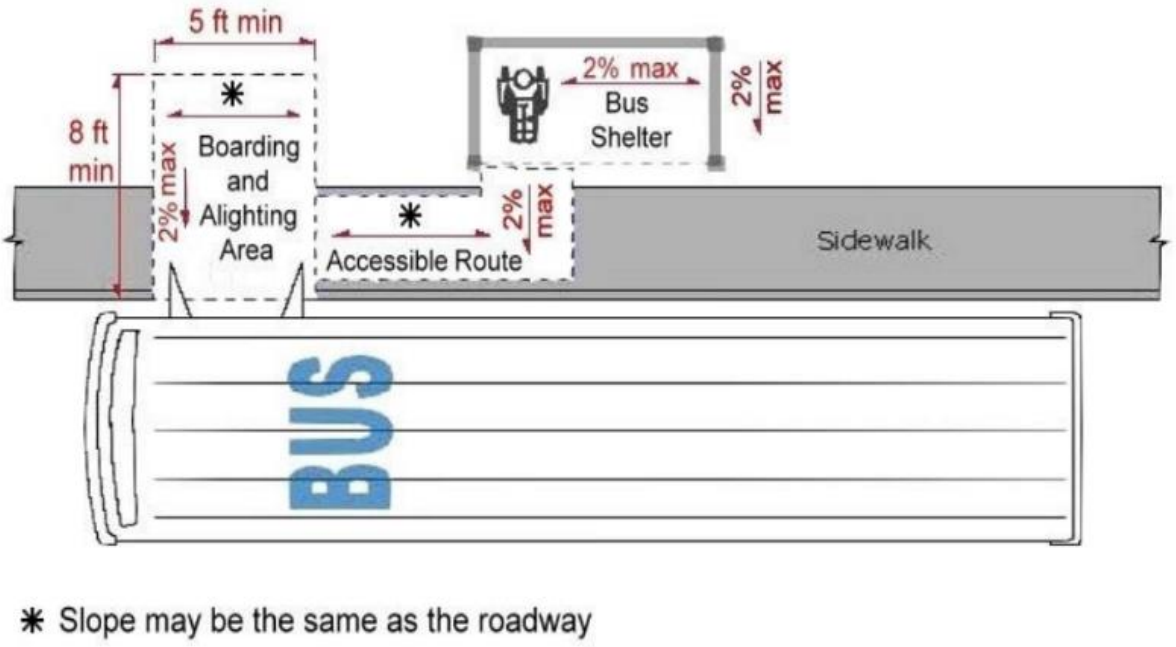
15.7.2.a – B&A Area

A level loading or B&A area should be provided where the front bus doors open to receive and discharge passengers. Locating a clear area at the front of the bus allows easy deployment of the front door ramp or the "kneeling" feature (lowering bus suspension) for wheelchair access.

The dimensions of bus stop B&A areas may be adjusted as necessary to accommodate site conditions. However, the minimum size of B&A areas, per ADA standards, is 8 feet (perpendicular to roadway) by 5 feet (parallel to roadway), as illustrated in **Exhibit 15.7.2**. Buses operating in more-urban areas often have two doors that require B&A areas. For driver and passenger ease, design recommendations include a minimum 30-foot long area (ideally 40 feet) along the roadway, rather than two 5-foot by 8-foot B&A pads.

Parallel to the roadway, the slope of the B&A area shall be the same as the roadway, to the maximum extent practicable.

Exhibit 15.7.2 Bus Stop Accessibility Features



(Source: Washington State DOT, *Design Manual*, 2021)

Perpendicular to the roadway, the slope of the B&A area shall not be steeper than 1:48. B&A areas for sheltered stops may include conduits and junction boxes for utilities. B&A areas may also be sized according to the dimensions of a planned shelter. In urban areas, and where right-of-way permits, it is ideal to provide a continuous 8-foot wide concrete pad along the entire length of the bus stop (i.e., 40 feet to accommodate a standard bus and 60 feet for an articulated bus) adjacent to the curb and gutter. An additional 50-foot length is recommended for each additional bus expected to stop at the bus stop at the same time.

A sidewalk provided with the B&A area shall be a minimum of 60 inches wide. It is preferred for the B&A to be at curb height with sidewalks connecting to the nearest intersection. A detectable warning surface is required where a sidewalk associated with a B&A area connects to the roadway at grade. Except for the area adjacent to the curb, the areas surrounding the B&A area shall be flush with the adjacent shoulder and side slopes. B&A areas must be positioned to coordinate with transit vehicles to minimize the vertical and horizontal gaps encountered when boarding the vehicle. The B&A area concrete pad should extend six inches beyond the area under the shelter canopy to prevent soil erosion caused by run-off. As discussed below, it is preferred for the B&A area to be at curb height with sidewalks connecting to the nearest intersection.

Any easement or right-of-way obtained for installing a B&A area concrete pad should extend at least two feet beyond the pad. ADA regulations require that accessible routes to bus stop B&A areas be designed to maintain a minimum clear width of 36 inches and vertical clearance of 80 inches along the pedestrian access route.

To create an arterial or collector roadway B&A area (i.e., roadways without curb and gutter where the shoulder and the roadway are at the same level), bus stops with a raised, clear, 5-foot by 8-foot B&A area may be constructed at the shoulder point (or edge of shoulder pavement on roadways with a design speed of 45 mph or less). A raised B&A area should be outside of the shoulder area to avoid vehicle/snowplow strikes. If the B&A area is raised, a ramp is needed to access it.

For rural bus stops, typically on flush shoulder roadways, care should be taken to avoid visually obstructing existing B&A area shelters with bus stop or road signs. Sidewalks must always meet ADA requirements.

15.7.2.b – Waiting Area

In addition to the B&A area, a bus stop waiting area should be sized to reflect expected passenger volumes and, at a minimum, wide enough at the curb line to provide a safe place for passengers to wait outside of the loading area. In locations where both pedestrian volumes and the number of transit passengers expected to use a stop are relatively low, the waiting area may overlap with the pedestrian path.

15.7.2.c – Pedestrian Access to Stops

A minimum 3-foot wide clear pedestrian path should be provided for access to the bus stop waiting area and loading area. A sidewalk that connects the bus stop to adjacent development or neighborhoods is the most common solution. Absent a sidewalk, shoulders can be used for access. Shoulders should be designed according to standard shoulder design criteria. The sidewalk or trail should provide a clear pedestrian path to and from the bus stop area, the bus stop loading pad, and the bus shelter or bench.

15.7.2.d – Pedestrian Path Connecting Stop Area to Surrounding Development

A stop location adjacent to a pedestrian path can be accommodated by providing a short pedestrian link to the bus pad and waiting area. The path can be used as a loading pad if it is wide enough to provide pedestrian passing space (in addition to the loading pad area) and is located adjacent to the roadway.

Cinder, gravel, or dirt trail surfaces are not suitable for withstanding wear from waiting passengers. A hard or impervious surface can be incorporated into the area of the path used for the bus stop. When a bus stop is required in an area that does not have a formal sidewalk, a pedestrian may use the shoulder and the shoulder should be in good condition unless pedestrian use of the shoulder is prohibited.

15.7.2.e – Bus Stop Signs

Bus stop signs are the most important elements in designating a bus stop. Therefore, the most important considerations in placing transit signs are passenger convenience, public safety, and bus stop visibility. The bus stop sign marks the area where passengers should stand while waiting for the bus and serves as a guide for the bus operator in positioning the vehicle at the stop.





R7-107A

Bus stop signs must be posted at all bus stops and bus passenger facilities, as they are frequently the only communication a passenger has with a transit facility. Passengers rely on signs to communicate route information, timing, location, and other basic characteristics of a transit facility. Bus stop signs should not be mounted on the same pole as a traffic control device.

Clear and distinct signage differentiates the stop area from other roadside information. A sign should indicate the agency's name and logo, bus route, and destination. Contact the transit agency for their specific sign standards. Parking prohibitions should be identified by pavement markings or by another sign (e.g., No Parking Bus Stop Sign, R7-107A, as found in Publication 236M, *Handbook of Approved Signs*). Bus stop signs should be double-sided for visibility from both directions, reflectorized or illuminated for nighttime visibility, and placed near where people board the front door of the bus. It is important that all bus stop locations (particularly near side bus stops) including the physical bus itself, and shelters, do not obscure lane use, yield/stop, and other necessary guidance signs from the view of other drivers.



Accessible signs are essential in creating an environment free of travel hazards to passengers with disabilities. Transit signs should be located where they are visually accessible to passengers. For patrons using wheelchairs, the bus stop signage should indicate where to access the vehicle wheelchair lift or ramp. It is also a visual queue for both the passenger and driver regarding the location of the safest B&A area.

All signs must comply with the requirements set forth in the MUTCD. Additionally, all sign content, including font and letter sizing, should be ADA-compliant.

15.7.2.f – Lighting

Lighting within the bus stop area (or from a nearby streetlight) enhances safety and visibility for both transit driver and passenger. It also provides a sense of security and helps define the waiting area. Bus stop signage (and shelter fixtures if present) can be illuminated. Wherever possible, energy-saving devices, such as efficient lamps, solar power, and daylight sensing equipment, should be used.

In addition:

- Where possible, local transit stops should be located within 30 feet of an overhead light source. A minimum distance of 15 feet is recommended between a shelter and light pole.
- Lighting fixtures should be oriented so that the bus stop infrastructure (such as the shelter or other amenities) does not cast shadows on the waiting area but allows the bus operator to see waiting patrons.
- Lighting scaled to the human body helps create pedestrian-friendly environments.
- Lighting fixtures of any height should minimize glare that could adversely affect drivers, while providing uniform illumination over the whole area. Uniform illumination also deters crime at bus stops.
- Glare on signs should be minimized to enhance their legibility.
- Illumination in places such as mid-block bus crossings, where significant vehicle and pedestrian interactions may occur, enhances the safety of bus patrons.
- In rural areas, proper lighting should also be considered to maximize the safety and security of bus stops. The designer should review conditions for lighting transit facilities on a location-specific basis. Where utility service is not readily available, solar powered illumination should be considered. When installing lighting, be cognizant of nearby land uses in both rural and urban areas.

15.7.2.g – Transit Shelters

Shelters provide important protection for waiting passengers. The shelter should be constructed of durable, architecturally sound materials to withstand heavy use and continuous exposure to the elements. The shelter should be oriented to protect against exposure to sun, rain, and snow. It should have a roof and provide a screen from prevailing winds. A clear view of the approaching bus and loading pad is necessary; for enclosed shelters, this can be accomplished by using tempered, clear glass panels. Films or clear view



materials can add design elements to the shelter exterior. Note: A Transit Shelter Agreement between PennDOT and the transit agency / owner to define installation and maintenance responsibilities will be required for shelters within PennDOT right-of-way. For shelters within municipal right-of-way, there may be special requirements for installation and maintenance.

The open side of the bus shelter should be placed toward the street and should be grade-separated from the travel lane. Shelters should be located upstream of the bus zone, so they do not interfere with B&A but maximize visibility for approaching buses, passing traffic, and waiting passengers. They should not be obstructive to pedestrian circulation and should be easily detectable to persons with visual impairments. The location of bus shelters should minimize walking distances for waiting passengers. Shelters should be located at least 5 feet from the front door of the bus along the direction of travel to provide adequate circulating space for people in wheelchairs, while not obstructing the 5-foot by 8-foot B&A area.

Other location considerations include:

- Proper horizontal clearance (i.e., distance away from the edge of the roadway) to shelters must be provided.
- When a shelter is located on the street side of a sidewalk, a minimum 4-foot pedestrian pathway shall be maintained on three sides of the shelter. In areas with high pedestrian volumes, a 6-foot sidewalk on one side of the shelter is preferred.
- Shelters should not be placed on the ADA-mandated B&A area.
- Shelters shall not be located within 15 feet of a fire hydrant or a disabled parking space.
- Shelters within the clear zone shall incorporate mechanisms to break away when impacted.

ADA standards require that shelters have provisions to accommodate older adults and people with disabilities. A shelter that is accessible to people in wheelchairs must have a minimum clear floor area that is 30 inches wide and 48 inches deep and entirely within the perimeter of the shelter. Shelter access entry and exit points shall provide a minimum clear width of three feet (with four feet recommended). The ADA-mandated B&A area can be extended into clear space within the shelter. However, no obstructions to the 5-foot by 8-foot area shall be allowed. If a bench is provided within a shelter, the 30-inch by 48-inch clear floor area should be located adjacent to the bench to allow wheelchair users shoulder-to-shoulder seating with a companion.

15.7.2.h – Bus Stop Benches

Transit users who have trouble walking and standing benefit from bus stop benches. Benches also provide comfort for waiting passengers, help identify a bus stop, and cost much less than installing a shelter. Benches are recommended when a shelter with seating is not provided and if bus headways (i.e., time between bus arrivals) are longer than 15 minutes.

Benches must not obstruct the full 5-foot by 8-foot B&A area or passenger access to loading and unloading areas. As a best practice, benches should be placed no closer than 5 feet and no

farther than 12 feet from the forward end of any bus stop. Benches should also be placed so that streetlights or other objects do not obscure the visibility of waiting passengers or oncoming buses. Bench placement should accommodate passengers' legs and feet without placing them too close to traffic.

ADA guidelines state that benches must be able to support 250 pounds of force applied at any point on the seat, fastener, mounting device, or supporting structure. The bench shall provide for back support or shall be affixed to a wall. All benches should be slip-resistant and designed to shed water. Benches should have a minimum length of 6.5 feet, or the equivalent of three seats. In interior locations, grab handles should be provided for those with difficulty standing up.

15.7.2.i – Bicycle Racks and Storage Shelters

Bicycle racks and storage shelters accommodate commuters who use bicycles to access transit but prefer not to use on-board bike racks. Supplying bicycle parking in a well-lighted, secure area will help to deter theft.



Where possible, bicycle racks should be kept underneath a covered area to protect the bicycles from exposure to the weather. Bicycle racks should be placed in areas without potential for water damage (such as adjacent to landscape watering systems or in areas where rainwater accumulates) but not in the B&A area. Bicycle racks should be placed so that bicycles stored in the racks will not overlap or block the B&A area. Additionally, they shall not be placed where they obstruct pedestrian traffic either on the sidewalk or to and from the bus stop B&A area.

The upper elements of a bicycle rack shall not protrude and potentially create an obstacle for a traveler with visual impairment in accordance with ADA standards. Bicycle rack locations must meet the setback and minimum clear recovery zone requirements.

The height of bicycle racks should not exceed 4 feet from the paved surface. Bicycle racks should provide 48-inch aisles, measured from the tip-to-tip of bicycle tires across the space between racks or between the tip of the tire and an adjacent obstacle. One person should be able to walk one bicycle through the aisle. A depth of 6 feet should be allowed for each row of parked bicycles. Depending on the size of the transit stop and projected bicycle usage, multiple bicycle racks can be installed to create a bicycle parking lot.

Overall, it is important to coordinate with cities regarding any current and potential Bike-Sharing programs to address specific design features that Bike-Share infrastructure may require. Chapter 14, *Bicycle Facilities*, provides details on the design of bikeways and bicycle facilities.

15.8 – Roadside Treatments at Stops

15.8.1 – Bus Bulbs/Bus Bulb Outs/Curb Extensions


(Source: NACTO)

A bus bulb (also known as a bus bulb out and curb extension) incorporates the extension of a sidewalk across a shoulder or parking lane to the edge of the first through-traffic lane, providing additional space for pedestrians to walk, and for transit patrons to wait for the bus. Bus bulbs may be located on the near side, far side, or both sides of an intersection. Buses stop in the moving traffic lane to pick up and discharge passengers. Bus bulbs provide additional space for waiting, boarding, and alighting passengers. They better segregate waiting bus passengers from pedestrians, reduce street crossing distances, and provide space for amenities such as shelters and bus benches. Bus bulbs can also accommodate more on-street parking than a conventional bus stop requiring additional space for bus transitions.

Because buses stop in the moving traffic lane to pick up and discharge passengers, bus bulbs tend to reduce delays associated with buses re-entering traffic. However, bus bulbs may cause cars to queue behind a stopped bus and embolden motorists to make dangerous maneuvers to avoid a stopped bus.

Bus bulbs may be appropriate in urban settings with high-density, mixed-use developments and crowded sidewalks, where the number of people moving along the street as pedestrians or as transit patrons is high and may exceed the number of people in personal vehicles. Bus bulbs may be suitable:

- Where parking is critical (and bus bay/bus pullouts may take up too much space).
- Where buses experience delays in re-entering the traffic lane.
- Where traffic calming is desired.
- On streets that are perceived to be pedestrian friendly.
- On the near side of signalized intersections.
- On streets with design speeds up to 40 mph.
- In low traffic-volume areas or on streets with diagonal or parallel parking.
- Where mid-block stops may be appropriate to serve transit demand generators.

Bus bulbs and curb extensions **should not be used**:

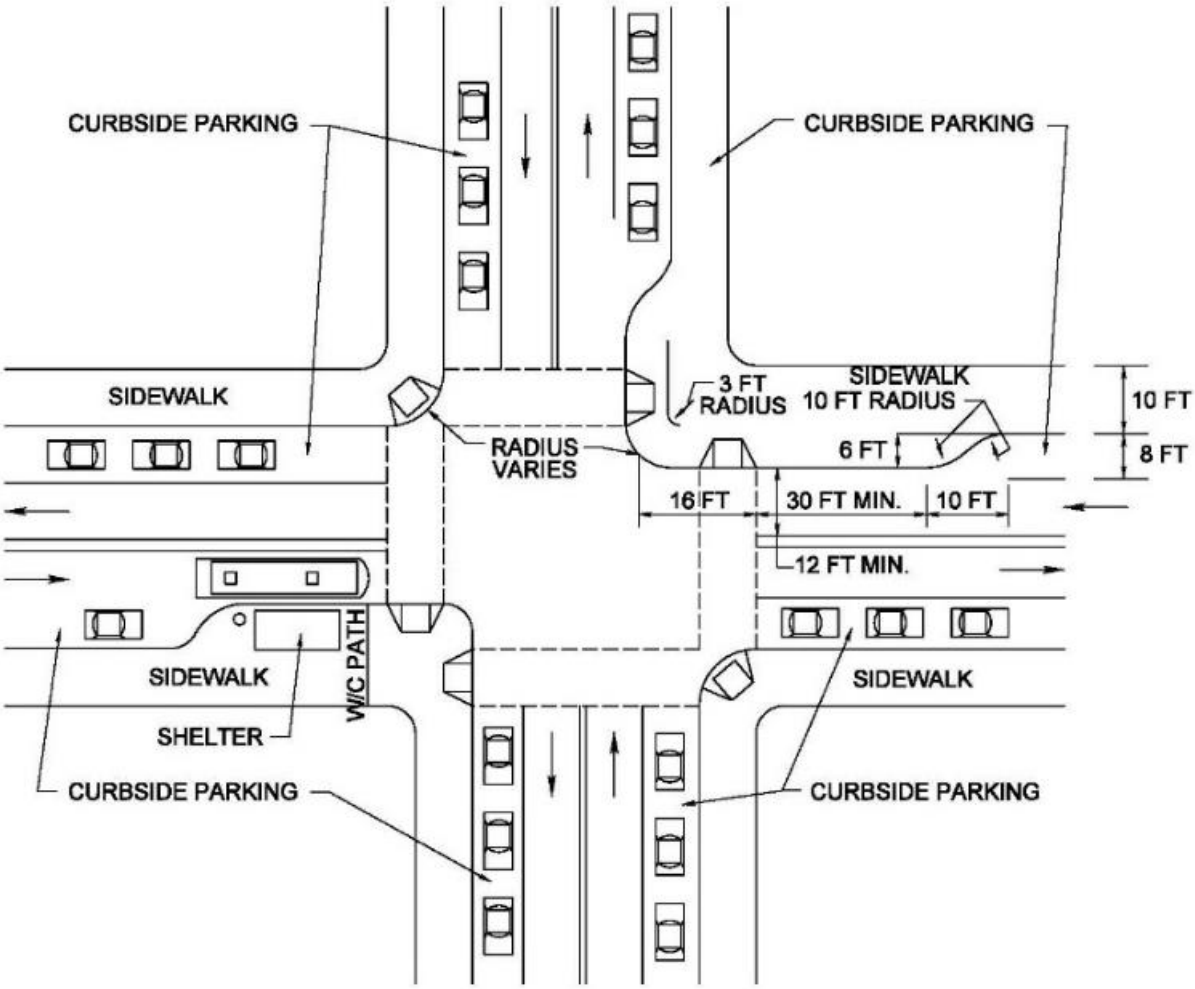
- On streets that have design speeds greater than 40 mph or high-volume facilities.
- Where the bus route requires the bus to make a right-turn unless the bulb precedes a right-turn lane.
- In transit corridors that serve a large wheelchair-dependent population.
- In areas have low transit ridership or pedestrian activity.
- On streets with high traffic volumes.
- On streets that do not have 24-hour on-street parking.
- On streets with high bicycle traffic.
- On sites with drainage problems, making boarding difficult for patrons.
- Where bus stops allow buses to lay over.

As illustrated in **Exhibit 15.8.1**, the bus bulb should be a minimum of 6 feet wide, leave a 2-foot offset between the bulb and the edge of the travel lane, and be long enough to allow for the simultaneous boarding of several buses as required. The AASHTO *Guide for Geometric Design of Transit Facilities on Highway Streets* offers additional information regarding specific dimensions for bus bulbs and curb extensions.

A near-side bus bulb design somewhat limits bus traffic signal priorities. Cars behind a stopped bus, however, are queued mid-block. The far-side bus bulb design permits bus traffic signal priority, and cars turning right can use the curb lane. Drainage patterns may need to be reworked to prevent water from ponding in the stop vicinity. Right-turn restrictions may be required because of the tighter curb radius associated with the treatment.

At intersections, bus bulbs should allow for bus turning movements and for buses to make curbside stops without weaving in and out of the travel lane.

Exhibit 15.8.1 Typical Bus Bulb Configuration



(Source: AASHTO, *Guide for Geometric Design of Transit Facilities on Highway Streets*, 2014)

15.8.2 – Bus Bays/Bus Pullouts

Bus bay/bus pullouts, also known simply as bus pullouts, improve safety for passenger B&A and provide a protected area away from moving traffic for stopped buses with long dwell times or for layovers. Bus bay/bus pullouts can be closed or open-ended, and positioned near-side, far-side, or mid-block in relation to an intersection. They also may incorporate queue bypass lanes.

A greater distance between waiting passengers and the travel lane increases safety at a stop. Bus bay/bus pullouts are encouraged on roadways with high operating speeds, such as roads that are part of an urban principal arterial system. For a particular bus stop, a high frequency of crashes involving buses is a good indicator of the need for a bus bay/bus pullout. They may also

be appropriate in downtown or shopping areas where many passengers may board and alight at the same time.

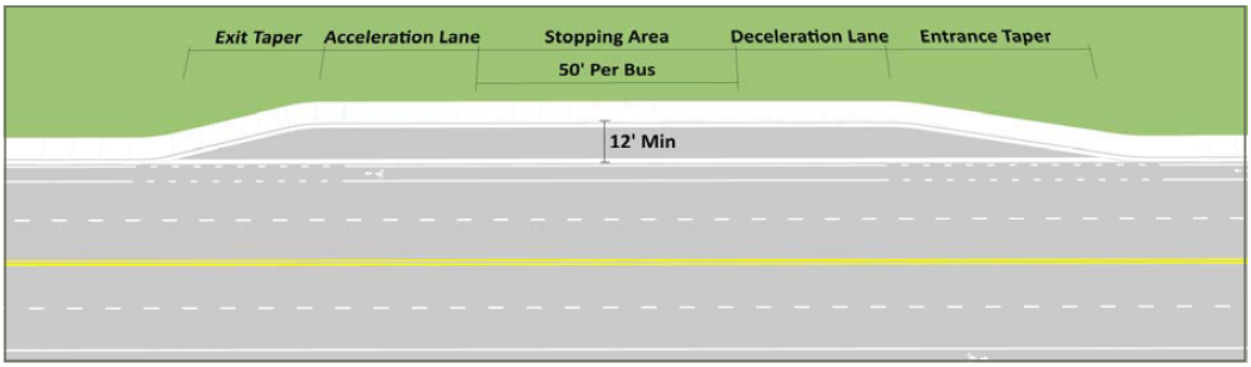
Bus bay/bus pullouts should be considered when right-of-way width is adequate to construct the bay without adversely affecting sidewalk pedestrian movement and when improvements such as widening are planned for a roadway (presenting an opportunity to include a bus bay/bus pullout in the construction). In addition, bus bay/bus pullouts should also be considered when:

- The curb lane is or will be used by moving traffic.
- Traffic in the curb lane comprises between 250 and 500 vehicles during the peak hour.
- Traffic speed is greater than 40 mph.
- Potential exists for vehicle/bus conflicts that warrant separation of transit and passenger vehicles.
- There is a history of repeated traffic and/or pedestrian crashes at the stop locations, particularly rear-end collisions with stopped buses.
- Sight distances prevent traffic from stopping safely behind a stopped bus.
- Buses use the right-turn lane as a queue jump lane.
- Appropriate bus signal priority treatment exists at the intersection.
- Bus volume is between 10 to 15 buses each way in the peak hour.
- Passenger volume exceeds 20 to 40 boardings per hour each way.
- Average peak period dwell time exceeds 10 to 30 seconds per bus, or the bus stop location is the layover at the end of the bus trip.
- Parking in the curb lane is or can be prohibited.
- Buses have extended layover times to accommodate transferring passengers.

Bus bay/bus pullouts may be appropriate at mid-block stops associated with destinations that are major transit trip generators. Bus bay/bus pullouts at far-side stops should be placed at signalized intersections so that the signal provides gaps in traffic that permit bus re-entry into the travel lane. Near-side bus bay/bus pullouts should be avoided because of conflicts with right-turning vehicles and delays and difficulties associated with bus re-entry into the travel lane.

Bus bay/bus pullout designs typically incorporate five elements: an entrance taper, a deceleration lane, a stopping area, an acceleration lane, and an exit taper. B&A areas at bus bay/bus pullouts shall comply with surface, dimension, connection, and slope requirements for an ADA-compliant B&A area. The design of bus bay/bus pullouts should aim to reduce automobile-bus conflicts, provide greater separation between traffic and pedestrians waiting for a bus, and allow a bus to quickly regain its travel speed upon its re-entry into traffic. **Exhibit 15.8.2** shows the elements and key measurements of a bus bay/bus pullout.

Exhibit 15.8.2 Typical Bus Bay/Bus Pullout Elements



(Source: Florida DOT, *Accessing Transit Design Handbook for Florida Bus Passenger Facilities*, 2017)

Exhibit 15.8.3 provides sample lengths for acceleration lanes, deceleration lanes, and entrance and exit tapers. The lengths are based on the through-speed of the adjacent travel lane and the speed of the bus entering the bus bay/bus pullout. Reduced bus bay lengths may be appropriate for some locations and design should be closely coordinated with the transit agency and the roadway owner.

In curbed locations, the bus bay/bus pullout pavement should slope into the roadway at a 2% cross-slope that directs run-off to a drainage structure located outside of the pullout area. In the absence of a curb, the bus bay/bus pullout pavement or B&A areas should be sloped away from the roadway (at a 2% cross-slope minimum or matching the adjoining roadway pavement slope) to direct run-off to roadway drainage structures.

Exhibit 15.8.3 – Bus Bay/Bus Pullout Element Lengths and Speeds

Through Speed (mph)	Enter Speed (mph)	Element Length					
		Entrance Taper (feet)	Decel. Lane (feet)	Stopping Area (feet)	Accel. Lane (feet)	Exit Taper (feet)	Total (feet)
<30	<20	5:1 min	None	50	None	3:1 max	130 min
35	25	170	165	50	250	170	805
40	30	190	265	50	400	190	1,095
45	35	210	360	50	700	210	1,530
50	40	230	470	50	975	230	1,955
55	45	250	595	50	1,400	250	2,545
60	50	270	735	50	1,900	270	3,225

(Source: AASHTO, *Guide for Geometric Design of Transit Facilities on Highway Streets*, 2014)

Both standard asphalt and concrete pavements are normally adequate to handle bus traffic, including bus bay/bus pullouts. For concrete pavements, it is important to provide adequate sub-grade drainage, thickness, and joint details.

Signing/pavement markings near bus bay/bus pullouts shall differentiate bus bay/bus pullouts from travel lanes. Generally, a broken 6-inch white stripe, 2-foot dash, 4-foot skip should be used in areas where buses will be entering and leaving the bus bay/bus pullout (i.e., acceleration and deceleration lanes). A solid 6-inch white stripe should be used between dashed areas to delineate the travel lane for through vehicles.

Drainage inlets should not be placed in a bus bay/bus pullout, except at the exterior edge when drainage restrictions are severe.

15.8.2.a – Closed Bus Bay/Bus Pullout

A closed bus bay/bus pullout comprises a physical entrance taper, a stopping area, and a physical exit taper. Acceleration and deceleration can also be a component for through speeds over 30 mph. Closed bus bay/bus pullouts are usually located at far-side bus stops at signalized intersections. The signal creates breaks in the flow of traffic to permit bus operators to re-enter the travel lane. Closed bus bay/bus pullouts are also provided at mid-block bus stops near major transit destinations with high passenger activity and longer-than-average dwell time.

Exhibit 15.8.4 Closed Bus Bay/Bus Pullout



(Source: Florida DOT, *Accessing Transit Design Handbook for Florida Bus Passenger Facilities,*

Near-side bus bay/bus pullouts are generally not recommended because of conflicts with vehicles approaching the intersection in a curb lane to make a right turn. **Exhibit 15.8.4** provides an example of a closed bus bay/bus pullout.

15.8.2.b – Open Bus Bay/Bus Pullout

An open bus bay/bus pullout does not have a physical entrance taper and is open to the upstream intersection. This type of bus bay/bus pullout is recommended for far-side applications at signalized intersections, as the signal creates breaks in the flow of traffic to permit bus operators to re-enter the travel lane. Open bus bay/bus pullouts are not recommended on facilities of six or more lanes. In near-side applications, an open bus bay/bus pullout at an intersection may be used by right-turning traffic

Exhibit 15.8.5 Open Bus Bay/Bus Pullout



(Source: Florida DOT, *Accessing Transit Design Handbook for Florida Bus Passenger Facilities,* 2017)

but can be effectively used as part of a queue jump bus bay/bus pullout.

The typical size of an open bus bay/bus pullout for a 40-foot bus with a design speed of 40 miles per hour consists of a 50-foot stop area for one bus and a 400-foot acceleration lane. (Exhibit 15.8.3 defines element dimensions and design speed for bus bay/bus pullouts.) **Exhibit 15.8.5** presents an example of an open bus bay/bus pullout.

15.9 – Traffic Signal Control/Signal Priority

Transit Signal Priority (TSP) is an operational strategy that facilitates the movement of transit vehicles through signalized intersections. It typically gives vehicles an extended green or reduced red at signalized intersections under certain pre-defined conditions (e.g., late-arriving buses only). This allows for more reliable travel times and improved schedule adherence. TSP deployments across the country generally demonstrate a decrease in average bus travel times of between 2% and 20% (depending on existing signal delay) with minor impacts on cross-street traffic.

Granting priority treatment to buses at signalized intersections can contribute significantly to operating buses in a fast, reliable manner on arterial streets. TSP can be implemented as a standalone initiative or as an integral part of a bus rapid transit scheme for the corridor signal priority.

With TSP, a bus is automatically detected on its approach to a signalized intersection and the signal timing and phasing is adjusted to provide the bus with clear passage through the intersection. This may save the bus one minute or more of waiting time at a red light. When transit priority is implemented along a lengthy corridor, the cumulative travel-time savings can be significant, and even more so when considered on a per-passenger basis.

The most basic and widely used TSP strategies include passive and active priority. Passive strategies provide some level of transit priority using pre-timed modifications to the signal system that occur whether or not a bus is present. Applications could range from just one signal to an entire signal system in a corridor. Active strategies adjust the signal timing once a transit vehicle is detected approaching an intersection.

Most traffic signals in Pennsylvania are owned and maintained by municipalities. PennDOT reviews and approves traffic signal permit plans. Therefore, implementation of any TSP measure requires close coordination between the public transit agency, one or more municipalities along a bus route, and PennDOT.

15.9.1 – Passive Transit Signal Priority

In passive TSP, traffic control devices are adjusted to suit the bus schedule along the route, generally using a combination of fixed-time and schedule-based control strategies. Passive priority is usually implemented only on roads with significant transit usage, often close to the bus

origin point where schedules are most likely to be adhered to. Passive priority costs less but offers limited potential to improve bus operations.

Passive improvements may also include strategies such as adjusting signal-timing plans, reducing cycle length, or coordinating signals on a corridor. Timing the intersection to minimize person delay as opposed to vehicle delay (signal timings typically minimize vehicle delay) is considered a passive transit signal priority strategy. Passive signal priority can benefit transit service, requires no equipment, and operates regardless of the presence or absence of a transit vehicle.

15.9.2 – Active Transit Signal Priority

An active transit signal priority system detects buses on approach to an intersection, then changes the traffic signals. For example, a green extension strategy can extend the green light at an intersection as a bus approaches so that there is no wait at the intersection. Similarly, a red truncation strategy can shorten a red light to reduce the wait. An active transit signal priority system is usually installed at specific points along the corridor with signalized intersections.

Active signal priority can take several forms:

- **Early Green** – When a bus is detected approaching on a red signal phase, the cross street's green phase is truncated.
- **Extend Green Phase** – When the bus is approaching on a green signal phase, the phase extends until the bus passes through.
- **Special Bus Phase** – This strategy includes introducing a transit-only signal or adding a signal phase into an intersection. This typically involves provision of one or more of the following features at intersections:
    - Special Left-Turn – Provision of a special left-turn signal at a desired location to allow transit vehicles to make left turns onto a cross street.
    - Special Right "Bus-Only or Turn" – When a bus is on the far-right lane at the intersection, a bus-only or turn phase allows the bus to move while other vehicles are stopped.
    - Re-Order Phases to Favor Bus Route – A shift, for example, of a lagging left-turn phase to a leading left to accommodate a waiting or approaching bus.

15.9.3 – Queue Jump

A queue jump is a strategy that allows transit vehicles to bypass general traffic at an intersection through a relatively short lane. The transit vehicle enters into a right- or left-turn lane (the right lane being most common) or an exclusive transit lane developed on the intersection approach. The lane must be sufficiently long to allow transit vehicles to effectively access the lane without blockage if there is an adjoining through-traffic queue.

See Section 15.9.3.b for factors to consider for queue jumps.

Instead of a turn lane, an exclusive bus lane (i.e., bus bypass) located between the through-lane and the right-turn lane should be considered when right turn volumes exceed 400 vehicles per hour in the curb lane during the peak hour, and/or when the right-turn movement operates on a phase with non-conflicting cross-street movements.

15.9.3.a – Queue Jump with Turn Lane/Transit Signal Priority

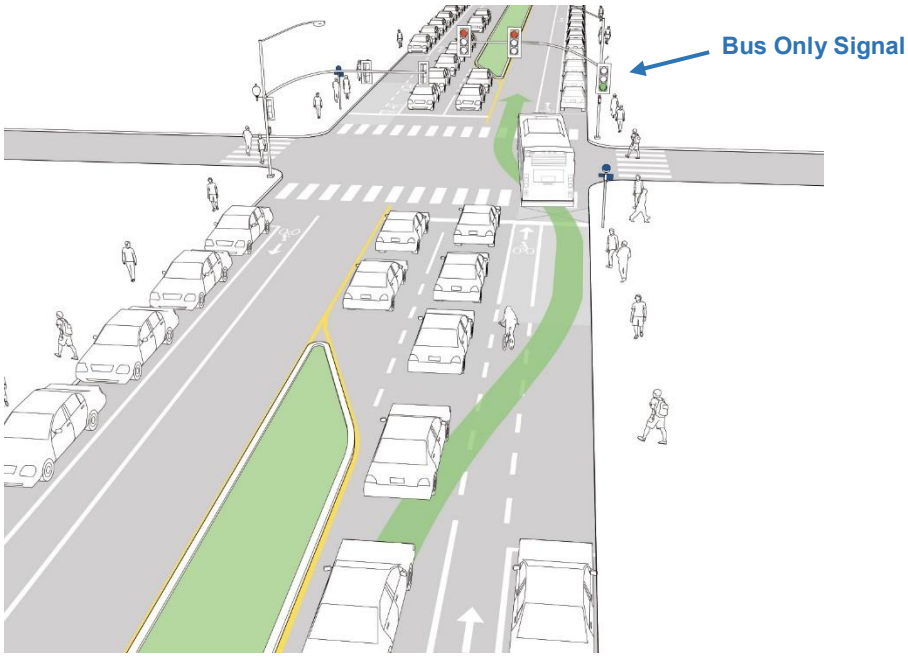
This queue jump treatment provides a separate, short-signal phase to allow the transit vehicle an early green indication to move into the through-lane or bus loading area on the far side of the intersection, ahead of through traffic. Typically, green time from the parallel general traffic movement is reduced to accommodate the special bus signal phase, but usually in the range of only three to four seconds. If there were an optional transit stop at an intersection, it typically would be located near-side.

At near-side stops located at the curb lane with a “Right Turn – Except Bus” sign, passenger B&A could occur during a red signal. In this situation, a signal priority call is sent to the controller to activate the special signal phase immediately after the closure of vehicle doors. Based on AASHTO’s *Geometric Design Guide for Transit Facilities on Highways and Streets*, the length of the extended lane should be sufficient to exceed the traffic queue but not less than 240 feet.

15.9.3.b – Queue Jump with Turn Lane/Open Bus Bay/Bus Pullout

This application requires an open bus bay/bus pullout on the far side of a signalized intersection. The length of an extended lane in a queue jump bus bay/bus pullout should be sufficient to exceed the traffic queue, but not less than 240 feet. **Exhibit 15.9.1** presents an example of a queue jump open bus bay/bus pullout at an intersection with transit signal priority. This type of bay is most effective with signal prioritization that allows buses to bypass traffic congestion by moving ahead of other vehicles through the intersection. It provides additional benefits by removing stopped buses from the traffic stream and guiding them through congested intersections. It is most suitable for high-frequency bus service routes on streets with traffic volumes of 250 vehicles per peak-period hour or level of service "D" or worse.

Exhibit 15.9.1 – Queue Jump



(Source: NACTO, *Transit Street Design Guide,* 2016)

A separate signal must be used to indicate when transit proceeds and when general traffic proceeds. Transit signals can be either a transit specific signal head or a louvered/ visibility-limited green indication, making it visible only to the right-most lane. Examples of signing to consider includes "BUS SIGNAL" or "TRANSIT SIGNAL" placard for the exclusive signal and "RIGHT LANE BUSES ONLY" for the open bus bay/bus pullout.

If provided as a shared right-turn/queue jump, a protected right-turn signal may be used, with a sign indicating "RIGHT TURN SIGNAL" (MUTCD R10-10R) and EXCEPT BUSES placard below.

If signal priority is not provided, a transit vehicle could still use a right-turn lane or right-side separate lane to bypass a general traffic queue, then proceed under the normal through-signal phase into a far-side bus bay/bus pullout. However, bus stop placement at turn lanes should be carried out only after careful consideration of all related aspects to ensure the safety of transit riders, buses, and motorists.

15.10 – Park-and-Ride Facilities

Park-and-ride lots provide parking for people who wish to transfer from private vehicles, bicycles, and other modes to public transit or carpools. Transit agencies serve most park-and-ride lots located within urban areas. Leased lots, such as at churches or shopping centers, or park-and-rides in rural locations may have no bus service and only serve carpools.

The need for and location of park-and-rides are determined through planning processes typically conducted by transit agencies and/or RPOs and MPOs. Once the need is identified, project leads should be identified. Early and continual coordination between the project leads and other stakeholders, authorities, and agencies is critical.

Park-and-rides should include:

- Passenger waiting and loading areas.
- All the amenities planned for the on-street stations.
- Parallel stops or saw-toothed bus bay/bus pullouts or islands.
- Design for circulation of articulated buses.
- A bus turnaround (in some locations).

Any required bus layover areas should be located on the inbound roadway to the passenger loading area, with a minimum layover area to accommodate two buses. Storage capacity is determined by the service plan developed for the lot.

The bus loading area should be separated from roadways used by other vehicles. This area is ideally accessed directly from the street and should be consistent with the capacity requirements of the service plan.

Local transit access should allow for efficient transit operations. It may be desirable to provide a transit loop or drive-through area within the park-and-ride facility, with space provided for transit layover. Park-and-ride activities (e.g., kiss-and-ride drop offs) should not impede pedestrian passengers or interfere with the visibility between the transit loading zone in the parking lot or impede bus operations.

Chapter 19, *Parking Facilities*, provides details on the design of park-and-ride lots.

15.11 – Advanced Technology, Transit and Multi-modal Coordination

New technologies are rapidly progressing with the aim of improving overall traveler movements through improved coordination of all transportation modes and facilities, especially within transit. Such technologies include but are not limited to:

- Electronic monitoring and data transfer devices within Park-N-Ride Lots to determine parking availability.

- Electronic messaging (e.g., DMS's) along roadways or at transit facilities to inform all transportation users of full parking lot conditions.
- Revised bus route conditions, options to change travel schedules or routes in real time.
- Third-party apps developed and incorporated by many transit agencies.

While these new technologies may fall under the Transit Agency's jurisdiction, the new technologies may influence traditional transit locations and features. With these changing technologies, Department and transit agencies coordination during design is critical.

Chapter 16 – Freight Facilities

In this chapter there are references to future chapters 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 16 – Freight

16.0 – Introduction



The efficient movement of goods is an essential transportation component for the economic vitality of the Commonwealth. Pennsylvania is geographically located within 500 miles of 40% of the nation's population and serves as the transportation gateway of freight movement to major population centers in the Northeast. As a national transportation hub, Pennsylvania needs to accommodate a large volume of bulk and containerized freight traveling within and through the state by truck, rail, and ship as well as a proliferation of warehouses, distribution centers, rail to truck intermodal transfer facilities and international port facilities that help serve the nation's freight supply chain. Freight movement by truck has a direct impact on infrastructure, road conditions, traffic congestion, and the safety and security of the transportation network. However, heavy vehicles that require accommodation are not only freight carriers using tractor trailers (WB-67 design vehicles) moving between ports and regional distribution centers; they are more commonly smaller delivery single unit trucks (SU-30 and SU-40 design vehicles) such as box delivery vehicles, resource, service, and emergency vehicles.

It is important to account for the many characteristics of freight movement when designing new roadways or making improvements to existing roadways. Characteristics range from, but are not limited to:

- Vehicle size and weight impacting mobility (longer vehicle start/stop times)
- Roadway dimensions -wider lanes, increased sight distance and stopping needs, reduced clearances to highway hardware, and turning radius which may conflict with passenger vehicles, bicycles, and pedestrians
- Tracking of wheels onto shoulders requiring full-depth pavement structure in shoulders
- Accommodating 'permitted' and enforcement of 'non-permitted' oversize/overweight vehicles
- Providing refuge (parking/rest) for freight drivers

This chapter provides guidance and considerations on the incorporation of freight movement into various roadway design elements, balancing these needs with those of motorists, pedestrians, transit, and bicyclists. Consideration of freight movement early in project planning, will help to better manage current and future transportation impacts associated with the increasing volume of goods movement in Pennsylvania. The designer should ask these important context questions:

- What is the volume and type of freight movement within the project region? Will future development (e.g., warehouse or distribution centers) cause an increase in truck volumes in the near future?
- How does freight movement affect local and regional roadway congestion?
- What design features can be used to provide a safer interaction between trucks, other vehicles, and pedestrians?
- What are some considerations for improving last-mile (i.e., where the last step of the delivery process where package finally arrives at the buyer's door) local freight movement?
- What resources are available to help in designing facilities for expected higher freight volume?

Key design components include:

- **Know Your Business Community.** It's important to understand the needs of the businesses in the area of the transportation project, and to design the roadway to accommodate the most common vehicle. When intersections are too small (very tight turning radii), some large trucks may go up on curbs and sidewalks when making turns, which poses a danger to pedestrians and contributes to traffic congestion. On the other hand, designing intersections for only the occasional very large truck means that pedestrians have a much wider roadway to cross. In addition to the exposure of the vulnerable pedestrian over a longer crossing distance, the longer pedestrian crossing distance also significantly impacts traffic signal operation to provide the necessary clearance time. Know your business community and design appropriately to accommodate the needs of all types of transportation.
- **Look for Controlled Access Opportunities.** Access management has numerous benefits in terms of reducing traffic congestion, in addition to improving safety and overall livability. Consider designated access areas for freight deliveries. Carriers appreciate the designations and other motorists appreciate the higher levels of overall mobility that they generally experience when freight access is limited to certain areas. However, some types of access management may limit the mobility and add to the travel time of pedestrians, bicyclists, and transit users.
- **Consider Compatibility of Modes.** The interaction of freight with other travel modes, both motorized and non-motorized, presents challenges for all users. Freight vehicles, with their unique operational characteristics, require different design considerations for sight distance, turning radii, and other aspects that are not well-matched with pedestrians, cyclists, or transit vehicles. If freight volumes are significant, the designer needs to fully evaluate these multimodal interactions.

- **Look for Designated Freight Routes.** In highly congested areas, a designated freight route or truck route may be identified.

  These freight routes may move many slow-moving trucks off other road corridors to free up their roadway capacity and potentially improve their conditions for other motorists, pedestrians, and bicyclists. Freight routes may also provide for better freight access, which may help bolster business success. However, even with a designated freight route, trucks are typically not prohibited from most other public roads.



  Refer to the following resources to help identify freight routes:

  - Publication 46, *Traffic Engineering Manual*, Chapter 2, *Signing,* under "*2.6 Guide Signs and Road Markers / Numbered Traffic Routes / Types of Traffic Routes*", provides a definition of numbered truck routes (as seen in photo above).
  - Freight routes on the National Highway Freight Network are identified on the FHWA website listed in Section 16.0.1.
  - A list of critical urban freight corridors and critical rural freight corridors are included in the Publication 833, *2045 - Pennsylvania Freight Movement Plan*.
  - Title 23, Chapter I, Subchapter G, Part 658 - *Truck Size and Weight, Route Designations*, Appendix A provides the National Network of federally designated routes.
  - *National Highway Freight Network Map and Tables for Pennsylvania* provides a breakdown of the national highway freight network routes into primary highway freight system routes (PHFS), PHFS intermodal connectors (also identified as NHS Intermodal Connectors), and portions interstates not yet on the PHFS.

16.0.1 – Resources and References

- Code of Fedral Regulations, Title 23, Chapter I, Subchapter G, Part 658*, Truck Size and Weight, Route Designations - Length, Width and Weight Limitations.* https://www.ecfr.gov/current/title-23/part-658
- FHWA, *National Highway Freight Network Map and Tables for Pennsylvania*. https://ops.fhwa.dot.gov/freight/infrastructure/ismt/state_maps/states/pennsylvania.htm
- FHWA, *National Network for Conventional Combination Trucks,* 2009 Map*.* https://ops.fhwa.dot.gov/freight/infrastructure/national_network.htm.
- PennDOT, *PA-511.* https://www.511pa.com
- FHWA, *Pennsylvania – FHWA Freight Management and Operations*. https://ops.fhwa.dot.gov/freight/freight_analysis/state_info/pennsylvania/pa.htm
- PennDOT, *Pennsylvania Railroad Map*, 2022. https://gis.penndot.gov/BPR_PDF_FILES/MAPS/Statewide/parail.pdf
- PennDOT, Posted and Bonded Web Viewer. https://pennshare.maps.arcgis.com/apps/webappviewer/index.html?id=5fcd857b5874471f8cda56337566861f
- PennDOT, Publication 46, *Traffic Engineering Manual*.
- PennDOT, Publication 833, *Pennsylvania - 2045 Freight Movement Plan*, (scheduled to be published in September 2022).
- PennDOT, *Rail Freight & Ports – Planning*. https://www.penndot.pa.gov/Doing-Business/RailFreightAndPorts/Planning/Pages/default.aspx

16.1 – Freight Modes

The movement of freight throughout Pennsylvania is facilitated by a variety of transportation modes. The expansion of the Panama Canal allows larger container ships to travel directly to east coast ports thus avoiding the congestion at west coast ports. This redirection of ships contributes significantly to the growing volume of waterborne freight for distribution to Pennsylvanian's and its surrounding states. Over the last few decades, the rail network has played an increasing role in transporting bulk freight throughout the country having been expanded to accommodate double stacked shipping containers. This has helped reduce the number of trucks that would otherwise travel on highways. However, as a freight hub to major U.S. markets, Pennsylvania's highway network often suffers due to the increased truck traffic accessing the many truck-rail intermodal facilities, warehouses, and distribution centers. Just-in-time delivery has also increased the volume of air freight flowing out of our airport facilities. Consumer convenience afforded by next day package delivery together with large, localized volumes of last-mile truck deliveries can impact roadway conditions and lead to higher congestion and reduced level of service largely within urban and suburban areas. To address these issues, it is important to consider truck-friendly design solutions that may be appropriate to improve the function of the regional freight network, enhance multimodal features in certain corridors, and be compatible with existing and future local land use patterns.









16.2 – Freight Activity Generators

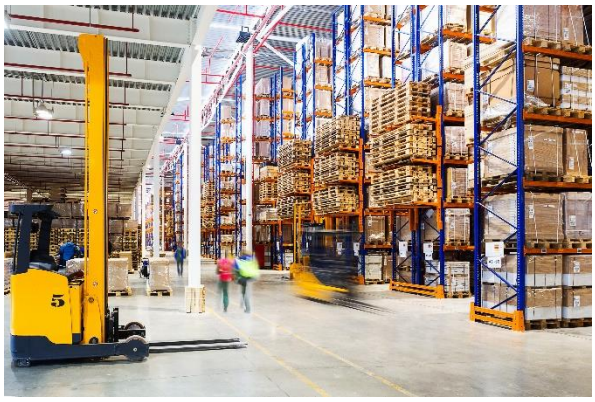
Whether designing new transportation projects or improvements to existing infrastructure, identifying local freight facilities that generate significant freight activity will help to effectively accommodate truck movements in conjunction with the needs of other roadway users' mobility. Truck volumes and peak periods of movement, as well as local travel patterns and the types of roadways used to and from the freight generator facility, are principal factors to consider.

Freight generators can include any of the following facility types:

Intermodal transfer facilities (truck-rail-port). These facilities provide an intermodal junction point for cargo containers to transfer between shipping modes, including container ships, rail freight carriers, and tractor trailers. These facilities also offer opportunities for container storage and allow for flexibility in delivery method. A major measure of these facilities is the efficiency with which they can distribute their containers to the surrounding transportation network and can be limited by the roadway network they are sending trucks out for deliveries.



Distribution warehousing. These facilities are primarily serviced by truck carriers and provide the transition point between shippers and the final retail locations. Often, these warehouse and storage facilities are large parcel facilities with multiple access points and significant employee bases. These facilities can also have differing regional levels of coverage, with some larger warehouses serving as the final distribution point before store delivery. There is also an increase in direct residential delivery in lieu of supplying retail stores. The truck volumes from these warehouses and home deliveries can have significant impact on the adjacent interchanges, arterials, and local roadways.



Industrial/Manufacturing. Industrial and manufacturing facilities can range in size from small, specialized facilities to sprawling major chemical, auto production, or other facilities spanning miles in length. These facilities are often served by multiple modes (rail, water, and truck). The number of vehicles servicing these facilities, both from a freight and private vehicle standpoint, can create significant congestion impacts on the surrounding network.





Commercial business. Commercial business facilities can include anything from the corner shop in an urbanized area to major 'big-box' retail centers in more suburban areas. For 'big-box' developments, tractor trailers arriving from distribution centers can make up a fair amount of the vehicle mix. Access points to the facility need to accommodate the larger turning templates of these vehicles and may exacerbate any congestion issues that arise from these major shopping centers.

16.3 – Truck Design Vehicles, Volumes and Oversize and Overweight Vehicles

16.3.1 – Truck Design Vehicles

Trucks come in a variety of sizes. These sizes and overall dimensions are dictated by the goods or materials being transported.

When designing a roadway with a freight component, among the most critical items is the appropriate Design Vehicle. This vehicle will serve as a major factor in determination of key design elements, such as lane widths, intersection radii, and vertical grades.

The selection of a Design Vehicle to determine intersection turning movement design will vary depending on the roadway context. Typically, the largest design vehicle anticipated to use the facility with considerable frequency is the vehicle to use to design pavement features and specific intersection turn movements. Projects in areas with higher truck volumes should consider larger turning radii and a stronger pavement design to accommodate more efficient and safer truck traffic flow.

Refer to Chapter 2, Section 2.3, *Design Vehicles and Control Vehicle Selection,* for more information.

16.3.2 – Truck Volume

When designing a facility, an accurate estimation of the vehicle and classification distribution that will be using the facility is required. A breakdown of the land type is also important in determining how much truck volume will be in the region. Truck volumes are preferred to using truck percentages when designing for an area. The volume-based count is a better representation of the number of times a truck uses the facility daily.

Trucks generally use higher classification roadways, but often must get to and from delivery origins/destinations along lower classification roadways. It is possible an identified truck route, such as a Critical Urban or Rural Freight Corridor is carried by a road classified as 'Local'.

Consider wider lanes and larger curb radii than local road criteria might dictate in these instances.

Fire trucks, garbage trucks, school buses, and snowplows frequently use lower classification roadways such as a roadway classified as 'Local'. As with truck freight, consider larger curb radii, and possibly wider lanes

Refer to Chapter 2, *Design Controls,* for more information on truck volume considerations.

16.3.3 – Oversized and Overweight Vehicles

On some routes, oversized and overweight vehicles are common users of the facility and where identified, should be considered as part of the design. These vehicles present unique operational characteristics, as well as impacts on facility maintenance and wearing.

511PA identifies bridges with a low vertical clearance restriction on a state route, potentially impeding legal height vehicles (flagged as a "Low Bridge" on the map). However, the map only shows low bridges over state routes and not over PA Turnpike roadways or locally owned roadways. PennDOT's APRAS system is used to route over-height vehicles. Operation of oversize and overweight vehicles on state highways is subject to PennDOT's permitting process.

Both vehicle height and weight considerations should be inputs into the roadway design. For routes that both serve significant freight volumes and feature overhead restrictions, advance signage should warn of the height restriction and direct overheight vehicles away from the obstruction. When considering a design or retrofit of the facility, removal or mitigation of the vertical obstruction should be considered, if feasible. Where a significant volume of overwidth vehicles may exist, minimums for lane and shoulder widths should be avoided to allow for additional operational width for wider vehicles. The use of curb in these areas may also be discouraged.

For overweight vehicles, pavement structure is a critical aspect of the design. Overweight vehicles can have significant impacts on long-term pavement performance, even in fairly small numbers. In areas where industrial or shipping operations could potentially result in significant numbers of overweight vehicles using the facility, an 'overdesign' of the pavement structure may be appropriate to minimize the need for repetitive maintenance and/or full depth pavement rehabilitation. Full depth shoulders, particularly in areas where roadway geometry may encourage tracking off the roadway, should also be included where overweight vehicles are present.

On many occasions non-permitted oversize/overweight vehicles have been caught illegally travelling Pennsylvania's roadways. Designers should refer to PennDOT's Posted and Bonded Web Viewer to find information on the posted roadways and their weight limits. Designers, when designing interstate reconstruction projects in particular, should consider opportunities to incorporate roadway features that assist the Pennsylvania's Truck Size and Weight Enforcement Program. These may include permanent Weigh-in-Motion scale stations

constructed along highway mainlines or within roadside rest areas. Or adequate pull-off areas might be considered for law enforcement to perform portable weight measurements and enforcement. Designers should consult with the PennDOT's Highway Safety and Traffic Operations Division, Special Hauling Permits Unit (with participation of Pennsylvania State Police Commercial Vehicle Safety Division) to determine if opportunities exist within the planned highway improvement project for new or expanded Size and Weight (S/W) Enforcement features. Features may include wider shoulders at opportunistic highway locations (i.e., widen shoulders in a short section to provide truck parking) with S/W infraction history, or S/W enforcement facilities within parking or rest areas. Refer to Chapter 19, *Parking Facilities*, and Chapter 24, *Rest Areas and Welcome Centers*, for more information.

16.4 – Freight Activity

Framing freight transportation characteristics within specific land use contexts can help define more appropriate design considerations for a transportation project. Knowing the type of freight activity typically found in a particular land use area can often refine the scope of potential freight movement improvements.

16.4.1 – Coordination with Project Context

The project context informs many elements of design intent regarding the balance between goods movement and livability. As part of the project development process, any roadway project that includes consideration of freight should consider the impacts of freight traffic in conjunction with land use planning, at the local, regional, and statewide levels. Certain types of freight transport are either more or less compatible with certain land use types than others. An effective design will incorporate local agency goals for land use planning, while also permitting the appropriate freight vehicle the ability to access critical locations (retail, distribution centers, key roadway junctions) without creating excessive congestion or safety concerns.

It is important to know the business community and understand their needs related to accommodating expected freight vehicles. When intersections are under designed relative to common freight vehicles, safety and maintenance concerns may arise i.e., larger vehicles jumping curbs and sidewalks when making turns, or excessive pavement wear, etc. On the other hand, intersection design that caters to unnecessarily large vehicles may result in overdesign which encourages excessive speed or does not effectively accommodate non-motorized users. Through a public involvement process, communicate with the impacted business community and design appropriately based on common design vehicles and appropriate design frequency.

With the rising demand for Economic Development, aging infrastructure, Active Transportation, increasing safety and decreasing congestion, it is of upmost importance communities prioritize and balance land use with Economic Development. Deviating from the Pennsylvania Municipal Planning Code may negatively impact Active Transportation, Long Range Transportation Plans,

safety and congestion, and the need for additional infrastructure improvements post construction.

16.4.2 – Low Freight Activity Areas

Typically, low freight activity areas are characterized by having lower populations that are widely dispersed among rural regions sporadically interspersed with higher density towns/boroughs. The roads have generally lower volumes and are identified by local/collector classifications. However, certain areas can have more localized freight activity due to isolated industrial facilities, large warehouses, large agricultural related facilities, mining, or utility facilities. An example is the drilling or 'fracking' sites that require large amounts of heavy vehicle activity on local roadways and/or gravel roads not currently designed for heavy truck traffic. Another example could be that transload facilities e.g., truck/rail bulk transfer centers are often located in rural areas and should be considered during network improvements.

Guidance

- Be conservative in ESAL estimation to ensure pavement integrity.
- Analyze the operation of the selected design vehicle (turn analyses, loading ratings, etc.) to confirm the ability of the vehicle to navigate through design features.
- Evaluate the feasibility of turnouts and climbing lanes to remove potential heavy vehicle constraints.
- Look to accommodate truck volumes, as opposed to design for.

Existing roadway geometry, i.e., roadway width, turning radii, etc., and substandard pavement can present issues that may require specific design considerations in areas with known or anticipated higher freight activity. Some of these areas may also feature interstates or other major roadways with a significant volume of heavy vehicle/freight traffic.



16.4.3 – Mixed Freight/Community Activity Areas

Guidance

- Confirm design vehicles can navigate key intersections with minimal encroachment, while not unnecessarily widening pedestrian crossings.
- Confirm visibility of traffic signals at locations with significant heavy vehicle volumes (are signals obscured if queued behind tractor trailers?) and consider longer start-up times and coordination if accommodating high volumes of heavy vehicles.
- Consider the different sight distance concerns (higher eye height, differing mirror positions) and operational characteristics (slower acceleration and deceleration) of heavy vehicles in interactions with pedestrians and cyclists.
- Confirm design vehicles can navigate key intersections and ramp junctions efficiently and with minimal reductions in speed.
- Consider the resulting capacity reductions that heavy vehicles exert on a facility when planning and designing a facility.
- In areas where freight generators or retail facilities may be present, look to design for freight
- In more residential areas, look to accommodate for freight



(Source: Google Earth Imagery)

Freight movement in denser land use areas can be made up of service and delivery vehicles such as mail, packaged goods, and home furnishings, as well as larger tractor trailer vehicles servicing retail and distribution facilities. Collector/distributor roads serve mostly residential neighborhoods and developments with a greater interaction of pedestrian and bicycle modes. Significant arterial roadways can serve as major conduits for freight traffic, particularly if adjacent to or serving as an alternative to interstates, freeways, and expressways. These land use areas typically have narrower streets, tighter turning radii, and multiple access points. They may also be adjacent to larger shopping centers and other commercial/business districts. Although lower truck volumes are typical, suburban roads need to consider design features that are adequate for fire trucks, school buses, delivery trucks, and the occasional large tractor trailers that may need to navigate the local road network.

Areas with mixed freight activity typically comprise more densely populated urban and suburban settings that include commercial downtown districts with a mixture of business, office buildings, commercial,

manufacturing, and industrial facilities. These areas typically present the most conflicts between freight mobility and community livability. Freight movement can vary from large trucks to delivery vans with higher volumes on collector and arterial roadways. Land use context can vary from high density commercial/business and residential building units to more suburban shopping center and single-family units. Potential transportation design issues generally encompass traffic congestion, roadway width and condition, loading/unloading zones, intersection control, turning radii, utilities, driveway access, excessive idling, and conflicts with pedestrian and bicycle travel.

Concerns will vary between urban and suburban business owners. Suburban businesses (including big box retailers), often with large off-street parking lots and high-volume driveways, will be concerned with adequate access to/from their retail locations and distribution centers. Intersections which do not accommodate or design for tractor trailer traffic or congestion bottlenecks will interfere with a timely delivery of goods. Urban retailers will have differing issues. Curbside management is one. Many local jurisdictions designate curbside truck parking and loading zones. The purpose of truck parking and loading zones is to provide adequate space for trucks to load and unload their goods and prevent illegal and double parking by trucks. Cities provide guidelines for locating parking and loading zones and often allow businesses to apply to establish a new parking and loading zone. Cities can also regulate the type of truck and length of time that trucks can park in a parking or loading zone and establish fines for violations. The designer should contact the local municipality to identify parking, loading zone, and vehicle size regulations at the outset of the project.

Refer to Chapter 19, *Parking Facilities,* for more information on parking coordination with municipality.

16.4.4 – High Freight Activity Areas & Freight Corridors

Guidance

- Freight corridors should be designed to provide for truck mobility, access, and circulation.
- Freight corridors require adequate lane width to allow travel without encroaching on an adjacent lane.
- Refer to Chapter 3, *New Construction and Reconstruction,* for required vertical clearances.
- Other freight corridor considerations include corner and median island radii, location of signs, utility and signal poles, street trees, and other roadside features.
- Look to design for freight activity.

High Freight or Freight-oriented activity areas generally have more dense concentrations of multiple truck-reliant businesses. Typically, these areas include

interchanges along the interstate system, freeways, and arterial expressways where warehousing facilities, distribution centers and industrial parks are more likely to be located. Intermodal

facilities, e.g., rail/truck transfer centers and ports are generally located in more industrial regions near rail lines and significant waterways. Most freight-oriented areas are accessed by high volume/high-capacity roads. However, there can be impacts to arterial and collector roadways utilized by increased truck traffic which may also need to be considered in designing roadway improvements.



(Source: Google Earth Imagery)

16.4.5 – Truck Restricted Routes

Truck restrictions are a major tool in freight management. Restrictions are needed to slow the deterioration of routes caused by weight capacity or for safety reasons due to roadway geometrics, speed, and/or crash history. Publication 46, *Traffic Engineering Manual,* the Weight and Size Restrictions section identifies restriction requirements and the required engineering and traffic study.

When appropriate, projects should consider removing the conditions which initiated the truck restrictions with possible roadway and bridge improvements. Local and community input should be taken into consideration to help determine if truck restrictions should be lifted.

16.5 – Design Considerations

Guidance

- Freight corridors should be designed to provide for truck mobility, access, and circulation.
- Freight corridors require adequate lane width to allow travel without encroaching on an adjacent lane.
- Refer to Chapter 3, *New Construction and Reconstruction,* for required vertical clearances.
- Other freight corridor considerations include corner and median island radii, location of signs, utility and signal poles, street trees, and other roadside features.



(Source: Google Earth Imagery)

The design for an individual road should not be developed in isolation. Some roads are more important for freight mobility, others are more important for freight access, and others are less important for freight movement overall. Designers must consider the function of the roadway and its context within the network when deciding what design criteria is

most appropriate to accommodate the transportation needs of the roadway in question. Existing roadway bridge structures which may be impacted by network improvements should be evaluated for increased truck weight and/or volume related loadings.

Refer to Chapter 9, *Maintenance and Protection of Traffic,* for truck considerations during construction, including information on truck detour routes.

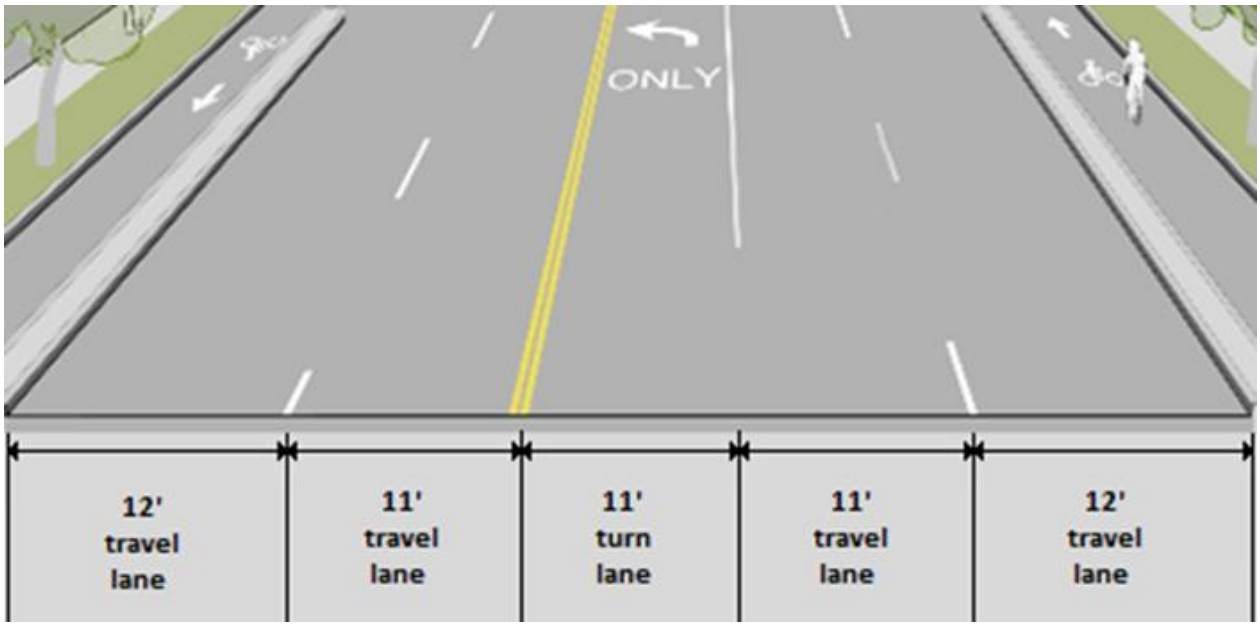
16.5.1 – Lane and Shoulder Widths

The most critical element for designing typical sections for high volumes of large trucks is lane width. A typical passenger car is only seven feet wide. Single unit trucks are typically eight feet wide, and tractor trailers can reach 10-10.5 feet in width with their mirrors. Characteristics of larger trucks including field-of-vision limitations, slower acceleration and deceleration rates, and a higher center of gravity make it crucial to provide more space for operation and reaction (i.e., a more forgiving lane width) for these vehicles. Lane widths determine the proximity to other road users in adjacent vehicular lanes, bicycle lanes, and to the curb.

16.5.1.a – Flexibility

Traditionally, designers prefer to select wider lane widths to increase the amount of space between two road users traveling adjacent to each other. While this often increases the comfort and perceived safety for road users, it also encourages higher travel speeds. Faster speeds negate the benefits of additional width for driver correction, and crashes that occur at faster speeds result in more injuries and fatalities than crashes at low speeds. Outside travel lanes (those nearest the curb) can be travel lanes, parking lanes, bus lanes, bicycle lanes, or a combination of each. Inside travel lanes are closest to the median of a street, and may include turn lanes, through lanes, or a combination of both. Outside travel lanes are the preferred location for truck and bus traffic because these vehicles tend to accelerate slower, travel more slowly, and have large blind spots to the right side of the vehicle. A moderate inside lane width discourages high vehicle speeds. A wider outside lane with a paved shoulder accommodates infrequent conflicts between on-street bicyclists and trucks and provides added room for truck maneuvers. A painted median allows space for frequent left turns. Because of a greater presence of trucks in the outside travel lane they are often wider than inside travel lanes. Refer to **Exhibit 16.5.1** for an example of flexibility in lane widths. Refer to Chapter 18, *Traffic Calming*, for more information on flexibility for lane widths.

Exhibit 16.5.1 – Flexibility in Lane Widths Used with Road Diet



Guidance

- Freight corridors should be designed to provide for truck mobility, access, and circulation.
- Freight corridors should provide adequate lane width to allow travel without encroaching on an adjacent lane.
- Refer to Chapter 3, *New Construction and Reconstruction,* for required vertical clearances.
- Other freight corridor considerations include corner and median island radii, location of signs, utility and signal poles, street trees, and other roadside features.

16.5.1.b – Freight Corridor

For multi-lane freight corridors (refer to Section 16.0 for identification), a moderately wide inside travel lane and wide outside travel lane is preferred.

If a shoulder is not provided in a curbed roadway which services a high volume of freight, then a 2-foot curb offset should typically be provided. Additionally, wider lane widths should be provided to allow more cross-sectional room for the larger vehicles to navigate. These recommended wider widths are noted in the Guidance box in this section. If the minimum lane widths in Chapters 3, 4 or 5 are larger than these widths, then the larger lane widths should be used for the design. The lane and shoulder widths in

Chapters 3, 4 and 5 are the controlling criteria for which a design exception may be required if the criteria are not met.

Local street design regarding freight should consider the local entity's design criteria, but PennDOT design criteria govern for PennDOT projects. In areas where high truck traffic is observed or expected (retail and industrial areas), considerations such as interactions with other modes (bicycles, pedestrians), intersection operations, and right-of-way limitations should factor heavily in the design.

Guidance

The widths below are recommended for freight corridors and are not required design criteria. These wider widths should especially be considered in curbed roadways with narrow or no shoulders. 13-foot lanes should only be considered when minimal shoulders are provided, such as curbed or local roadways.

- Rural arterials and collectors have a recommended lane width of 12 feet.
- Rural town, suburban, and urban arterials and collectors have recommended lane widths of 12 feet for left turn lanes and 12-13 feet for through and right turn lanes.
- Urban core arterial and collectors have a recommended lane width of 13 feet for through, 12-13 feet for right turn lanes and 12 feet for left turn lanes.
- Multi-lane roadways may have narrower inside lanes and flexibility can be used as noted in Section 16.5.1.a.

16.5.2 – Vertical Grades and Curves

Vertical Grade Impacts. An additional consideration in designing for freight is the impact of grade on operations. While design criteria will not be impacted by truck percentage, in areas with higher truck percentages, maximum grades should be avoided. Extended grades near the maximum value will lead to capacity reduction of the roadway and potential safety issues. In areas where this may be an issue, truck climbing lanes may be considered. Please refer to Chapter 3, *New Construction and Reconstruction - Change in Road Type*, the Green Book, and the Highway Capacity Manual for additional guidance.

Vertical Curves. Longer or low-clearance vehicles may get 'hung-up' or 'bottom out' on vertical curves or intersections with too great a grade differential. Chapter 3, *New Construction and Reconstruction - Change in Road Type,* provides design details to alleviate the 'bottom-out' issue.

16.5.3 – Intersection Layout

The design of intersections that can accommodate freight and other modes can be very challenging. Trucks can require large radius turns, resulting in significant right-of-way needs. These turns may also affect the stop bar placement, requiring the stop bar for some lanes to be offset from the other lanes. Changing stop bar location may require the need to revise the yellow and red timings. Truck turns may also require longer pedestrian crossings. This, combined with their slower acceleration speeds, may require an adjustment to the traffic signal. Along with adjusting timings for truck turns, it is important to consider the exposure of the vulnerable pedestrian over a longer crossing distance, the longer pedestrian crossing distance also significantly impacts traffic signal operation to provide the necessary clearance time. It is also important to keep in mind the intersection sight distance as freight traffic requires different sight distance than passenger vehicles.

Refer to Chapter 6, *Intersections and Driveways,* for more information on intersection layouts and Chapter 3, *New Construction and Reconstruction - Change in Roadway Type,* for more information on Intersection Sight Distance.

16.5.4 – Pedestrian, Bicycle, and Transit Considerations for Truck Corridors

While truck circulation is an important design principle, truck corridor streets must also safely and conveniently accommodate and balance the needs of pedestrians, bicyclists, and buses. There are no standard solutions for resolving truck conflicts with other modes. Each situation needs to be evaluated separately on a case-by-case basis.

16.5.4.a – Pedestrian Considerations

Crosswalks, median refuge islands, and curb extensions are three design elements that assist pedestrians in urban environments. However, along freight corridors these design elements can impede truck movements. With wider intersections for truck turn movements, pedestrians may have longer crosswalks to negotiate at intersections and curb extensions may not be possible. Longer crossing times may be needed for pedestrians. On wider roadways, pedestrian median refuges may need to be designed with mountable curbs and pedestrians need to be aware of large vehicles turning into the road they intend to cross.

For more information regarding pedestrian considerations, refer to Chapter 13, *Pedestrian Facilities.*

16.5.4.b – Bicycle Considerations

Bicycles on freight corridors also require special consideration. At intersections with high volume truck turn movements, dedicated right-turn lanes are preferred so a bicycle lane can be transitioned to the left of the right-turn lane, minimizing truck/bicycle conflicts. Turn lane warrants are detailed in Chapter 11 of PennDOT Publication 46, *Traffic Engineering Manual*. This transition can even be from a shoulder used by bicycles. When designing these features, designers must recognize that a truck driver's vision is limited when making right turns at intersections. Chapter 14, *Bicycle Facilities,* provides additional guidance on bicycle facility design.

16.5.4.c – Transit Considerations

From an operational perspective, transit circulation on truck corridors is generally compatible with truck circulation. Similar to trucks, buses require wider lanes and more generous curb radii for right-turn movements. However, potential conflicts with trucks need to be considered where passengers access bus stops and at pedestrian crosswalk locations.

Guidance

Fixed Guideway Transit Facilities

When designing truck access across and adjacent to fixed guideway transit facilities such as light rail, where parts of existing streets are dedicated for transit, an analysis of truck movements should be made to ensure that trucks entering the transit street can make their turn(s) without encroaching into the transit right-of-way.

Easy and convenient pedestrian access needs to be considered wherever a bus stop is located and where truck operations are being addressed. Transit stops should be located to balance good passenger access with pedestrian safety. Stop locations should minimize the potential for jaywalking, minimize passenger walking distance and

avoiding unnecessary crosswalk movements. Details on transit stop design can be found in Chapter 15, *Transit Facilities*.

In respect to light rail which run on a fixed guideway system, the location and height of the overhead catenary wires need to be considered to allow adequate clearance for truck movements.

16.5.5 – Truck Parking / Rest Areas

Efficient and safe movement of freight requires adequate parking and rest facilities for long-haul freight movers. Designers should look for opportunities to create or expand parking and rest facilities for long-haul freight haulers. Increased truck traffic and regulated 'time-on-road' schedules create disruptions in completion of point-to-point trips. Freight corridor parking and rest considerations should accommodate the corridors' truck traffic volumes, sizes of vehicles and extended down (rest) time.

Designers should also look for opportunities to incorporate or expand parking and rest facilities within proposed project limits, or incorporate notification systems (signing, etc.) to alert freight haulers to available parking when present. Additionally, coordination and cooperation with adjacent, private property owners should be considered where the potential exists for providing access to additional parking development (often combined with food/retail complexes). Opportunities may exist for new or expanded truck parking adjacent to interstate highways at existing or proposed interchange locations.

Refer to Chapter 19, *Parking Facilities,* and Chapter 24, *Rest Areas and Welcome Centers,* for more information on these areas.

Chapter 17 – Plain People Community Considerations

In this chapter there are references to future chapters 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 17 – Plain People Community Considerations

17.0 – Introduction



Throughout Pennsylvania, there are hundreds of Plain People communities that rely on the same transportation facilities as those who use motor vehicles. When developing projects near these communities, it is imperative to evaluate which transportation modes to include and the unique requirements associated with each mode to provide safe transportation facilities for all. Beyond typical vehicles, designers should consider modes such as bicycles, scooters, roller skates/roller blades, horseback, horse-drawn buggies, and horse-drawn farm equipment.

The types and styles of horse-drawn vehicles used are subject to local custom and church regulations. Distinctive features have developed over the years in each community and group. However, the average horse-drawn buggy is 6 feet wide and typically travels at 5 to 8 mph. It is legal to use horse-drawn buggies on non-freeway public roadways (as they are non-motorized vehicles) but the interaction between motor vehicles and these buggies can lead to conflicts and delays. This interaction can be particularly problematic when drivers are not accustomed to sharing the road with horse-drawn vehicles.

In addition to riding in buggies, many Plain People use scooters, roller skates/roller blades, and bicycles as a necessary means of day-to-day transportation. While the use of these modes has remained relatively constant, rural populations have increased, and tourism in Plain People communities has risen. This leads to many more motorists sharing the same roads with non-motorized vehicles. The use of these modes in this case is for transportation and not for fitness or recreation. It is important to consider that when non-motorized vehicles are a means of transportation, more of this type of travel is done in poor weather and in low-visibility situations.



Additionally, the Plain People community travels on foot for school, work, or social trip purposes every day. The travel times vary but are primarily from dawn to dusk. In particular, the children attend parochial schools typically located within walking distance of home. Traditionally, these schools cover elementary level through eighth grade. Since students walk to school, these facilities are generally located on local streets, although it is often necessary for the children to walk on state routes to reach the local street network.

The designer should ask these important context questions:

- Are Plain People community considerations along an urban or rural corridor?
- What types of Plain People transportation modes will likely use the facility (e.g., pedestrian, scooter, roller skate/roller blade, horseback, horse-drawn buggy, and horse-drawn farm equipment)?
- Is the corridor along a primary walking path to the Plain People community school?
- Are there destination points for the Plain People community along the corridor (e.g., markets and workplaces)?

Key design components include:

- **Minimizing Conflicts.** As Plain People communities continue to grow throughout the Commonwealth, the interaction between high-speed and low-speed travel modes increases. Potential safety concerns exist when horse-drawn vehicles, which move at speeds of 5 to 8 miles per hour, share roadways with motor vehicles traveling at speeds up to 55 miles per hour. Rural roadways are often narrower than urban roadways, resulting in very little room for motorists to maneuver around horse-drawn buggies, especially considering the potential reactions of horses to traffic.
- **Cognizance of Obstacles.** Numerous obstacles can be significant barriers to Plain People's modes of transportation. For example, shoulders should be of adequate width with a smooth surface. Detours beyond a mile become consequential. Roadway geometry and sight distance plays a key role in corridor safety for all modes.
- **Working Toward Continuity.** The key to a convenient non-motorized commute is continuity of facilities. The designer should evaluate the routes and / or locations of Plain People facilities and consider links to other paths and routes in the community. Providing continuity for non-motorized commuters may take additional time in project development and may require the acquisition of additional right-of-way.

17.0.1 – Resources and References

- Iowa State University - Center for Transportation Research, *Improving Safety for Slow Moving Vehicles on Iowa's High-Speed Rural Roadways – Final Report*, 2009.
- Ohio DOT, District 12, *Amish Safety Strategic Plan, Geauga County, 2016*.
- PennDOT, Publication 212, *Official Traffic Control Devices*, (most recent version).
- PennDOT, Publication 236, *Handbook of Approved Signs*, (most recent version).
- PennDOT, Publication 632, *Horse and Buggy Driver's Manual*, (most recent version).

17.1 – Design Considerations

Plain People use roadways primarily for five trip purposes: work, school, market, church, and social. When developing a project near or in a Plain People community, the designer should consider each purpose and how the project corridor fits into each type of travel. School trips are typically made on foot; work, social, and church trips tend to be made by buggy or cart.

During the development of the project, the following questions should be kept in mind:

- Will the proposed design adequately accommodate Plain People vehicles (e.g., farm equipment and horse and buggy traffic)?
- Will the proposed design accommodate all classes of pedestrians (e.g., schoolchildren, elderly people, and disabled individuals)?
- Does the proposed design provide continuity of sidewalks and shoulders, including on bridges?
- Will the proposed design adequately accommodate bicyclists?
- Will the proposed design be consistent with adjacent roads, landforms, and traffic management?

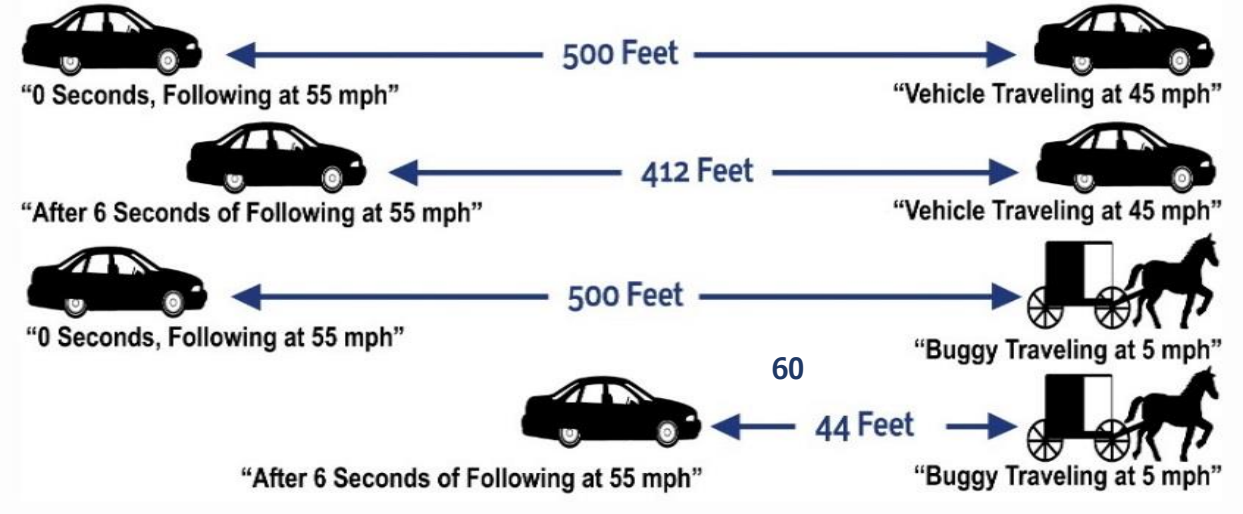


A majority of Plain People trips occur on rural roads, which are often narrower or varied in width. A narrow road gives motorized vehicle drivers less room to maneuver and can be especially dangerous when passing horse-drawn vehicles. Narrow shoulders, loose gravel, and open ditches add to the challenges for Plain People transportation modes. Additionally, in cold weather, a road shaded by trees or buildings may be icy because the sun has not shone on that part of the roadway; blind corners can be created by wooded areas, corn fields or other tall crops; and seemingly open roadways may have sharp dips or unexpected turns which limit reaction time for drivers, all creating unexpected hazards for the interaction of high versus low-speed vehicles.

Normal speeds for horse-drawn buggies on relatively flat terrain range between 5 and 8 miles per hour. Horse-drawn vehicles may be even slower when pulling large farm equipment or when crossing intersections because horses do not react as quickly as motorized vehicles. With this in mind, understanding the closure time (the time a driver has to recognize and respond when coming upon other vehicles) is a safety factor that should be considered in evaluating high-speed versus low-speed vehicle interactions in locating appropriate signage and roadway features.

For example, one car traveling at 55 mph follows a car 500 feet ahead traveling at 45 mph. After 6 seconds following at 55 mph, the driver of the following car will have 412 feet to react before colliding with the car ahead. However, a car traveling at 55 mph following a horse-drawn vehicle 500 feet ahead traveling at 5 mph will only have 6 seconds and 60 feet to react before colliding with the horse-drawn vehicle. **Exhibit 17.1.1** illustrates this closure time.

Exhibit 17.1.1 Following Distance at Varying Speeds



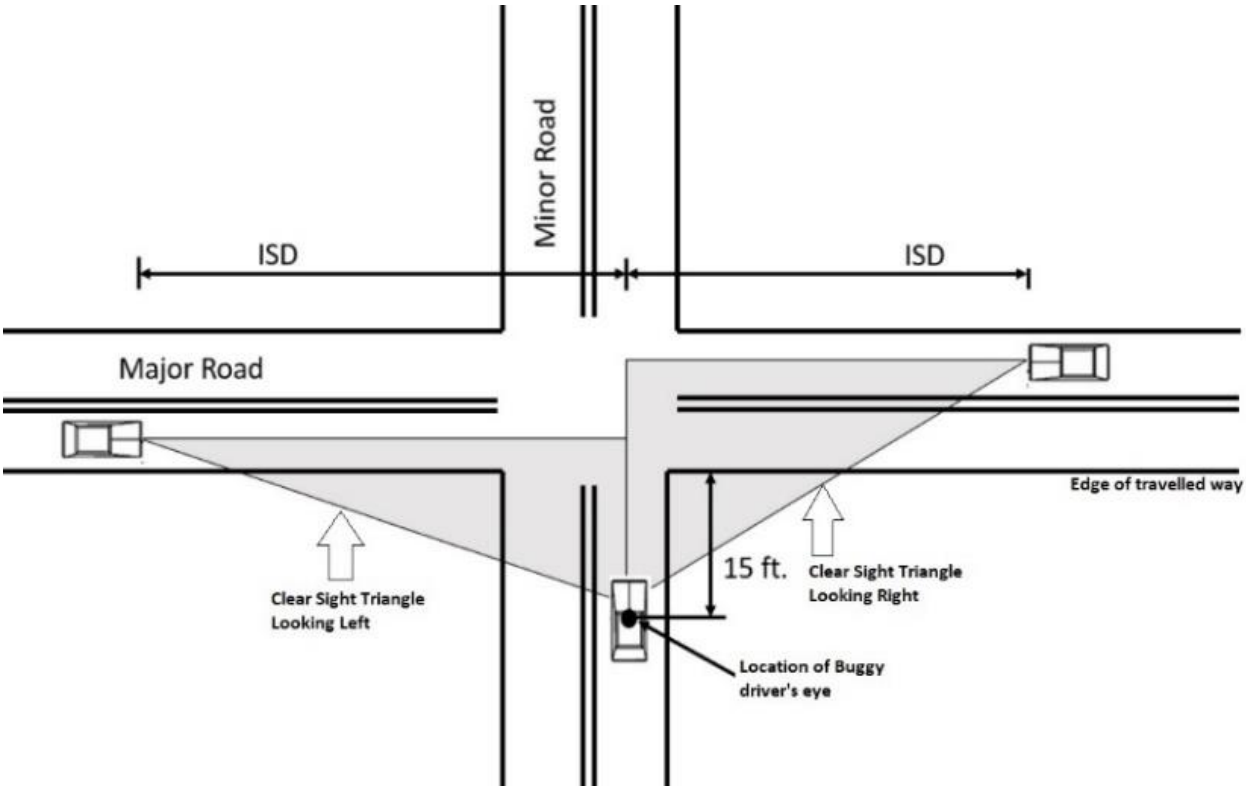
(Source: *Horse and Buggy Driver's Manual*)

17.1.1 – Intersection Sight Distance

Visibility at intersections is sometimes limited due to signs, fixed objects, skewed geometry, vegetation, embankments, and other obstacles. Compared to a motor vehicle driver, a horse-drawn buggy driver sits further back, which further reduces visibility. Clear sight triangles are necessary so that buggy drivers can see approaching vehicles on a cross street and for motorists to see a stopped vehicle on a minor street. Where applicable, the design should prohibit parking at critical locations.

Exhibit 17.1.2 illustrates the intersection sight distance (ISD), which for horse-drawn vehicles is measured 15 feet from the edge of the travel way. This is based on the front end of a stopped horse and buggy being positioned 6.5 feet from the edge of traveled way and the decision point (driver's eye) being positioned 8.5 feet from the front end of the horse and buggy.

Exhibit 17.1.2 Intersection Sight Distance



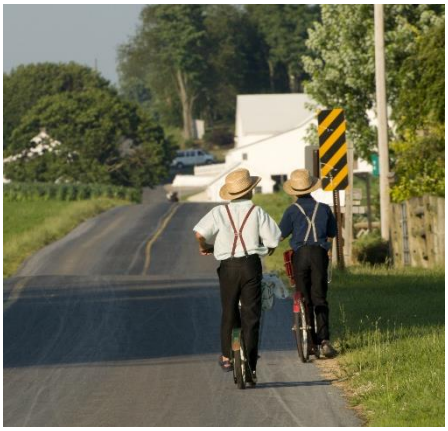
17.1.2 – Shoulder Treatments

The appropriate shoulder treatment is a function of the volume of motorized traffic in relation to the volume/regularity of the different Plain People transportation modes. The following sections address design issues related to shoulder treatments.

17.1.2.a – Pedestrian, Scooter, and Roller Skate/Roller Blade Treatment

Shoulders are generally adequate for pedestrian use when they are paved and at least 4 feet wide. Paved shoulder widths beyond 4 feet are desirable when one or more of the following conditions exist:

- Motor vehicle speeds exceed 40 mph.
- The percentage of trucks, buses, and recreational vehicles exceeds 5% of an overall ADT of 2000 or more.
- Bicycle, scooter, or roller skate/roller blade use of the shoulder is more than occasional.
- Pedestrian volumes are high, or groups of pedestrians typically travel together (e.g., on routes to school).



If the project corridor has pedestrian traffic due to its use as a travel path for a school, market, or church, it is recommended that the shoulders be widened to a minimum effective width of 5 feet regardless of the speed limit. If a guide rail or hard feature (for example, parapets) abuts the shoulder, it should be offset by 2 feet to maintain the effective shoulder width.

On shoulders frequently used by Plain People, the travel-lane edge should be clearly delineated with pavement markings to discourage motor vehicles from unnecessary shoulder encroachment.

17.1.2.b – Horse and Buggy, Carts, and Farm Equipment

If a corridor's ADT is 2,000 or more, or it has a truck ADT of 100 or greater, paved shoulders are vital for Plain People buggy drivers. Below these thresholds, paved shoulders should be considered if the corridor has a topography that limits vertical or horizontal sight distance at multiple locations, has limited passing zones, has long uphill or downhill grades of 4% or greater, or has a speed limit greater than 40 mph.

When accommodating for use by buggies, paved shoulders of 10 feet wide on arterials and 9 feet wide on collectors and local roads can function as buggy lanes to separate slow-moving horse-drawn buggies from high-speed motor vehicles. Guide rails or other hard features that abut the shoulder should be offset by 2 feet to maintain the effective shoulder width. It is important that the shoulder width is carried across structures when reasonable so that buggies are not required to move into the travel lane. This improvement will provide dedicated space for buggies and reduce the crash potential between buggies and motor vehicles.





Inadequate Shoulder Width Across Bridge

(Source: *Improving Safety for Slow Moving Vehicles on Iowa's High-Speed Rural Roadways – Final Report*)

Partially paved/partially graded shoulders should not be installed. This condition can cause a horse to walk unevenly on differing surfaces. Additionally, there is concern about pavement edge drop-off over time, which creates difficulty for a horse-drawn buggy in moving between paved and unpaved areas.

Shoulder and edge line rumble strips should not be installed along corridors with horse-drawn vehicle access. Rumble strips spook the horses and horses can easily turn a hoof in them. Additionally, buggies can fishtail when crossing the rumble strips, which may result in unsafe driving conditions as buggy drivers try to avoid driving on the strips.

Guidance

- Partially paved/partially graded shoulders should not be installed along corridors with horse-drawn vehicles.
- Shoulder and edge line rumble strips should not be installed along corridors with horse-drawn vehicles.

17.2 – Signage to Inform/Warn Motorists



W11-14

The W11-14 warning sign, with a symbol of horse and closed buggy, may be provided on roadways carrying Plain People buggies. The sign should be located in advance of where buggies enter the traffic stream and where sight distance is restricted, as well as intermittently on a roadway to remind motorists of the presence of buggies.



W11-2

Since walking and other non-vehicular modes are the primary means of travel for school and work trips, it is imperative that the motoring public be aware of the potential for pedestrians on roadway sections where motorists typically do not expect pedestrians. In these locations, pedestrian warning signs are installed per Publication 236, *Handbook of Approved Signs*.



W16-7P

Additionally, pedestrian crossing warning signs should be installed on the major street approaches where motorists may not commonly expect pedestrians. An arrow sign (W16-7P) attached to the pedestrian sign shows pedestrians where to cross and alerts drivers about where to expect pedestrians. This sign is used whether the crossing is marked or not. The statutory sign, "Yield Here to Pedestrians" (R1-5L and R1-5R), may be used to remind motorists where pedestrians have the right-of-way at intersections with or without crosswalks.



R1-5L

17.3 – Hill-Climbing and Downhill Lanes

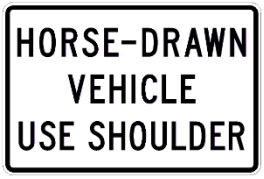
Climbing uphill on steep crest curves (4% or greater) causes horse-drawn buggies to travel slower than on a flat roadway. This delay could result in long queues of vehicles behind buggies, which may result is frustrated motorists trying to pass buggies, even under the reduced visibility conditions.

Additionally, the downhill side of the curve may be visible only after the motorist traverses the crest. When a motorist climbing uphill cannot see a slow-moving horse-drawn buggy on the downhill side, the time required to slow down to avoid striking the buggy may not be available.

For these locations, a buggy hill-climbing/downhill lane should be provided. A hill-climbing lane and a downhill lane meant for horse-drawn vehicles is a paved shoulder that allows motor vehicles to continue in the travel lane unimpeded. When installed to accommodate buggies, the paved shoulder should be a minimum of 10 feet wide on arterials and 9 feet wide on collectors and local roads. If a guide rail or hard feature abuts the shoulder, it should be offset by 2 feet to maintain the effective shoulder width.

These lanes must be long enough to account for buggies that gain momentum on the downhill side and need to merge back into the travel lanes safely.

In some cases, this wide shoulder will be consistent with the remaining portion of the corridor. However, if this widened area is developed for a specific vertical curve, signing should be provided so the buggy driver knows to move to the shoulder and then back to the lane. The R3-104 sign is installed at the beginning of the widened shoulder to alert buggy drivers to move to the shoulder. The W8-25 sign is installed 200 feet prior to the narrowing of the shoulder so that buggies can merge back into the travel lane. When providing a transition at the end of a shoulder driving section, a 50:1 taper should be used.



R3-104



W8-25

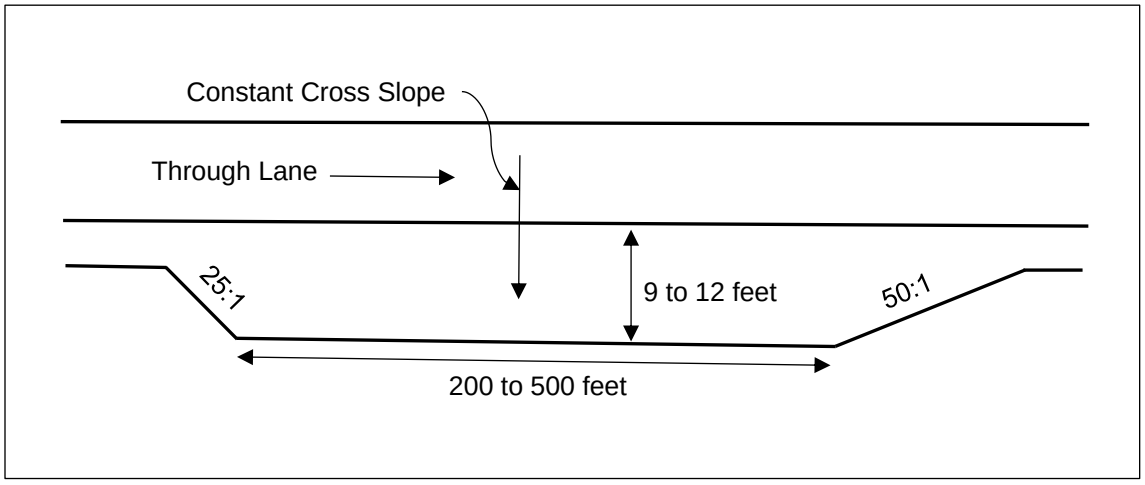
17.4 – Horse-Drawn Vehicle Turnout

On many of Pennsylvania's rural two-lane roadways, the horizontal and/or vertical geometry results in No Passing Zones, due to limited sight distance. In sections where wide shoulders are not available, buggy drivers use the travel lane. If motorists attempt to cross the double yellow line within the No Passing Zone, there is potential for crashes with opposing vehicles and/or buggies.

To alleviate this condition, a horse-drawn vehicle turnout may be considered. A horse-drawn vehicle turnout is not an auxiliary lane. Rather, its purpose is to provide sufficient room for a horse-drawn vehicle to pull out of through-traffic, stop if necessary, allow vehicles to pass, and then return to the through-lane. Generally, a horse-drawn vehicle turnout is provided on roadways where passing opportunities are limited, and horse-drawn vehicles are common.

Sound engineering judgment is the basis for the design of a horse-drawn vehicle turnout. Designs may vary from one location to another but should provide a length of between 200 and 500 feet, excluding tapers, for the horse-drawn vehicle to leave the through-lane. The designer should select an adequate width (typically between 9 feet and 12 feet) that allows the horse-drawn vehicle to use the turnout. The higher the roadway speed or volume, the wider and longer the turnout. If a guide rail or hard feature abuts the turnout, it should be offset by two feet to maintain the effective turnout width. **Exhibit 17.4.1** illustrates the turnout configuration.

Exhibit 17.4.1 Horse-Drawn Vehicle Turnout Configuration



To improve the ability of a vehicle to safely re-enter through-traffic, a slow-moving vehicle turnout should be located where adequate sight distance is available from the rear. The minimum design range for slow-vehicle turnouts should be where at least stopping sight distance is available.

17.4.1 – When to Consider a Horse-Drawn Vehicle Turnout

A horse-drawn vehicle turnout should be considered on two-lane roadways where passing opportunities are limited and where horse-drawn vehicles cause unacceptable motor vehicle delays. This is particularly important for rural routes through areas where the installation of continuous wide shoulders would be prohibitive. When choosing turnout locations, the designer should balance the passing opportunities for each direction and avoid long no passing sections.

Guidance

- Horse-drawn vehicle turnouts should be considered when the percentage of no-passing zones exceeds 60% and crash history or field observations indicate that dangerous passing maneuvers are caused by driver frustration.
- On long sections of roadway, turnouts should be located to reduce the length of the continuous no passing zones to between 0.5 mile and 1 mile.
- Turnouts should not be installed where passing is allowed.
- Access points are not permitted within turnouts. Access points opposite the turnouts should be avoided.
- Stopping sight distance for the design speed (or 85th percentile, whichever is greater) should be available preceding and through the entire length of the turnout.
- Turnouts should not be installed on steep grades due to the impact to horse-drawn vehicles.

17.4.2 – Signing

Signing for Horse-Drawn Vehicle Turnouts should follow the guidance in Publication 236. The Horse-Drawn Vehicle Turnout (XX) Miles Sign (D16-101) should be used in advance of a horse-drawn vehicle turnout to indicate where horse-drawn vehicles may leave the roadway to allow faster moving vehicles to pass. The D16-101 sign should be used in conjunction with the Horse-Drawn Vehicle Turnout (Arrow) Sign (D16-102). In lieu of 'MILE', 'MILES' or 'FT' may be used as appropriate. Depending on the spacing of turnouts, either one or two D16-101 should be used at ½-mile increments. The D16-102 sign should be placed at the beginning of the shoulder widening that develops the turnout.



D16-101



D16-102

17.5 – Horse-Drawn Vehicle Detection at Traffic Signals

Typical detection at traffic signals includes in-roadway loops that perceive a vehicle by weight/metal and communicate to the traffic controller to serve that vehicle's movement. Due to its construction, a horse-drawn vehicle often is not detected by traditional loops. This results in longer wait times, and non-compliance of the signal. To resolve this issue, radar detection (in lieu of loop or video detection) at the stop bar is recommended to identify horse-drawn vehicles.



Horse Drawn Vehicle Detection
(Source: Wavetronix)

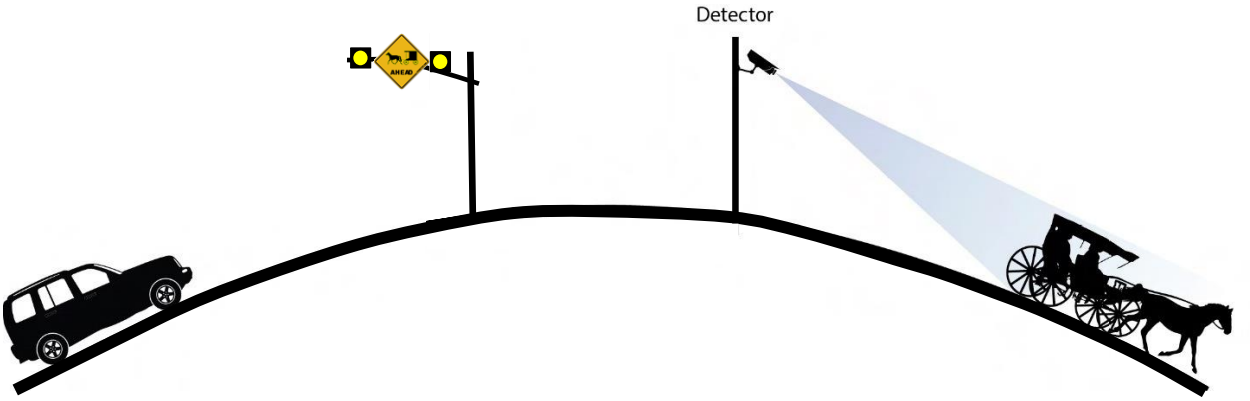
17.6 – Horse-Drawn Vehicle Warning Detection System

In some situations, it may not be possible or practical to install a shoulder to accommodate horse-drawn vehicles, yet there are vertical and horizontal conditions that provide limited sight distance for the speed differential between a motorized vehicle and a horse-drawn vehicle.

This condition can be mitigated with an enhanced warning sign that is active when a conflict exists, (i.e., a detection system that can identify a slow-moving vehicle) and activate a flashing sign to warn motorists of the presence of a horse-drawn vehicle.

Loop detectors have been found to be ineffective with buggies. Therefore, other detection systems (i.e., advanced radar, video, microwave) are recommended. These detection systems are beneficial at vertical curves, so that a horse-drawn vehicle on the downhill side is detected and a warning sign is activated on the uphill side, informing drivers of a slow-moving vehicle. This allows drivers to slow down as they pass the crest. This treatment can also be applied to horizontal curve locations. **Exhibit 17.6.1** illustrates the detection system concept. This system can also be installed on horizontal curves with limited sight distance.

Exhibit 17.6.1 Horse-Drawn Vehicle Warning Detection System Sketch



(Source: Ohio DOT, *Amish Safety Strategic Plan, Geauga County*)

Note: The designer should consider sight lines when deciding placement for detector and warning device in order alert driver with ample time to react when a horse-drawn vehicle is out of sight due to the crest curve.

A blank-out sign should be designed for use on the mast arm. The sign operates similarly to the pedestrian in crosswalk sign (on the right) but has the message of horse-drawn vehicle or slow-vehicle ahead (as on the left). The Bureau of Maintenance and Operations shall review and approve the sign and the detection system chosen. This type of signing also requires a Flashing Warning Device Permit to be issued by the District Traffic Unit. More information regarding the use of these signs can be found in Publication 212, *Official Traffic Control Devices*.





Chapter 18 – Traffic Calming

In this chapter there are references to future chapters 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 18 – Traffic Calming

18.0 – Introduction

The Institute of Transportation Engineers (ITE) defines traffic calming as the combination of measures that reduce the negative effects of motor vehicle use, alters driver behavior, and improves conditions for non-motorized street users. This chapter contains updated material based on current research and supersedes Publication 383, *Pennsylvania's Traffic Calming Handbook*. Note that Pennsylvania Code, Title 67, Chapter 212, § 212.9, *Traffic Calming*, refers to "*Pennsylvania's Traffic Calming Handbook"* (Department Publication 383)." Therefore, the Department must maintain Publication 383 as a "redirect publication". Publication 383 will be voided of contents and consist only of a title page redirecting the reader to this chapter. Until Chapter 212 is revised, or an administrative action is taken, both this chapter and Publication 383 will remain in effect.

The primary focus of traffic calming is to manage and reduce the speed of vehicular movements through self-enforcing designs to enhance the safety of all users. It is intended to reduce the severity and likelihood of crashes, increase safety and comfort for pedestrians and bicyclists, enhance aesthetics and landscaping, provide a more equitable balance among transportation modes, and reduce noise pollution. Traffic-calming measures are not applicable to Interstates and Freeways.

Traffic calming also:

- Reduces the number of crashes with fatalities or serious injuries.
- Supports Vision Zero goals and Safe System Approach.
- Increases livability, and quality of life.
- Encourages use of the street by all modes of transportation.

However, in some cases traffic calming will negatively impact traffic operations to some degree. This effect should be analyzed and considered. This chapter covers considerations in determining appropriate treatments and provides guidance on the evaluation of traffic-calming measures. It also defines a process to assist in the justification of traffic calming, including traffic-calming applicability in Pennsylvania, multimodal considerations, and study and approval processes (see Appendix 18.A).

Additionally, this chapter includes a Toolbox of Traffic-Calming Measures and Design Guidelines that provides designers with detailed guidance on traffic-calming measures.

18.0.1 – References and Resources

- AASHTO, *A Guide for Achieving Flexibility in Highway Design*, 2004.
- AASHTO, *Highway Safety Manual* (HSM) (edition defined in Publication 638A).
- FHWA, *Engineering Speed Management Countermeasures: A Desktop Reference of Potential Effectiveness in Reducing Speed*, 2014.
- FHWA, *Interactive Highway Safety and Design Model (IHSDM)*.
- FHWA, *Flexibility in Highway Design* (FHWA-PD-97-062).
- FHWA, *Speed Concepts: Informational Guide*, 2009.
- FHWA, *Traffic Calming ePrimer*, 2017.
- Institute of Transportation Engineers (ITE), *Traffic Calming Measures*, 2018.
- ITE, *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach*.
- National Association of City Transportation Officials (NACTO), *Urban Street Design Guide*, 2013.
- PennDOT, Publication 46, *Traffic Engineering Manual*, 2014.
- PennDOT, Publication 111, *Traffic Control-Pavement Markings and Signing Standards*.
- PennDOT, Publication 212, *Official Traffic Control Devices*, 2006.
- PennDOT Publication 236, *Handbook of Approved Signs*, 2013.
- PennDOT, Publication 295, *Transportation Project Development Process – Public Involvement Handbook*, 2021.
- PennDOT, Publication 383, *Pennsylvania's Traffic Calming Handbook*, 2012.
- PennDOT, Publication 638, *Highway Safety Program Guide,* 2021.
- PennDOT, Publication 787, *Pennsylvania Active Transportation Plan,* 2020.

18.0.2 – PennDOT Policies and Regulations

Publication 212, *Official Traffic Control Devices*, Section 212.9, *Traffic Calming*, includes the following:

a) ***General policy.*** *The Department (on State-designated highways) and local authorities (on any highway within their boundaries) may implement traffic-calming measures in conformance with Pennsylvania's Traffic Calming Handbook (Department Publication 383).*

b) ***Department approval.*** *Local authorities shall obtain approval of the Department prior to implementing a traffic-calming measure on a State-designated highway, except when the Department's handbook provides otherwise or when the Department has entered into an agreement with local authorities that provides otherwise.*

Section 212.4, Application, includes the following:

a) ***General.*** *This chapter (Pub 212) applies to the approval, location, installation, revision, operation, maintenance and removal of all traffic signs, signals, markings and other traffic-control devices on all streets and highways in this Commonwealth. All signs, signals, markings, and other traffic-control devices erected shall conform to this chapter. Traffic restrictions, which were posted or erected prior to February 4, 2006, in accordance with any regulations in effect at that time, are not subject to this chapter (Pub 212).*

b) ***New restrictions.*** *Except as noted in § 212.109 and 212.117 (relating to bridge speed limits; and weight, size, and load restrictions), engineering and traffic studies can be performed by police officers, roadmasters, maintenance supervisors or traffic technicians. The establishment or revision of a traffic restriction may be warranted if one of the following applies:*

   (1) *One or more of the engineering and traffic study warrants covered in this chapter (Pub 212) justifies the traffic restriction.*

   (2) *Sound engineering judgment based upon a combination of all data sources substantiates the need for the restriction.*

PennDOT supports the implementation of traffic-calming measures. In line with national best practices, such as Complete Streets initiatives, Context-Sensitive Solutions (CSS), and Context-Sensitive Design (CSD), PennDOT encourages designing for all modes of transportation by addressing issues on existing streets and designing new or reconstructed streets.

18.1 – Objectives of Traffic Calming

18.1.1 – Speed Reduction

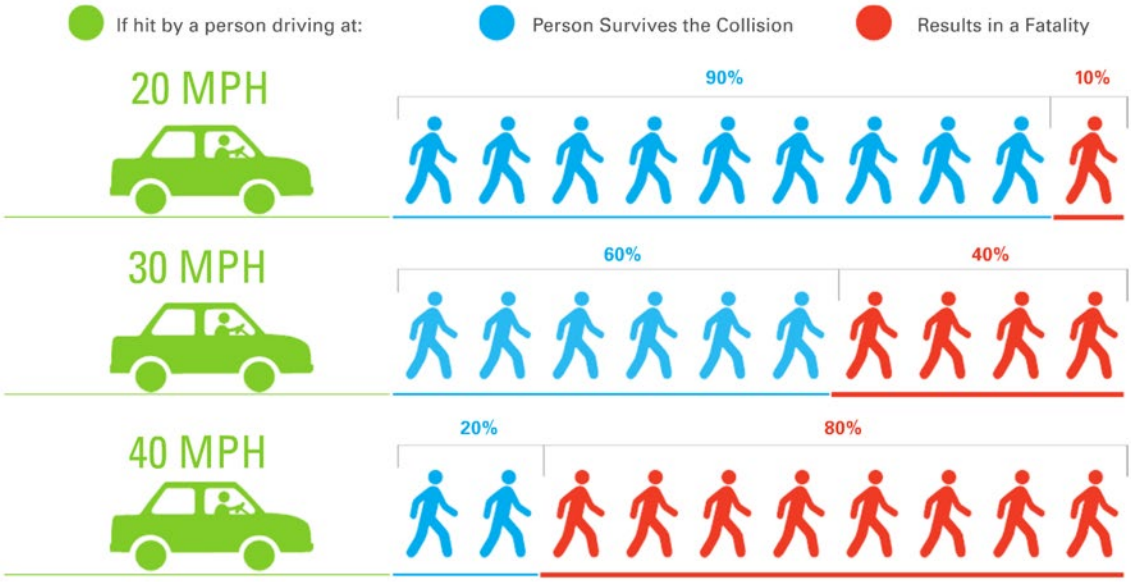
Traffic calming aims to reduce operating speeds along a roadway. For more information refer to Chapter 2, *Design Control*. Changing a roadway's geometric design (along with the posted speed) to support a desired operating speed is more effective than solely changing the posted speed. Horizontal and vertical traffic-calming measures modify the roadway geometry in order to reduce and self-enforce vehicle operating speeds.

18.1.2 – Crash Reduction

According to FHWA's, *Speed Concepts: Informational Guide*, reducing vehicular speed simultaneously reduces the number and severity of motor vehicle crashes. Implementing traffic-calming measures often results in fewer crashes, fewer fatalities, and less severe injuries, thus supporting Vision Zero goals and Safe System Approach.

Exhibit 18.1.1 depicts the relationship between vehicular speed and the likelihood of a pedestrian fatality upon collision. As illustrated, a pedestrian has a 20% chance of surviving a collision with a vehicle traveling 40 mph, as compared to a 90% chance of surviving a collision with a vehicle traveling 20 mph.

Exhibit 18.1.1 Vehicle Speeds and Pedestrian Fatality Rates



18.1.3 – Quality of Life

Traffic calming can improve the quality of life by increasing the comfort level of pedestrians and bicyclists. Some of the ways it does this is by incorporating landscape design elements, creating pedestrian and bicycle amenities, enhancing aesthetics and reducing noise. Traffic calming also reduces vehicle speeds which allows for more reaction time among motorists, bicyclists, and pedestrians. Traffic calming is consistent with the increasing interest in Active Transportation Plans. Studies have demonstrated that traffic calming has led to an increase in the number of pedestrians, bicyclists, and transit riders.

18.2 – Traffic Calming Applicability

PennDOT's *Speed Management Action Plan*, identifies traffic-calming measures as one of the tools for speed management along with public education, enforcement, and other engineering measures.

Traffic calming is used by many municipalities to manage vehicle speeds. However, for State Routes traffic-calming measures should typically only be considered after education, enforcement, and other low-cost efforts fail to produce desired results. Traffic-calming measures must be evaluated against potential negative impacts to regional operational demand. For measures being implemented, an acceptable balance of effectiveness for all modes of transportation should be attained.

Most projects, whether they are minor or major, on new, modified, or existing roads, are potential candidates for traffic calming or speed management. Other project candidates include Complete Streets projects and projects that meet the goals of the Active Transportation Plan. Community input should be obtained from roadway users, local residents, adjacent property owners, and others.

Roadway and project characteristics to evaluate include:

- Crash history.
- Roadway functional classification, typology, and context.
- Existing and proposed land use.
- Roadway users (including pedestrians and bicyclists).
- School zones and parks.
- Alignment of posted speed and operating speed.
- Roadway geometry.
- Transit routes.
- Drainage and utilities.
- Maintenance.
- Traffic volume.
- Emergency response vehicles.
- Noise.

18.2.1 – Context

Context classifications assess the context of the roadway by indicating who the roadway users are, how the roadway is used, and how the roadway fits into the larger transportation area.

Context considerations include access, mobility, livability, land use, economic development, density, and building setbacks. Consideration should also be given to the larger transportation network, the planning vision, and any issues specific to the location. Consideration should also be given to corridor access management (see FHWA's, *Access Management Manual*, Second Edition and PennDOT's, *Access Management Manual Application Guidelines.*)

For more information on context, refer to Chapter 1, *Context Based Design and Flexibility*.

Local governments or regional agencies may benefit from refining the statewide context classifications to better define context-sensitive solutions within their jurisdictions.

----- LOCAL AUTHORITY SPECIFIC CONTEXT CLASSIFICATION -----
Local authorities may create a traffic-calming program and guidance catered to their unique or specific needs. While the guidance may not replicate the exact details of this chapter, the tenets of the program should be similar. When creating a local traffic-calming program, deviations from the guidance in this chapter, such as roadway classification or context, should be based on a thorough engineering evaluation of data and the most current information, studies, and research available. Local authorities creating their own program shall obtain PennDOT District approval if the program involves state-owned roadways.

18.2.2 – Volumes

Roadway volumes may be used to determine the applicability of traffic-calming measures. Traffic calming may be justifiable on a high-volume roadway if there is existing or projected high pedestrian activity. (Noted throughout the chapter as “high pedestrian activity.”) However, traffic-calming measures should be avoided on high-volume roadways that serve as major throughways or emergency detours for major highways.

18.2.3 – Speed

Traffic-calming measures encourage appropriate operating speeds consistent with the level of multimodal activity and context to create a comfortable environment for all modes of transportation.

Refer to Publication 46*, Traffic Engineering Manual,* and to Chapter 2 for more information on determining appropriate design speeds based on functional classifications, context, and typologies.

18.2.4 – Roadway Users

Roadways serve a mix of users, including those who drive, walk, bike, or use public transportation. These users deserve safe and comfortable connected transportation networks. When considering roadway changes, all modes should be considered in early planning and design phases. Consideration should be given to the possibility of increased pedestrian and bicycle usage if facilities were implemented. While traffic-calming measures are intended to improve conditions for some transportation modes, they should not cause undue burden to other modes or users. Ensure that operational aspects of other users are adequately considered.

For more information on pedestrians, refer to Chapter 13, *Pedestrian Facilities*. For more information on bicyclists, refer to Chapter 14, *Bicycle Facilities*.

18.2.5 – Regional Roadway Network Impacts

The designer must consider the overall context and roadway network when implementing traffic-calming measures instead of focusing solely on spot treatments which could lead to traffic diversion. Traffic diversion can negatively impact regional levels of service and operations for motor vehicles. Implementing additional treatments along parallel routes or at a network level can reduce traffic diversion. Regional roadway network considerations include:

- Context of vehicle network and viable alternate routes.
- Adjacent roadways.
- Intersection spacing and type of traffic control.

Where spot treatments are being considered, temporary treatments may be installed to monitor the traffic diversion impacts. Then, before-and-after studies can be used to assess the impact of rerouted vehicular trips on parallel roadways to determine if permanent traffic-calming measures are appropriate.

18.2.6 – Emergency Response Vehicles

Police departments and emergency service providers are generally supportive of the traffic-calming goals of speed and crash reduction. However, these emergency responders must slow their vehicles to a greater extent than passenger cars in order to navigate some traffic-control measures and traffic-calming measures. These entities should be involved in the planning, design, and implementation to ensure that the traffic-calming measures will not overly impede their operations.

Traffic-calming measures must be designed to accommodate fire trucks, ambulances, and other large vehicles that require specific turning radii and clearances. For example, vertical deflection treatments such as raised crosswalks and speed humps, may impair emergency-vehicle access

to hospitals or on-call sites and may be jarring for passengers on board. Additionally, horizontal treatments, such as roundabouts or curb extensions, must accommodate the wide turning radii of emergency response vehicles. Modifications to traffic-calming measures, such as traversable curb extensions, flex posts, and truck aprons may accommodate fire trucks and ambulances. Street closures and diverters can be designed with operable, transponder-responsive removable bollards that allow emergency access only.

FHWA's *Traffic Calming ePrimer* documents a range of studies which found speed tables and speed humps caused between 0 to 9 seconds of delay on emergency response times. The general magnitude of delay may vary by jurisdiction and other factors such as: vehicle type, type of traffic-calming measure, and testing procedure.

18.2.7 – Noise

By reducing vehicular speeds, traffic calming can reduce the volume of vehicular noise. Alternatively, vehicles traversing speed humps or other vertical treatments may generate noise upon impact (due to vehicle deceleration and acceleration). Potential consequences of traffic-calming measures on the adjacent community beyond the travel mode improvements desired, should be considered.

18.3 – Traffic Calming Design Considerations

Traffic-calming measures are intended to improve conditions for all transportation modes. Treatments should not cause undue burden on any single mode of transportation or categories of user. Traffic-calming planning requires interagency coordination and collaboration. The following sections provide an overview of traffic-calming considerations for pedestrians and bicyclists, emergency and transit vehicles, streetscape elements, snow removal, drainage, network impacts, and noise considerations. These considerations are expanded upon for each traffic-calming measure in Section 18.5.

18.3.1 – Pedestrian and Bicycle Passage

Pedestrian and bicycle passage should not be impeded or fully blocked by traffic-calming measures (curb extensions, etc.). Refer to Chapter 13, *Pedestrian Facilities,* and Chapter 14, *Bicycle Facilities*, for specific information regarding the design of pedestrian and bicycle infrastructure.

Per recent research, bicycle Infrastructure can serve as a traffic-calming measure. See FHWA's, *Separated Bike Lane Planning and Design Guide*, for additional information.

18.3.2 – Vehicle Accommodation

Public transit vehicles require accommodations in traffic-calming design. The local authority should coordinate with transit agencies to identify transit routes and stops when considering changes in geometric roadway design, especially vertical or horizontal treatments that may impede bus maneuvering or impact travel times. Transit vehicles typically drive along the curbside lane and require minimum clearances for lane width, curb height, vertical height, and lateral clearance.

More information on public transit accommodations may be found in Chapter 15, *Transit Facilities.* For more information on design controls, design vehicles, and control vehicles, refer to Chapter 2.

18.3.3 – Drainage

To avoid water accumulation (ponding) and ice formation, drainage shall be considered when determining appropriate traffic-calming measures and locations. Treatments may be designed to accommodate or improve existing drainage systems. Appropriate accommodation includes curb extensions with cutouts for curbs and gutters or landscaping to improve drainage and runoff.

18.3.4 – Snow Removal

Traffic-calming measures may impede the removal of snow and ice and should therefore be discussed in advance with PennDOT's County Maintenance Office or the local municipality's public works department. Refer to Appendix 18.B, Maintenance and Ownership.

Appropriate signage helps to alert snowplow operators where traffic-calming measures are present. Vertical traffic-calming measures constructed with more gradual slopes will allow for easier snow removal.

18.3.5 – Streetscape Elements

Traffic-calming projects are often coupled with streetscape and landscape improvements, such as tree-lined streets, landscaped curb extensions, permeable pavers, bioswales, and rain gardens. These can improve the aesthetics, stormwater management, and the overall effectiveness of the traffic-calming measures.

Streetscape and landscape designs at intersection should not include large trees or rocks, but should consist of smaller shrubs, plants, and features that will not obstruct sight distance. Sight-distance problems may also result from poor plant selection, lack of maintenance, or improper placement. Designers should consider plant type, growth, and location.

Typically, the local authority is responsible for maintenance of landscape and streetscape features. Responsibility can be legally assigned through a maintenance agreement or as part of a highway occupancy permit.

18.4 – Selection of Traffic-Calming Measures

18.4.1 – Traffic-Calming Study and Approval Process

Implementing a traffic-calming measure should be based on an established process. Refer to Appendix 18.A for information about the Traffic-Calming Study and Approval Process.

18.4.2 – Screening Tools and Process

The following two decision matrices can aid designers in the preliminary screening of traffic-calming measures for a site or project.

Exhibit 18.4.1 shows the typical applicability of various traffic-calming measures with respect to intended outcomes.

Exhibit 18.4.2 shows the applicability of each traffic-calming measure with respect to the five context classifications and posted speed ranges.

After a preliminary screening of potential traffic-calming measures, the toolbox criteria in Section 18.5, *Toolbox of Traffic-Calming Measures and Design Guidelines*, should be reviewed and consulted for further details. The toolbox outlines each of the potential traffic-calming measures with respect to advantages, disadvantages, impacts, opportunities, and effectiveness.

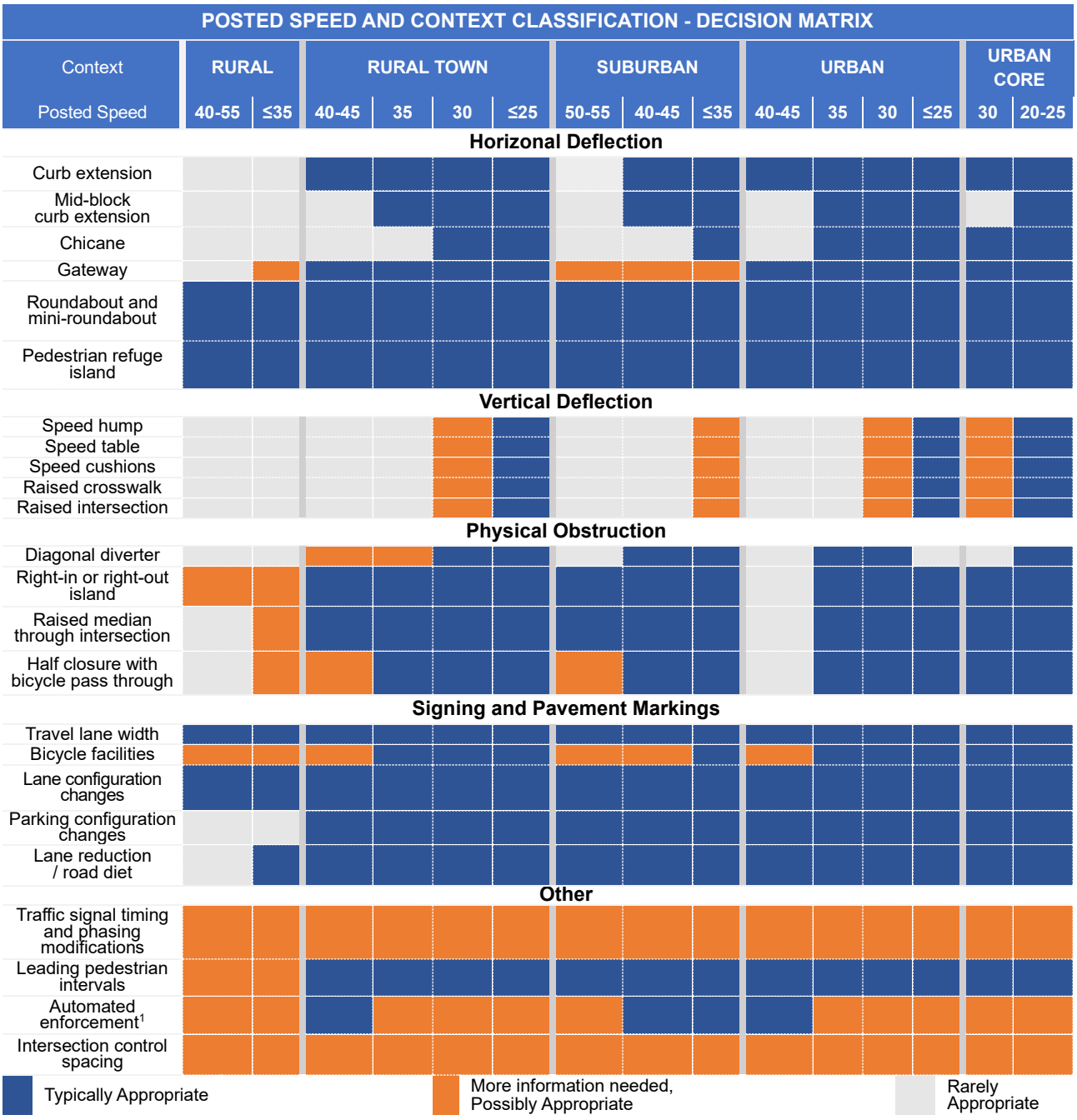
Exhibit 18.4.1 Intended Outcome

INTENDED OUTCOME OF TRAFFIC-CALMING IMPLEMENTATION – DECISION MATRIX									
Traffic-Calming Measure	Reduce Vehicular Operating Speeds	Reduce Vehicular Crash Severity and Frequency	Reduce Crossing Distance	Decrease Pedestrian Exposure	Increase Pedestrian Safety and Comfort	Reduce Conflict Points	Improved Visibility of Pedestrians	Improve Line of Sight for Pedestrians	Enhance Multimodal Connectivity and Access
Horizonal Deflection									
Curb extension and Mid-block curb extension	■		■	■	■		■	■	■
Chicane	■								
Gateway	■				■				
Roundabout and mini-roundabout	■	■	■	■		■			
Pedestrian refuge island	■		■	■	■		■	■	
Vertical Deflection									
Speed hump	■	■			■				
Speed table	■	■			■				
Speed cushions	■				■				
Raised crosswalk	■	■			■		■	■	■
Raised intersection	■				■		■	■	■
Physical Obstruction									
Diagonal diverter						■			
Right-in or right-out island			■	■		■			
Raised median through intersection			■			■			
Half closure with bicycle pass through						■			■
Signing and Pavement Markings									
Travel lane width	■		■	■	■				
Bicycle facilities						■			■
Lane configuration changes	■		■		■				■
Parking configuration changes	■				■				■
Lane reduction and road diet	■		■	■	■				■
Other									
Traffic signal timing and phasing modifications	■								
Leading pedestrian intervals				■			■		
Automated enforcement	■								
Intersection control spacing	■								■

■ **Applicable outcome**

NOTE: Refer to the traffic-calming toolbox for a complete description of the appropriate application of each measure.

Exhibit 18.4.2 Posted Speed and Context Classification



NOTE: Refer to the traffic-calming toolbox for a complete description of the appropriate application of each measure.[1] As applicable per regulations.

18.5 – Toolbox of Traffic-Calming Measures and Design Guidelines

Traffic-calming measures are chosen based upon criteria such as the site-specific context and conditions, the potential of measures to address volume or speed reduction on affected roadways, and the type of roadway. The intended goal of implementing traffic-calming measures is to enhance the safety of all users by reducing driver speeds, reducing conflicts between vehicles, pedestrians, and bicyclists, and reducing the frequency and severity of crashes.

Key points for traffic-calming measure selection include:

- Weighing the advantages and disadvantages associated with potential traffic-calming measures by comparing the measures' effectiveness in achieving intended outcomes.
- Considering tradeoffs, such as safety, accessibility, cost, maintenance, multiple roadway users, vehicles, and other modes of transportation.

Detailed information is provided for each traffic-calming measure within the toolbox, such as:

- Description and Purpose.
- Typical Application (e.g., traffic volumes, speed, functional classification, number of travel lanes, grade, curves, context: land use and area) with example images.
- Advantages and Disadvantages.
- Effectiveness (e.g., speed and crash reduction).
- Design, including criteria (e.g., dimensions, spacing, pavement marking, location, signage, lighting) and details.
- Design Considerations and Context.

Traffic-calming measures are organized into five categories in the toolbox: horizontal deflection, vertical deflection, physical obstruction, signing and pavement markings, and other.

18.5.1 – Horizontal Deflection

Horizontal deflection refers to two types of traffic-calming measures for managing speeds. The first type hinders the driver's ability to drive in a straight line by creating a horizontal shift in the roadway. This shift forces drivers to slow their vehicles to safely navigate the measure.

The second type of horizontal deflection measure is designed to narrow the width of the travel lane. Reducing the width of the travel lane causes drivers to slow their vehicles to maintain an acceptable level of comfort. In addition, horizontal deflection measures that narrow the travel lane can improve pedestrian safety by reducing the length of the crossing.

Horizontal deflection measures may also have the secondary effect of reducing volumes; however, the effects will typically be minor.

The toolbox includes the following horizontal deflection traffic-calming measures:

18.5.2 – Curb extension and Mid-Block Curb Extension

18.5.3 – Chicane

18.5.4 – Gateway

18.5.5 – Single-lane Roundabouts and Mini-Roundabouts

18.5.6 – Pedestrian Refuge Island

18.5.2 – Curb Extension and Mid-Block Curb Extension

Description and Purpose

Curb extensions narrow the width of a roadway through the expansion of the sidewalk and curb, usually to the edge of an on-street parking lane. Curb extensions, also referred to as bulb-outs or bump-outs, can be implemented at an intersection or at mid-block.

The purpose of a curb extension is to reduce pedestrian crossing distance and exposure to traffic, improve the line of sight for pedestrians, make pedestrians more visible to oncoming traffic, encourage slower vehicular speeds by narrowing the street width, and reduce right-turn vehicle speeds by reducing the curb radius.

Mid-block curb extensions (often referred to as chokers, pin points, or neckdowns) can be created by a pair of curb extensions located mid-block or by using other roadway-narrowing physical devices, such as planters or roadside islands. Mid-block curb extensions provide opportunities to increase public space, including additional sidewalk and greenspace.

Daylighting is when parking restrictions are created at intersection corners using signage, pavement markings, or flexible post delineators. This short-term or temporary traffic-calming measure provides many of the same benefits as curb extensions (e.g., improve pedestrian visibility, shorten unprotected crossing distance, narrow street widths). See Publication 111, TC-8604, for pavement delineation details type SM-1 and Chapter 13. See **Exhibit 18.5.5** for an example of daylighting.

Exhibit 18.5.1 Intersection Curb Extension



Exhibit 18.5.2 Mid-Block Curb Extension



Exhibit 18.5.3 Curb Extension Typical Application

CURB EXTENSION TYPICAL APPLICATION		
	INTERSECTION	**MID-BLOCK**
SPEED	Appropriate for a maximum speed limit of 40 mph. Additional consideration should be given to mid-block curb extensions if the travel lanes are narrowed, such as adequate shy distance between the travel lane and the mid-block curb extension. Refer to Chapter 13 for additional design considerations for mid-block crosswalks, or crosswalks at unsignalized intersections.	
STREET FUNCTIONAL CLASSIFICATION	Appropriate for all street types with on-street parking.	Appropriate on all roadway types, but contexts such as land use, speeds, and geometry should be considered.
NUMBER OF TRAVEL LANES	Appropriate for streets with any number of travel lanes.	May be used on one-lane, one-way, two-lane, one-way, and two-lane, two-way streets.
CURVES	May be installed on a vertical curve, when adequate stopping sight distance and/or warning signs are provided.	
CONTEXT: LAND USE AND AREA	Appropriate in urban, suburban, and rural town settings. Works well in downtown areas and near pedestrian generators or high levels of pedestrian activity. Also applicable in residential areas, commercial corridors, community places (e.g., transit stop, school, library, park), or an emergency route.	Generally, not acceptable in rural areas where vehicle speeds are typically higher and pedestrian volumes are low or non-existent. Work well in rural towns and on non-arterial suburban, urban, and urban core roadways.

Exhibit 18.5.4 Advantages and Disadvantages of Curb Extensions

ADVANTAGES	DISADVANTAGES
• Reduces right-turn vehicle speeds at intersections with tighter curb radii and slows traffic by narrowing vehicle travel lanes. • Manages traffic volumes by reducing cut through traffic. • Improves pedestrian safety: reduces crossing distance and therefore decreases pedestrian exposure, improves pedestrians' line of sight, and improves visibility of pedestrians for oncoming traffic. • Facilitates pedestrian access to transit. • Enhances neighborhood appearance through the inclusion of landscaping, green stormwater infrastructure, or textured treatments. • Can prevent motorists from parking too close to an intersection or crosswalk. • Can have lower cost options through use of pavement marking and flexible post delineators as a short-term improvement. • Improves traffic signal operations.	• May result in the loss of one on-street parking space on each side of the roadway. • May cost more than other traffic-calming measures. • Makes turning movements more difficult for large vehicles and trucks. • Presence of existing drainage features may increase the cost of implementation, because of drainage impacts. • Potential for utility impacts in urban areas. (Some jurisdictions use pavement markings to designate curb extension areas and use raised pedestrian median refuge islands to reduce drainage and utility impacts.) • Impacts snow removal.

Effectiveness

Research has shown a reduction in speeds at mid-block locations where curb extensions are installed. Studies conducted in urban locations measured a reduction in the 85th percentile speeds by 1 to 4 mph.

Exhibit 18.5.5 Curb Extension Design Features and Typical Design Criteria

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Typical width is 6 to 8 ft from the existing curb (typically 1 to 2 ft narrower than the parking lane). • 10-ft corner curb radii are typical, but it is determined by design and/or control vehicle (e.g., trucks, emergency vehicles, school buses). • 10-ft transition curb radii are typical as depicted in **Exhibit 18.5.6**. • Length of choker or mid-block curb extension should include the full width of the crosswalk, and it is best practice to design the curb extension to extend 20 ft from the edge of the crosswalk to the point of reverse curvature to provide a clear sight line from where vehicles are able to park.
PAVEMENT MARKING	• Daylighting with pavement markings and flexible post delineators can provide similar benefits to curb extensions in a short-term or temporary application.
LOCATION	• Primarily located at intersections. • Can be installed at mid-block locations. Mid-block curb extensions may be combined with a crosswalk. (The designer can refer to Form TE-113 for mid-block crosswalk criteria and Publication 46, *Traffic Engineering Manual,* for unsignalized midblock crosswalk information.) When mid-block curb extensions are not combined with a crosswalk, they are typically referred to as a choker.
LIGHTING	• Placement near street lighting is preferred for mid-block curb extensions.
LANDSCAPING	• May be incorporated into the design of curb extensions but adequate sight lines must be provided. Likewise, consideration should be given to the safety requirements and depth needed to support plants and the depth required for utility lines, as well as provide a safe space for pedestrians.

Exhibit 18.5.6 Typical Curb Extensions or Bulb Outs

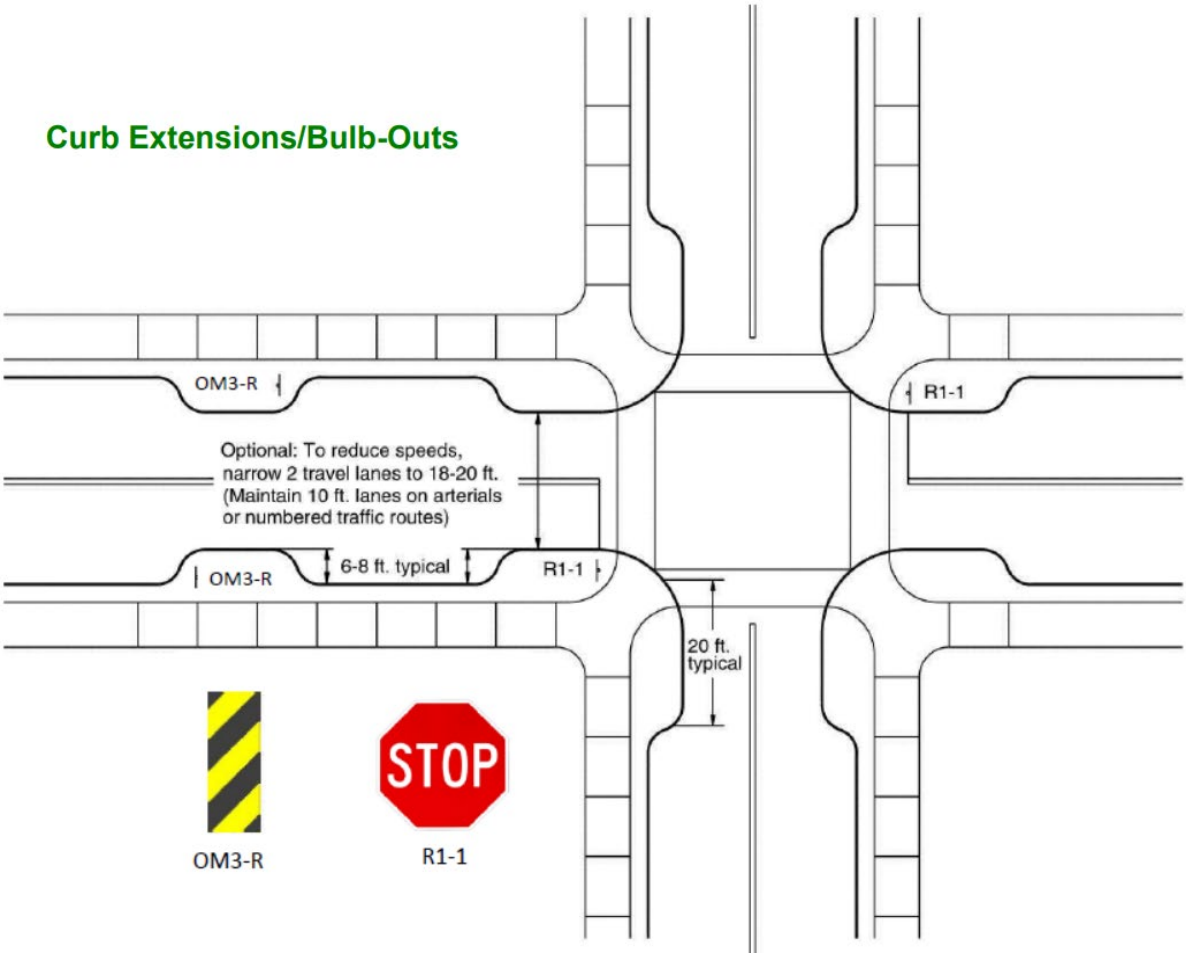


Exhibit 18.5.7 Curb Transition Radii with 10 ft Radii

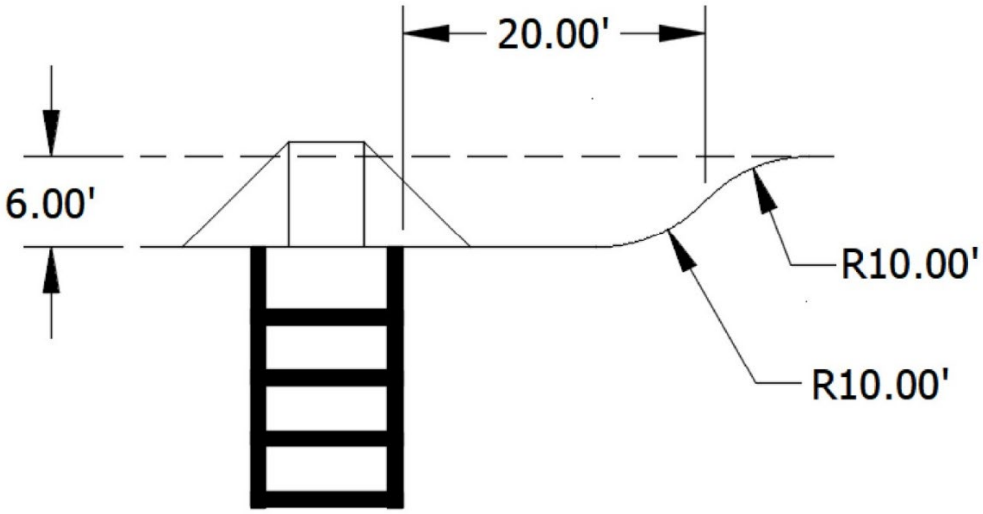
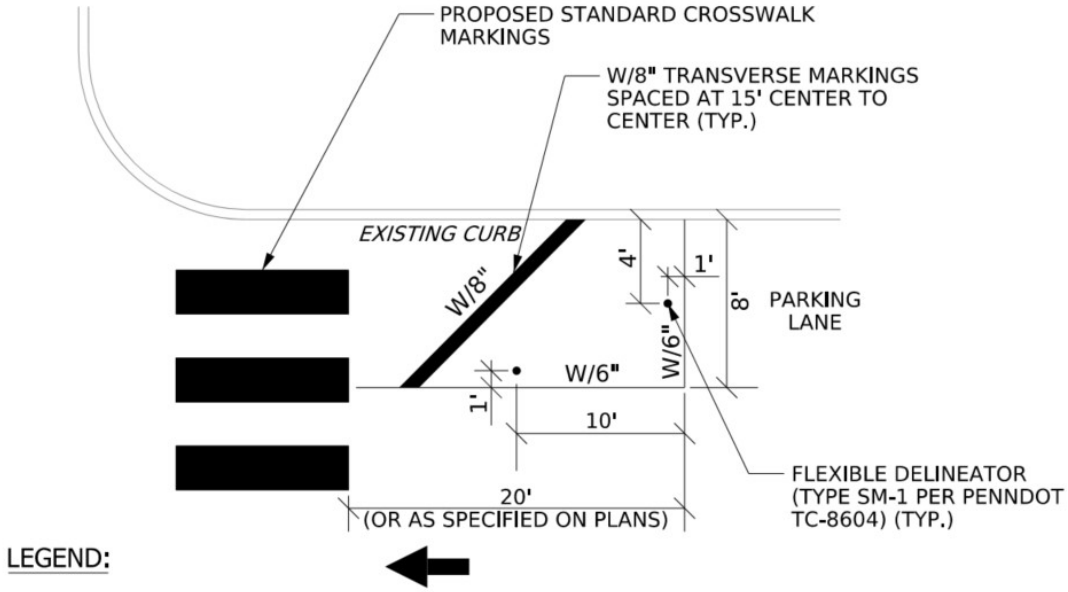


Exhibit 18.5.8 Intersection Daylighting



INTERSECTION DAYLIGHTING

NOT TO SCALE

Design Considerations and Context

- **Located at transit stops (bus bulbs).** Curb extensions located at transit stops can provide advantages to riders boarding and alighting. In this context, the location of the bus doors could impact the length of the curb extension, which should be long enough to accommodate simultaneous loading and unloading from front and rear doors.
- **Located at mid-block locations.** Mid-block curb extensions that include vertical features should not obstruct the driver's view of pedestrians. It is preferable that mid-block curb extensions be located at crosswalk locations. Raised crosswalks may be combined with mid-block curb extensions to accommodate pedestrian activity and further slow traffic.
- **Multifunctional use.** Intersection and mid-block curb extensions can incorporate landscaping features and be used to collect stormwater.
- **Bicycle and pedestrian facilities.** Curb extensions should be designed to accommodate bicycle movements that avoid vehicular conflicts and incorporate accessible curb ramps and detectible warnings for pedestrians. Travel lane width may be reduced for bicyclists. Curb extensions can be used in conjunction with separated bicycle facilities, where the curb extension includes an opening for the bike facility along the curb or a bypass lane for bicyclists.

  Mid-block curb extensions provided on both sides of a street (i.e., pin points) can narrow the roadway and serve as a form of speed control on neighborhood bikeways or bicycle boulevards. Bicycle facilities can be designed to cut through curb extensions.
- **Maintenance.** With the implementation of curb extensions, typical maintenance considerations include street sweeping impacts, snowplowing impacts, and landscaping maintenance.
- **Temporary materials.** The application of pavement markings, flex curb, and flexible post delineators can be used for daylighting at intersection approaches as a short-term or temporary application.

18.5.3 – Chicanes

Description and Purpose

Chicanes (also referred to as lane offsets, serpentines, or reversing curves) lower speeds by requiring motorists to shift laterally through a series of alternating curves, staggered parking, or alternating curb extensions. Chicanes may narrow the width of the roadway or width of travel lanes. They provide opportunities to increase public space, including additional sidewalks and greenspace. Medians may be used at deflection points to prevent speeding motorists from disregarding roadway markings.

Exhibit 18.5.9 Examples of Chicanes





(Source: United States Department of Transportation, *PedSafe*)

Exhibit 18.5.10 Chicane Typical Application

CHICANE TYPICAL APPLICATION	
TRAFFIC VOLUMES	Appropriate on low to moderate volume roadways. Most effective when traffic volumes are balanced in each direction. For higher volume roadways, additional considerations should be documented.
SPEED	Maximum posted speed limit of 35 mph.
STREET FUNCTIONAL CLASSIFICATION	Typically, only implemented on local roadways in non-rural locations.
NUMBER OF TRAVEL LANES	Appropriate on single-lane, one-way streets and two-lane, two-way streets.
GRADE	Avoid locations where grades exceed 8%.
CURVES	Applicable on vertical curves, given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	Works well in downtown areas and near pedestrian generators or high levels of pedestrian activity. Also applicable in mixed land uses, including residential areas and community places (e.g., transit stop, school, library, park). Not recommended in rural contexts.

Exhibit 18.5.11 Advantages and Disadvantages of Chicanes

ADVANTAGES	DISADVANTAGES
• Reduces travel speeds by introducing horizontal deflection, narrowing vehicle travel lanes, and narrowing the roadway. • Manages traffic volumes by reducing cut through traffic. • Improves pedestrian safety; reduces crossing distance and therefore decreases pedestrian exposure; improves the visibility of pedestrians for oncoming traffic. • Enhances neighborhood appearance through the inclusion of landscaping, green stormwater infrastructure, or textured treatments. • Can be created by alternating on-street parking but must be occupied with parked vehicles to effectively promote traffic calming. • Minimally impacts drainage. • Reduces traffic noise.	• May result in the loss of some on-street parking. • Impacts emergency response time and heavy vehicle movements. • The presence of existing drainage features may increase the cost of implementation, due to drainage impacts. • Impacts snow removal.

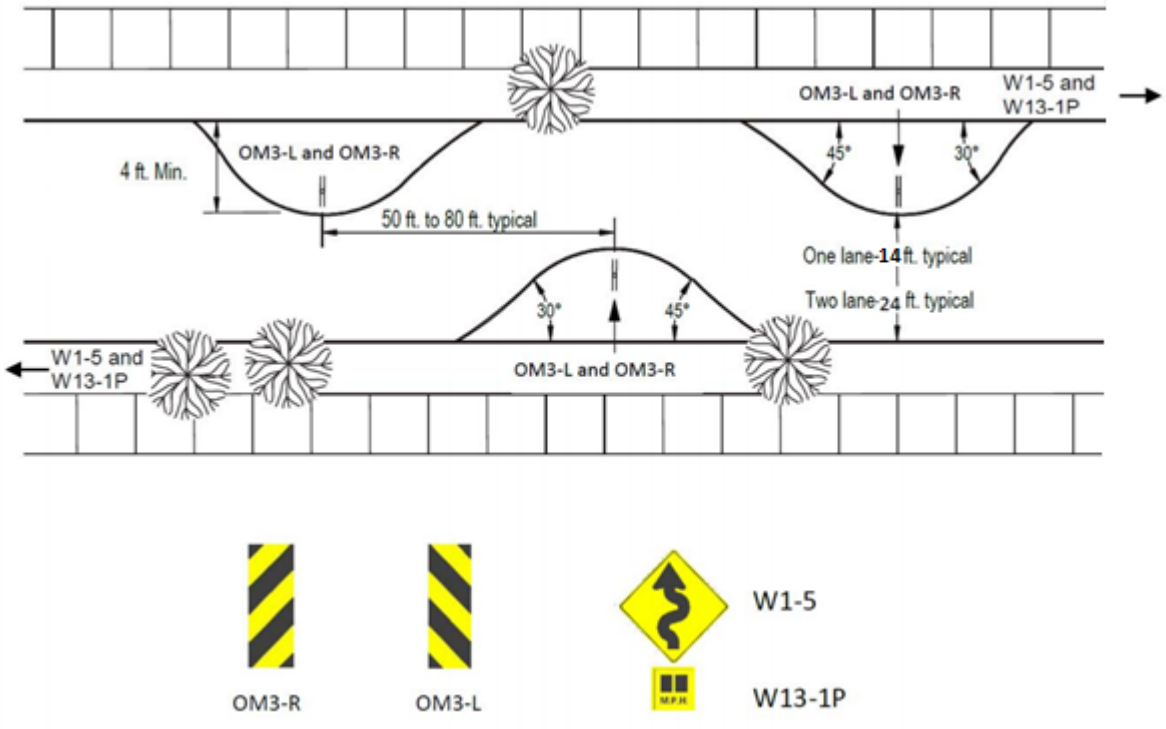
Effectiveness

Chicanes can reduce vehicle speeds within the chicane by 5 to 13 mph and vehicle speeds approaching and exiting the chicane by 1 to 6 mph. Studies have demonstrated that chicanes can reduce 85th percentile speeds by 3 to 9 mph.

Exhibit 18.5.12 Chicane Design Features and Typical Design Criteria

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• The recommended average lane width between chicane build-out and the opposite curb is a 14-ft clearance on one-way streets and a 24-ft clearance on two-way streets and determined by the design and/or control vehicle (e.g., emergency, transit vehicles). In addition, minimum required lane widths in Chapters 3, 4 and 5 must be met. • Flexibility can be considered if narrower spaces are desired, but decisions should be supported by design vehicle turning templates to ensure no overlapping vehicle paths. • The path angle of chicane treatments impacts speed reduction. A deflection angle of 30 to 45 degrees is recommended. • The number and length of chicane treatments depend on the length of roadway between intersections. A chicane should include a minimum of three shifts in the travel lanes using alternating treatments such as curb extensions, islands, or parking. • For design speeds of 15 to 20 mph, create a chicane with at least one reverse curve, minimum radius of 50 ft (15 mph) to 100 ft (20 mph) and offset curb extensions into travel lane (minimum of 4 ft to a full travel lane.)
SPACING	• The stagger length between chicane treatments is dependent on the location of driveways and drainage systems. • Stagger length has a direct impact on vehicle speeds. Reducing the stagger length has been shown to reduce speeds more effectively. The typical spacing ranges from 50 ft to 80 ft.
PAVEMENT MARKING	• Pavement markings can be used to increase safety and alert motorists to a curvature in the street. Street centerlines keep vehicles from traveling straight through chicanes.
LOCATION	• Must be installed at mid-block locations.
SIGNAGE	• The Winding Road (Left) sign, W1-5L, with an appropriate Advisory Speed plaque, W13-1P, should be used at least 150 ft in advance of a chicane. Reflectors, street lighting, and elevated landscaping can be used to improve visibility.

Exhibit 18.5.13 Chicane Dimension Details



Design Considerations and Context

- **Located at mid-block.** Chicanes may utilize curb extensions paired with mid-block pedestrian crosswalks, where appropriate.
- **Multifunctional use.** Chicanes can incorporate landscaping features, on-street parking, or additional sidewalk pavement, and can be used to collect and filter stormwater.
- **Bicycle facilities.** Chicane treatments should accommodate bicycles on major bicycle thoroughfares, as the effective roadway width is reduced. Where bicycle routes and chicane treatments are paired, effective striping of shared-lane markings and shared-roadway signage should be used to alert motorists and bicyclists. Chicane designs can feature bike lane cutouts to create additional space and allow bicyclists to bypass the traffic-calming measure.
- **Warning measures.** Chicanes may require additional lighting, signing, and striping to ensure that motorists are aware of a winding roadway.
- **Drainage.** Where a chicane design might adversely impact drainage, curb extensions can be designed as islands located 1 to 2 ft from the curb.

- **Maintenance.** Landscaping should only be incorporated into traffic-calming devices where clear maintenance responsibilities have been established. PennDOT typically requires an agreement with municipalities for maintenance responsibilities.
- **Materials.** Short-term materials, such as flex-posts, planters, and other street furniture, may be used as interim treatment options.

18.5.4 – Gateway

Description and Purpose

Gateways use physical and textural changes to indicate the entrance to areas with higher pedestrian activity and slower-speed environments, such as urban cores, residential neighborhoods, school zones, or shared streets. Gateways provide identity to an area and include features such as curb extensions, raised crosswalks, signs, textured pavement, street furniture, and landscaping to narrow the apparent width of the roadway and potentially reduce the operating speed of motorists.

Exhibit 18.5.14 Example Neighborhood Slow Zone Gateway



(Source: Kittelson & Associates, Inc.)

Exhibit 18.5.15 Gateway Typical Application

GATEWAY TYPICAL APPLICATION	
SPEED	Applicable for transition areas between roadways with higher speeds and roadways with lower speeds.
STREET FUNCTIONAL CLASSIFICATION	Appropriate on arterials, collectors, and local roads.
NUMBER OF TRAVEL LANES	Appropriate on single-lane, one-way streets and two-lane, two-way streets.
CURVES	Applicable on vertical curves given adequate stopping sight distance.
CONTEXT: LAND USE AND AREA	Works well in rural towns, urban areas, and urban cores. Also applicable in residential areas, commercial corridors, and community places (e.g., transit stop, school, library, park). Not typically applicable in rural contexts (without high pedestrian activity, or in higher speed areas) but could be considered as part of other potential traffic-calming measures to increase effectiveness (for example, curb extensions or textured pavement). May be used to maintain neighborhood character and create a sense of place.

Exhibit 18.5.16 Advantages and Disadvantages of Gateways

ADVANTAGES	DISADVANTAGES
• Reduces travel speeds. • Manages traffic volumes by reducing cut through traffic. • Improves pedestrian safety: reduces speeds in pedestrian activity areas and increases motorist awareness. • Enhances neighborhood appearance through the inclusion of landscaping, green stormwater infrastructure, or textured treatments. • May be combined with other traffic-calming measures (e.g., raised crosswalks, curb extensions) to increase effectiveness. • Improves parking compliance.	• Impacts emergency response time and heavy vehicle turning movements. • The presence of existing drainage features may increase the cost of implementation, due to drainage impacts. • Impacts snow removal. • Increases traffic noise if textured pavements are used.

Effectiveness

Research has shown a reduction in speeds at mid-block locations where gateway curb extensions are installed. European studies report that gateway traffic-calming measures achieve speed reductions of 3 to 13 mph.

Exhibit 18.5.17 Gateway Design Features and Typical Design Criteria

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Dependent on the type of gateway treatment. To be designed for an appropriate design and/or control vehicle (e.g., trucks, emergency vehicles, school buses). • Curb Extensions may be implemented as part of gateway design details. • Raised Median Through Intersection may be implemented as part of gateway design details.
LOCATION	• Located at entrances to Slow Zone areas, such as a school zone, neighborhood, or high-pedestrian traffic area. • May be installed at intersection or mid-block locations. Mid-block curb extensions may be combined with a crosswalk.
SIGNAGE	• Gateways may include signage to indicate entrance into a Slow Zone area.

Design Considerations and Context

- **Land use or speed limit changes.** Gateways can be used to mark a change in land use or speed limit.
- **Combination of traffic-calming measures.** Gateways are most effective when used in combination with other traffic-calming measures. Textured pavements, curb extensions, and medians may be combined to create effective gateway treatments.
- **Multifunctional use.** Gateways can incorporate landscaping features and be used to collect stormwater. Serves to slow vehicles and increase awareness for drivers entering slower zones.
- **Bicycle and pedestrian facilities.** Treatments should not impede bicyclists or pedestrians and should further accommodate comfortable movement. Curb extensions can be used in conjunction with a separated bicycle facility, where the curb extension includes an opening for the bicycle facility along the curb.
- **Maintenance.** Landscaping should only be incorporated into traffic-calming devices where clear maintenance responsibilities have been established. Additionally, snowplow operators should be informed where gateway treatments are present.

18.5.5 – Single-lane Roundabouts and Mini-Roundabouts

Description and Purpose

A roundabout is an intersection control treatment where traffic entering the circulatory roadway yields to circulating vehicles. They are not to be confused with traffic circles which are designed and operate differently.

There are safety and operational benefits to installing a roundabout. Safety benefits include a reduction in crash frequency, a reduction in crash severity, and slower vehicle speeds. Operational benefits include the potential for lower delays and queues compared to other intersection forms, in addition to the opportunity to reduce turn-lane requirements due to geometric characteristics.

Single-lane roundabouts and mini-roundabouts are included as traffic-calming measures because the geometric design of these intersection treatments can change the operating character of a roadway and slow speeds. Roundabouts can be effective in conjunction with other traffic-calming measures to reinforce a change in environment (for example, as a gateway treatment where higher-speed facilities transition to lower-speed facilities with pedestrian presence). A single-lane roundabout typically has a non-traversable central island. A mini-roundabout is a small roundabout with a fully traversable central island. They are typically used in an urban environment with operating speeds of 30 mph or less.

National Cooperative Highway Research Program's (NCHRP) Research Report 1043: *Guide for Roundabouts,* describes planning, operations, safety, geometric design, illumination, landscaping, and the construction and maintenance of roundabouts.

Refer to Chapter 6, *Intersections and Driveways,* Section 6.12, for more information about roundabout design.

Exhibit 18.5.18 Example Roundabout Constructed for Traffic Calming



Exhibit 18.5.19 Example Mini-Roundabout



(Source: Jimmie Brown, PennLive)

Exhibit 18.5.20 Single-lane Roundabout and Mini-Roundabout Typical Application

ROUNDABOUT TYPICAL APPLICATION	
TRAFFIC VOLUMES	• Typical daily traffic volume for a single-lane roundabout is up to approximately 25,000 vehicles per day. • Typical daily traffic volume for a mini-roundabout is up to approximately 15,000 vehicles but could potentially be higher.
SPEED	• Typical operating speeds for a single-lane roundabout or a mini-roundabout range from 20 to 25 mph or 15 to 20 mph, respectively.
STREET FUNCTIONAL CLASSIFICATION	• Appropriate for the intersections of arterial, collector, and local roadways.
GRADE	• Roundabouts are typically not recommended in locations where the grades through the intersection exceed 4%.
CURVES	• Provide adequate sight distance and visibility of the intersection.
CONTEXT: LAND USE AND AREA	• Can be appropriate in both urban and suburban settings.

Exhibit 18.5.21 Advantages and Disadvantages of Single-lane Roundabouts and Mini-Roundabouts

ADVANTAGES	DISADVANTAGES

• Improves safety by:
  ○ reduces crash frequency and severity
  ○ eliminates left-turn crashes
  ○ slows vehicle speeds
  ○ reduces conflict points compared to a traditional four-approach intersection
  ○ allows pedestrians to cross one direction of traffic at a time when splitter islands are provided
• Improves operational benefits with fewer delays and queues compared to other intersection forms and provides an opportunity to reduce turn-lane requirements.
• Enhances neighborhood appearance with landscaping.
• Accommodates trucks and large vehicles.
	• A larger right-of-way is required at the intersection but raises the potential for decreased right-of-way along the roadway approaches. (Turn lanes may not be required for achieving desired operations.)
	• The yield control entry to a roundabout presents challenges for pedestrians with visual disabilities. Consult Chapter 6 and NCHRP's *Report 834* for guidance on addressing these challenges at roundabouts.

Effectiveness

A roundabout is an FHWA Proven Safety Countermeasure and provides safety and operational benefits. Speed reduction is a factor of the design of the approach lanes of the roundabout. Research demonstrates a reduction in speeds at roundabouts. A study conducted in an urban area measured a 14-mph reduction in 85th percentile speeds; a study conducted in a suburban area measured an 8-mph reduction in 85th percentile speeds.

Research shows converting a two-way stop-controlled intersection to a roundabout yields an 82% reduction in severe crashes. Similarly, converting a signalized intersection to a roundabout yields a 78% reduction in severe crashes.

Exhibit 18.5.22 Single-lane Roundabout and Mini-Roundabout Design Features and Typical Design Criteria

Refer to Chapter 6 for single-lane roundabout geometric design features.

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Inscribed circle diameter (ICD) varies for each type of roundabout. The ICD of a modern single-lane roundabout typically ranges from 90 to 160 ft and 45 to 90 ft for a mini-roundabout. The ICD can vary, depending on the site context.
SPACING	• Closely spaced roundabouts may create a traffic-calming effect. However, design considerations include providing adequate spacing of 95th percentile queues.
LIGHTING	• May require additional street lighting on a roadway.
LANDSCAPING	• Landscaping must not interfere with minimum sight distance requirements.

Design Considerations and Context

- **Mini-roundabout.** Key additional design considerations for mini-roundabouts include vehicle channelization, design vehicle paths, and intersection visibility.
- **Context Considerations.** For additional context considerations, the designer can refer to Chapter 1 and NCHRP Research Report 1043, Guide for Roundabouts, Chapter 3: *A Performance-Based Planning and Design Approach*.
- **Accessible Design.** The designer can refer to NCHRP's *Report 834: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook* for accessible design considerations.
- **Bicycle and Pedestrian Facilities.** The designer can refer to NCHRP Research Report 1043, Guide for Roundabouts, Chapter 4: *User Considerations*; and to Chapter 13, *Pedestrian Facilities*, and Chapter 14, *Bicycle Facilities*, for additional considerations.
- **Maintenance.** The designer can refer to NCHRP Research Report 1043, Guide for Roundabouts, Chapter 15: *Construction and Maintenance,* which discusses landscaping maintenance, snow plowing and storage, and pavement maintenance and rehabilitation. The operating and maintenance costs of a roundabout tend to be higher than other unsignalized intersections but less than a signalized intersection.
- **Temporary materials.** Pavement markings and flex-posts can be used to convert an existing traffic circle, or intersection of two-lane roads to a roundabout.

18.5.6 – Pedestrian Refuge Island

Description and Purpose

Pedestrian median refuge islands provide added protection for pedestrians and bicyclists crossing at an intersection or mid-block and simplify each crossing into stages dealing with traffic from one direction at a time. Refuge islands may be incorporated into medians that are depressed, raised, or flush with the road surface. Pedestrian refuge islands are particularly helpful for assisting people with disabilities, older adults, children, and others less able to cross the street in a single stage.

Information regarding the design of pedestrian refuge islands is provided in Chapter 13.

Exhibit 18.5.23 Examples of Pedestrian Refuge Islands



(Source: NACTO)



(Source: NACTO)

Exhibit 18.5.24 Pedestrian Refuge Island Typical Application

PEDESTRIAN REFUGE ISLAND TYPICAL APPLICATION	
TRAFFIC VOLUMES	Applicable for all volumes. Recommended on urban and suburban roadways with a mix of bicycle and pedestrian activity and an ADT volume greater than 9,000.
SPEED	Applicable for all urban speed limits. Recommended for roadways with travel speeds of 35 mph or greater.
STREET FUNCTIONAL CLASSIFICATION	Appropriate on local, collector, and arterial roadways in both urban and suburban settings.
STREET WIDTH	Recommended if the crossing distance is greater than 60 ft. Depending on context, pedestrian refuge islands may be installed on narrower streets (30 ft wide minimum) or narrower if using the through crosswalk example.
NUMBER OF TRAVEL LANES	Appropriate on any size street. On larger streets pedestrian refuge island would need to be accompanied with other measures (such as signalized crossings).
CURVES	Can be applied on crest curves given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	Acceptable in all land use contexts.

Exhibit 18.5.25 Advantages and Disadvantages of Pedestrian Refuge Islands

ADVANTAGES	DISADVANTAGES
• Separates conflict points by allowing pedestrians to focus on one direction of traffic at a time and reduces crossing distance. • Improves pedestrian and bike safety: narrows lane width which results in slower vehicle speeds. • Can enhance neighborhood appearance with landscaping, green stormwater infrastructure, or added pedestrian infrastructure. • Minimizes impacts on drainage. • Improves pedestrian visibility of vehicles, vehicles have better visibility of pedestrians and can reduce right turning vehicle conflicts. • Limited impacts on emergency response and large vehicles access and operations.	• May impact snow removal efforts. Median delineators can be used to alert snow removal teams. • May require the removal of on-street parking to maintain appropriate travel lane width and turning radii.

Effectiveness

Pedestrian refuge islands reduce pedestrian exposure and increase the visibility of people who walk and bike. Pedestrian refuge islands and raised medians are FHWA Proven Safety Countermeasures and provide safety benefits, although the expected speed reduction is relatively low. Speed reductions range from 2 to 3 mph on average.

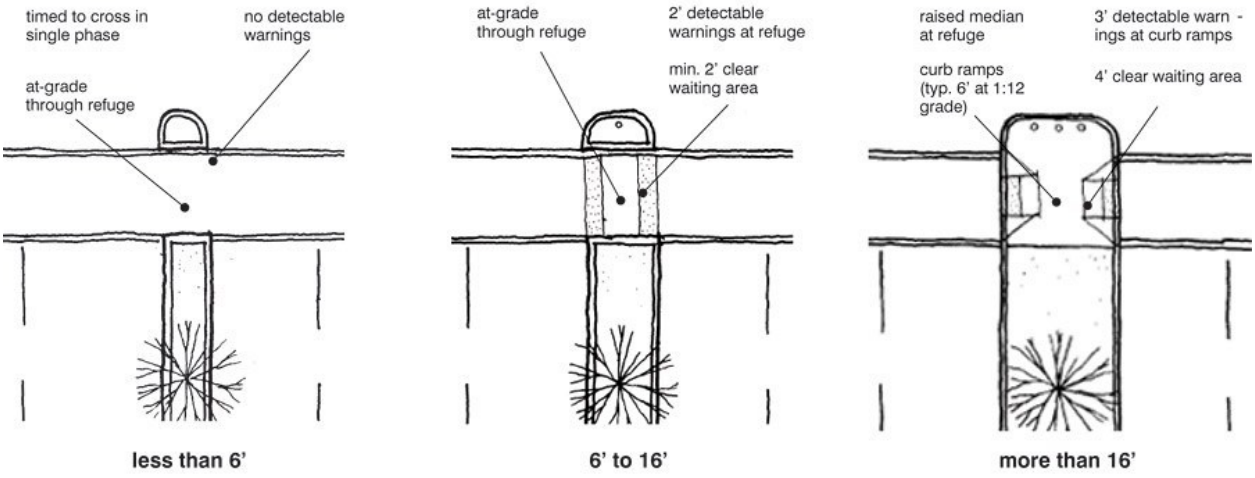
Research demonstrates that the installation of raised medians with marked crosswalks in urban or suburban areas results in a 46% reduction in pedestrian crashes; the installation of pedestrian refuge islands results in a 56% reduction in pedestrian crashes. Research also shows that raised medians and pedestrian refuge islands reduce the likelihood of crashes occurring as pedestrians cross the road in evening conditions by 78%.

Adding lighting, signage, and pedestrian crossing devices to the installation of raised medians and pedestrian refuge islands will ensure they are visible to motor vehicles.

Exhibit 18.5.26 Pedestrian Refuge Island Design Features and Typical Design Criteria

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Refer to Chapter 13. • Medians should be approximately 20 ft in length to discourage vehicle violations (e.g., illegal U-turns, parking). • The width of a pedestrian refuge island should be a minimum of 6 ft wide in the direction of travel to allow for 24-in detectable warning surface at each edge, and at least 24 in between the surfaces. When the 6-ft width cannot be achieved, detectable warning surfaces are not required. • The length of the pedestrian opening in refuge islands could be 5 ft minimum but should be 8 to 10 ft if accommodating bi-directional pedestrian and bicycle travel.
SPACING	• Spacing and length of medians to prevent violations can be found in Chapter 3 and Chapter 6.
PAVEMENT MARKING	• Reflective markers and/or markings should be used on the approaching sides of the curve. • Pavement markings should follow the *Approach Markings for Obstructions* section in the MUTCD. • The refuge pavement should be different than the roadway pavement, especially if the refuge is at grade.
LOCATION	• Refuge islands can be added at an existing crosswalk or with the addition of a crossing at an intersection or mid-block.
SIGNAGE	• Recommended signage includes R6-1, R4-7, R7-4 (Advanced Stop). • Bicycle signals or Rectangular Rapid Flashing Beacons (RRFB) can be used to inform drivers when a bicyclist or pedestrian is present at mid-block locations.
LIGHTING	• Median islands can be used for additional lighting infrastructure and signage. Signs over 2 ft tall should be checked to assure clear line of sight.

Exhibit 18.5.27 Pedestrian Refuge Island Dimension Details



(Source: SF Better Streets)

Design Considerations and Context

- **Raised median requirements.** The designer should consider raised median design requirements and suggestions outlined in NCHRP Report 500, Volume 10: *A Guide for Reducing Collisions Involving Pedestrians, Strategy 9.1 A3*.
- **Multifunctional use.** Raised medians can incorporate landscaping features, on-street parking, additional sidewalk pavement, transit facilities, and water treatment facilities.
- **Maintenance.** Landscaping should only be incorporated in traffic-calming devices where clear maintenance responsibilities have been established. PennDOT requires a maintenance agreement with local municipalities.
- **Local driveways.** Placing medians at or near home or business driveways should be avoided.
- **Landscaped medians.** Medians should have a 2-ft walkable edge to safely accommodate maintenance workers.
- **Raised versus at-grade refuge.** If the median width is greater than 16 ft, the refuge should be raised with ADA-compliant ramps and a 4-ft clear waiting area. If the median width is between 6 and 16 ft, the refuge should be at grade with 2-ft detectable warning strips on each side and a minimum 2-ft clear zone. If the pedestrian refuge area is primarily for bicycle use, at-grade refuges are recommended.
- **Angled refuge and Z-shaped refuge islands.** Angled 45-degree or Z-shaped refuge islands can be placed to turn users toward the oncoming traffic lane. Angled 45-degree refuges are recommended for exclusive bicyclist paths. Z-shaped refuges are

recommended for pedestrians, as the adjacent crosswalk should be perpendicular to the direction of vehicular travel; however, pedestrians may find them unattractive.

18.5.7 – Vertical Deflection

Vertical deflection refers to traffic-calming measures that create a change in the height of the roadway. When designed properly, drivers must slow down when traveling over these measures to maintain driver comfort. As with horizontal deflection measures, vertical deflection measures can be used to manage vehicle speeds, with only minor effects on traffic volumes. Vertical deflection measures can also be used to improve the safety of pedestrian crossings.

The toolbox includes the following vertical deflection traffic-calming measures:

- 18.5.8 – Speed Hump, Speed Cushion, and Speed Table
- 18.5.9 – Raised Crosswalk
- 18.5.10 – Raised Intersection

18.5.8 – Speed Hump, Speed Cushion, and Speed Table

Description and Purpose

A speed hump is a raised traffic-calming device located mid-block in the roadway to slow vehicular traffic and reduce speeds through vertical deflection. Typically, speed humps are 12 to 14 ft long in the direction of vehicle travel and 3 to 4 in high.

The spacing of speed humps typically determines the speed at which motorists can drive. For example, spacing of approximately 250 to 400 ft tends to achieve an 85th percentile operating speed of between 25 and 35 mph.

Speed cushions have similar dimensions and applications as speed humps, and are typically 3 in high, 6 ft wide, and 7 to 14 ft long. Speed cushions comprise two or more raised areas placed laterally across a roadway, with space between the raised areas that allow wider-axle emergency vehicles to cross with minimal disruption. Speed slots (a modified speed cushion) are typically 3 in high, 6 to 7 ft wide, and 22 ft long. On arterials, PennDOT recommends installing speed slots.

Speed tables also have similar dimensions and applications as a speed hump, except that they have a flat top designed to accommodate the wheelbase of a passenger car (generally 10 ft long). Speed tables are typically 22 ft long, with a 10-ft plateau and 6-ft approaches on either side.

If a speed table is designated as a crosswalk, it is known as a raised crosswalk.

Exhibit 18.5.28 Example Speed Hump, Speed Cushion, and Speed Table



Speed Hump (Source: Lucy Gibson)



Speed Cushion (Source: Jeff Gulden)



Speed Table (Source: NACTO)

Exhibit 18.5.29 Speed Hump, Speed Cushion, and Speed Table Typical Applications

SPEED HUMP, SPEED CUSHION, AND SPEED TABLE – TYPICAL APPLICATION	
TRAFFIC VOLUMES	• Appropriate where total traffic flow volume comprises no more than 5% long-wheelbase vehicles. • Appropriate on low to moderate volume roadways.
SPEED	• Research recommends a spacing of 200 to 400 ft to maintain an 85th percentile operating speed between 25 and 30 mph. On short blocks of 350 to 500 ft in length, install only one traffic-calming measure mid-block. • The design speed is determined by the dimensions and spacing of the speed hump. Posted speed limit typically 30 mph or less. • Not appropriate for roadways with 85th percentile speeds of 45 mph or more.

STREET FUNCTIONAL CLASSIFICATION	• The function and context of the street should be considered, particularly if the street serves as a community main street, includes large numbers of pedestrians, or has low traffic volumes.
	  ○ Speed humps: Local, collector, residential, or any street where the primary function is to provide access to residential properties.
	  ○ Speed cushions: Local, collector, and lower volume arterial roadways that also serve as primary residential access. Speed slots are recommended for use on arterials.
	  ○ Speed tables: Local, collector, and lower volume arterial roadways that also serve as primary residential access.

NUMBER OF TRAVEL LANES	• Appropriate for one-lane or two-lane, one-way streets or two-lane, two-way streets.
GRADE	• Speed humps are typically limited to installation on roadways with longitudinal grades of 8% or less. On a project-by-project basis following engineering evaluation, speed humps and other vertical traffic-calming measures may be installed on street sections with steeper grades up to 10%.
CURVES	• Should not be placed on sharp curves; the minimum recommended street curve is defined as a roadway with a centerline radius of 200 ft or less, or a roadway which has a curve with less than minimum safe stopping sight distance.
CONTEXT: LAND USE AND AREA	• Works well in residential areas and on local or collector roadways. • Should not be placed at curb cuts or obstruct driveways.

EMERGENCY OR TRANSIT ROUTE	• Speed humps:
	  ○ Additional considerations needed if locating on a primary emergency vehicle route, due to 3- to 7-second delays for fire trucks or ambulances. For example, limiting the number of speed humps on an emergency vehicle route.
	  ○ Not typically used on major roadways, bus routes, or primary emergency access routes.
	• Speed cushions:
	  ○ May be a viable alternative, providing similar speed reduction while allowing wide-axle emergency vehicles the ability to navigate unimpeded through the gaps in cushions.
	  ○ Appropriate for a bus transit route or a primary emergency vehicle route.
	• Speed tables:
	  ○ Not generally appropriate for primary emergency vehicle route or bus transit route unless the posted speed limit is 30 mph or less.

Exhibit 18.5.30 Advantages and Disadvantages of Speed Humps, Speed Cushions, and Speed Tables

ADVANTAGES	DISADVANTAGES
• Low cost to install and maintain compared to other traffic-calming measures. • Self-enforcing traffic-calming measure that effectively reduces vehicle speeds. • Increases pedestrian and bicyclist safety and comfort due to reduced travel speeds. • Minimally impacts on-street parking (speed humps or cushions.) • Drainage impacts along curb line are negligible: speed humps and speed cushions are typically installed on a roadway with a curb. Speed humps are typically spaced 1 ft from a curb. • Can be implemented in a system-wide approach.	• Impacts to drainage: For speed tables, the presence of existing drainage features could increase the cost of implementation. • Impact to emergency response time: Speed humps could cause delay for emergency vehicles. Speed cushions provide gaps for emergency response vehicles. Speed tables cause less delay than speed humps and a less jarring effect on passengers. • Impact to bus travel: Speed humps could be inappropriate on streets with bus traffic, due to rider comfort and reduced travel speeds. Speed cushions are more appropriate for a bus route while speed tables have less impact than speed humps. • Impacts on network if not used in a system-wide approach. • Impacts snow removal. However, speed humps have been successfully implemented in many jurisdictions with heavy snowfall. • Impacts on-street parking (speed table).

Effectiveness

Research shows a reduction in speeds at locations where speed humps, speed cushions, and speed tables are installed.

- Studies conducted on local roadways within urban areas to determine the effect of speed humps on vehicle speed show a reduction in 85th percentile speeds of 5 to 13 mph.
- Studies conducted to determine the effect of speed cushions on vehicle speed show a reduction in 85th percentile speeds of 5 to 7 mph.
- Studies conducted to determine the effect of speed tables on vehicle speed show a reduction in 85th percentile speeds of 6 to 11 mph in urban areas.

Research shows a reduction in crashes at locations where speed humps, speed cushions, and speed tables are installed.

- Studies conducted in urban areas regarding the effect of speed humps on crashes demonstrate a reduction of between 33% to 48% for all crash types. Studies documenting a change in volume due to speed humps also show a reduction in crashes.
- Studies conducted in urban areas to determine the effect of speed tables on crashes show a 38% reduction in total crashes, 93% reduction in injury crashes, and a 36% to 64% reduction in all crash types.
- There were no crash studies found for speed cushions.

Exhibit 18.5.31 Design Features and Typical Design Criteria of Speed Humps, Speed Cushions, and Speed Tables

TRAFFIC-CALMING MESURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• 3 to 4 inches in height, with a trend toward 3 to 3.5 in maximum. • Speed humps and speed cushions are typically 12 to 14 ft in length in the direction of travel. • Speed tables are typically 22 ft in length in the direction of travel. • Speed cushions are typically 6 ft wide, and 10 to 11 ft long in the direction of travel, with a 2-ft gap. • Speed slots are typically 6 to 7 ft wide, and 22 ft in length in the direction of travel, with a 2 to 3-ft gap. • Slopes should not exceed 1:10 or be less steep than 1:25. • Side slopes on tapers should be no greater than 1:6. • The vertical lip should be no more than 0.25 in.
SPACING	• Typically spaced between 200 and 400 ft apart in the direction of travel to achieve an 85th percentile speed between 25 and 35 mph. • Studies showed that speed humps placed at intervals of 275 ft resulted in 85th percentile speeds of 25 mph, while intervals of 550 ft resulted in 85th percentile speeds of 30 mph. • The configuration and layout of speed cushions (and speed slots) depends on the number of lanes, lane widths, and width of roadway to avoid instances of vehicles traveling across lanes to avoid vertical deflection.
PAVEMENT MARKING	• Typically, pavement markings are included on speed humps. Advanced Warning Markings can also be applied where added visibility is desired. • All pavement markings should comply with MUTCD. Details regarding speed hump pavement markings are provided in PennDOT's *TC-8600.*
LOCATION	• Treatments should be used mid-block. Installation within 250 ft of the approach to a signal, within 100 ft approaching a collector, or 20 ft to a local uncontrolled intersection should be avoided. • Locating speed humps directly in front of driveways should be avoided.
SIGNAGE	• Often have associated signing, such as an advance warning sign before first hump in series. • It is recommended that Speed Hump Warning signs (e.g., W8-1, W17-1) and optional Advisory Speed plaque (W13-1) be installed either 100 ft in advance of speed humps, at the speed humps, or in both locations. • All signage should comply with MUTCD and Publication 236, *Handbook of Approved Signs*.
CONSTRUCTION MATERIALS	• May be constructed from asphalt, textured or colored asphalt, or poured and stamped concrete.

Exhibit 18.5.32 Speed Hump Design Profiles

Profiles for Vertical Devices (Speed Humps)

Sinusoidal Profile

- reduces speed slightly less (compared to circular or parabolic profiles.)
- more difficult and expensive to construct
- provides greater comfort level for drivers and bicyclists.

3.00	2.55	2.07	1.50	0.69	0.27	0.00	Height (Inches)
100%	85%	69%	50%	23%	9%	0%	
1	1	1	1	1	1	Length of approach (feet)	



Circular Profile

- reduces speed moderately (compared to sinusoidal or parabolic profiles.)
- provides moderate comfort levels for drivers and bicylists.

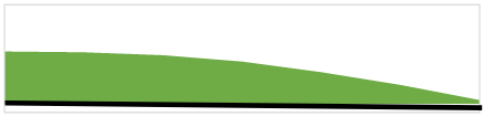
3.00	2.91	2.67	2.25	1.65	0.90	0.00	Height (Inches)
100%	97%	89%	75%	55%	30%	0%	
1	1	1	1	1	1	Length of approach (feet)	



Parabolic Profile

- reduces speed the most (compared to sinusoidal or circular profiles.)
- least comfortable for drivers and bicyclists.
- avoid on streets with bicycle traffic.

3.00	2.94	2.76	2.37	1.71	0.93	0.00	Height (Inches)
100%	98%	92%	79%	57%	31%	0%	
1	1	1	1	1	1	Length of approach (feet)	



Note: When balancing tradeoffs and considerations for comfort (bicyclists and drivers), sinusoidal profiles are preferred. Due to sinusoidal profiles being more difficult and expensive to construct, circular profiles are acceptable.

Design Considerations and Context

- **Land use.** Speed humps are typically used in residential areas on local and collector streets. However, they may be appropriate in areas with high pedestrian volumes, mixed-land uses, and denser land uses.
- **Pedestrian and bicycle safety and mobility.** The *Traffic Calming ePrimer* provides several considerations related to pedestrians and bicyclists. For example, some jurisdictions use a maximum grade of 5% for streets designated as a bicycle route.
- **Placement of speed hump in a series.** Speed humps should typically be located where they cannot be approached at a high speed.

- **Temporary materials.** The use of temporary speed cushions and speed humps is an alternative to permanent installations. For example, some municipalities install hard rubber speed cushions for use in pilot programs.
- **Maintenance.** Considerations related to the maintenance of speed humps, speed cushions, and speed tables include both snowplowing and street sweeping. Some jurisdictions alert snowplow operators to treatment locations; some work collaboratively with operators and use signage to alert drivers and operators. For example, a flexible delineator may be used to alert operators to lift their blades.

  The designer should recognize that temporary devices tend to come loose over time and require repair. Constructed devices may be designed with reinforcements for heavy vehicles and snowplows, as well as unique geometry to prevent edges from crumbling.

18.5.9 – Raised Crosswalk

Description and Purpose

A raised crosswalk is a vertical traffic-calming measure applied at pedestrian crossing locations to elevate a crosswalk from street level to sidewalk level. Raised crosswalks combine the benefits of a speed hump with enhanced visibility, improved awareness of pedestrians, reduced vehicle speeds, and enhanced pedestrian comfort and safety.

Typical approach ramps are 5 to 7 ft, with a top flattened width of 10 ft and a total length of 20 to 24 ft.

Exhibit 18.5.33 Raised Crosswalk Typical Application

RAISED CROSSWALK TYPICAL APPLICATION	
TRAFFIC VOLUMES	• Typically installed at locations with high pedestrian activity or near pedestrian generators, high vehicle volume, and low design speed.
SPEED	• Acceptable on roadways with posted speed limits of 30 mph or less. • Not appropriate where 85th percentile speeds are 45 mph or more. • Should be located where the desired speed is 20 to 25 mph.
STREET FUNCTIONAL CLASSIFICATION	• Appropriate on local roadways except in rural contexts. May be appropriate in rural towns. • May be appropriate on collector and arterial streets depending on context, including pedestrian activity, mixed-land uses, building proximity to streets, and vehicle speeds and volumes. • Additional analysis and context evaluation may be required under these context-sensitive scenarios.
NUMBER OF TRAVEL LANES	• Appropriate on single-lane, one-way or two-lane, two-way streets.
GRADE	• Raised crosswalks are typically limited to installation on roadways with longitudinal grades of 8% or less. On a project-by-project basis following engineering evaluation, vertical traffic-calming measures may be installed on street sections with steeper grades up to 10%.
CURVES	• Street should not have a curve with a radius of less than 300 ft for mid-block locations.
CONTEXT: LAND USE AND AREA	• Acceptable in all land use and area contexts except rural. May be appropriate in rural towns. • Commonly found in areas with high pedestrian activity.

Exhibit 18.5.34 Example Raised Crosswalks





Exhibit 18.5.35 Advantages and Disadvantages of Raised Crosswalks

ADVANTAGES	DISADVANTAGES
• Reduces travel speeds. • Manages traffic volumes by reducing cut through traffic. • Improves pedestrian safety by creating better visibility, clearly demarcating crossing areas, and proven to increase vehicles yielding to pedestrians. • Improves ADA accessibility by providing a level crosswalk. • Reduces illegal parking by preventing motorists from parking too close to an intersection or crosswalk.	• May result in the loss of one on-street parking space at mid-block locations. Unlikely to impact parking at intersections, due to roadway design standards. • May cause delay for emergency response vehicles but demonstrates less speed delay than traditional speed humps. • Requires more maintenance than traditional crosswalks. • The presence of existing drainage features could increase the cost of implementation, due to drainage impacts. • Impacts snow removal. • Creates traffic noise from vehicles braking and accelerating.

Effectiveness

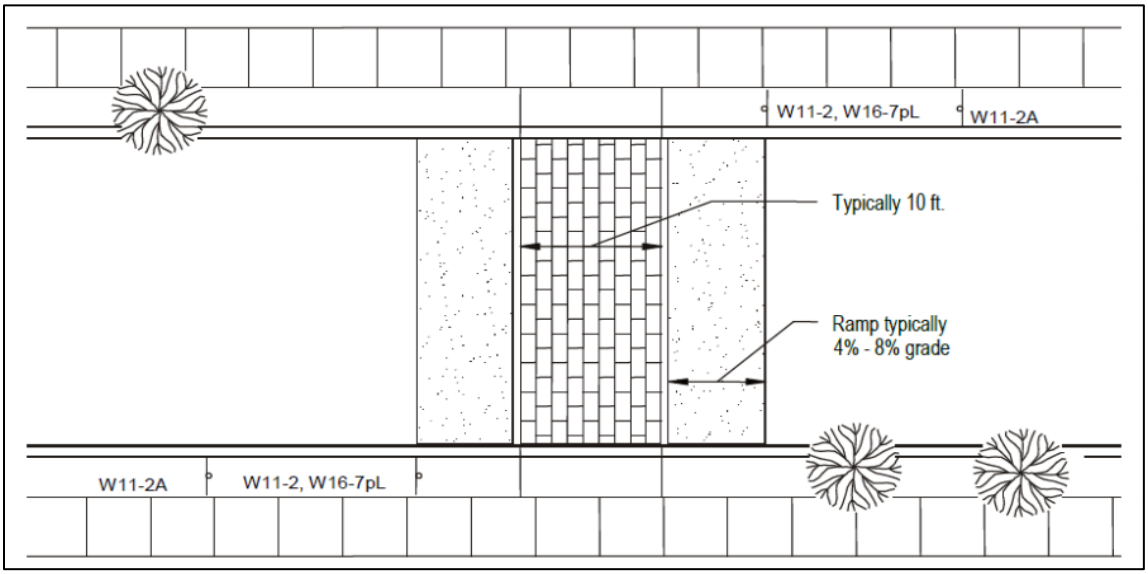
Raised crosswalks are one of the FHWA's Proven Safety Countermeasures for effectively reducing pedestrian crash rates at unsignalized intersections. Raised crosswalks have proven effective in improving motorists' yielding to pedestrians, with research demonstrating a 45% reduction in pedestrian crashes with raised crosswalk implementation.

Raised crosswalks have been shown to reduce speeds by 6 mph on average and to reduce 85th percentile speeds within the range of 20 to 30 mph for vehicles traversing the crosswalk. A series of raised devices is needed to maintain lower speeds throughout a roadway corridor and raised crosswalks have not been shown to decrease speeds as effectively as traditional speed humps.

Exhibit 18.5.36 Design Features and Typical Design Criteria of Raised Crosswalks

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Should be 3 to 6 in above street level. • Approach ramps should be 5 to 7 ft (4% to 8% slope.) • Top of crosswalk should have a minimum width of 10 ft. • Total length of 20 to 24 ft.
SPACING	• Spacing of 250 to 600 ft is recommended. • Should be located so that vehicles cannot approach at high speeds. May be located near other raised traffic-calming devices, near stop-controlled intersections, or near small-radius curves. • Typically spaced 5 ft from driveways.
PAVEMENT MARKING	• Should be marked with paint and/or pavement markings that denote an elevated surface. • Change in material or texture can be used to alert drivers and pedestrians of a crossing. • Pavement markings should conform to typical pavement markings for speed tables or speed humps with crosswalks as defined in the *Pavement Marking Standard (TC-8600)*. • Detectable warnings and/or color contrasting materials should be used to differentiate the roadway, raised crosswalk, sidewalk, and crosswalks.
LOCATION	• Located at intersections or mid-block. • Must be located at an existing crosswalk or a location where a crosswalk is warranted. • Can be used in isolation at channelized turn lanes.
SIGNAGE	• W11-2 (Pedestrian Crossing sign) and W16-7pL (Arrow Indication plaque) should be in proximity to raised crosswalk. • Refer to PennDOT Publication 236 for details regarding W11-2A (Raised Pedestrian Crossing) sign.
LIGHTING	• Location near existing lighting should be prioritized to improve visibility.

Exhibit 18.5.37 Raised Crosswalks Dimension Details



Design Considerations and Context

- **Tactile warning surfaces.** Where raised crosswalks are the same height as the curb, detectable warning surfaces should be used to alert visually impaired people. The designer should also provide enhanced crossings and access to push buttons. The same principles apply for a typical crosswalk location.
- **Mid-block locations.** If curb extensions include vertical features, they should not obstruct a driver's view of the pedestrian. The designer can refer to PennDOT's Publication 46*, Traffic Engineering Manual,* Section 11.9, *Unsignalized Midblock Crosswalks,* for more information regarding improving the visibility of pedestrians.
- **Maintenance.** Rebar or granite may be incorporated into the design to reinforce raised devices for heavy vehicles and snowplows.

18.5.10 – Raised Intersection

Description and Purpose

A raised intersection is a vertical treatment that raises the entire intersection above the surrounding roadway level. The intersection is typically raised to sidewalk height (3 to 6 in above street grade) and uses brick or other textured materials.

Also referred to as raised junctions, intersection humps, or plateaus, raised intersections combine the benefits of speed humps and raised crosswalks, resulting in improved pedestrian visibility and safety, reduced vehicle speeds, and increased driver awareness.

Exhibit 18.5.38 Example Raised Intersection

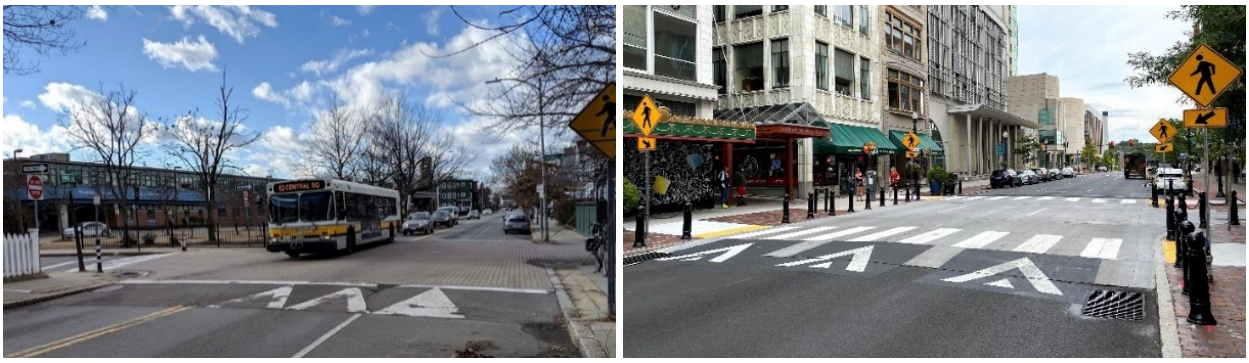


Exhibit 18.5.39 Raised Intersection Typical Application

RAISED INTERSECTION TYPICAL APPLICATION	
TRAFFIC VOLUMES	• Appropriate if the ADT on each intersection approach is low volume.
SPEED	• Should be located where the desired vehicle operating speed is 20 to 25 mph. • Speeds are of less concern, as raised intersections are constructed at intersections which may be signalized or have all-way or two-way stop-controlled approaches. Intersection operations and safety are the primary priorities. • Maximum speed limit should be 30 to 35 mph.
STREET FUNCTIONAL CLASSIFICATION	• Appropriate on local roadways, except in rural contexts. May be appropriate in rural towns. • May be appropriate on collector and arterial streets depending on context, including pedestrian activity, mixed-land uses, building proximity to streets, and vehicle speeds and volumes. • Additional analysis and context evaluation may be required under these context-sensitive scenarios.
NUMBER OF TRAVEL LANES	• Appropriate on intersections with one-way or two-way roadway approaches. • No limit on number of travel lanes.
GRADE	• Raised intersections are typically limited to installation on roadways with longitudinal grades of 8% or less. On a project-by-project basis following engineering evaluation, vertical traffic-calming measures may be installed on street sections with steeper grades up to 10%.
CURVES	• Adequate stopping sight distance and/or warning signs should be used if constructed on a vertical curve.
CONTEXT: LAND USE AND AREA	• Acceptable in all land use and area contexts except rural. May be appropriate in rural towns. • Raised intersections are commonly found in areas with high pedestrian activity.

Exhibit 18.5.40 Advantages and Disadvantages of Raised Intersections

ADVANTAGES	DISADVANTAGES
• Reduces vehicle travel speeds. More effective when implemented along with other traffic-calming measures. • Improves pedestrian safety by creating better visibility and clearly demarcating crossing areas. • Enhances neighborhood appearance. • Reduces illegal parking by preventing motorists from parking too close to an intersection or crosswalk. • Incorporates other traffic-calming measures such as textured pavement and curb extensions. • Includes bicycle facilities. • Reduces diversions. • Maintains access to surrounding businesses and driveways	• May cost more to construct and maintain compared to other traffic-calming measures. • Results in an average delay of 4 to 6 seconds for emergency vehicles. • Presence of existing drainage features could increase the cost of implementation, due to drainage impacts. • Impacts snow removal. • Creates traffic noise from vehicle braking and accelerating.

Effectiveness

Raised intersections target speeds at intersections. The reduction in mid-block speeds is typically less than 10%. Research at five raised intersections showed a reduction of 1 to 5 mph in 85th percentile speeds. An improvement in safety, rather than speed reduction, should be the primary focus when implementing raised intersections.

Exhibit 18.5.41 Design Features and Typical Design Criteria of Raised Intersections

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• 3 to 6 in above street level. • Approach ramps should be designed at a 4 to 8% grade.
SPACING	• A series of raised intersections can establish a Slow Zone and may be more effective in reducing area-wide speeds.
PAVEMENT MARKING	• Tactile pavement should be used where the raised intersection is the same height as the surrounding curb. • Detectable warnings and/or color contrasting materials should be used to differentiate the roadway, raised intersection, sidewalk, bicycle facilities, and crosswalks. • Bollards may be used to define the edge of the road. • Pavement markings should conform to typical pavement markings for speed tables or speed humps with crosswalks as defined in the *Pavement Marking Standard (TC-8600)*.
LOCATION	• Located frequently at signalized or all-way stop-controlled intersections but may be appropriate at two-way stop-controlled intersections. • Appropriate at intersections with crosswalks on all legs. • Appropriate only on roadways with curbs and sidewalks.
SIGNAGE	• Advance warning signs should be installed to alert drivers approaching a raised intersection. • Refer to PennDOT Publication 236 for details regarding W11-2A (Raised Pedestrian Crossing) sign.

Design Considerations and Context

- **High pedestrian activity.** Raised intersections should be considered in commercial districts, business cores, and other areas with high pedestrian activity.
- **Traffic-calming zones.** Raised intersections may be used as area-wide traffic calming. When implemented in conjunction with other nearby raised crosswalks or other traffic-calming measures, speed reduction may be more effective.
- **Safety.** The primary purpose of raised intersections is to improve intersection safety for all users. Raised crosswalks provide a safe crossing for vehicles, pedestrians, and bicyclists.
- **Maintenance.** Rebar or granite may be incorporated into the raised crosswalks surrounding the raised intersection to reinforce devices for heavy vehicles and snowplows.

18.5.11 – Physical Obstruction

Physical obstruction refers to measures that prevent vehicle movements, thereby discouraging or eliminating cut-through traffic. The overall traffic volume reduction depends upon the nature of the traffic-calming measure and the number of movements obstructed. Physical obstruction may be appropriate on local, neighborhood roadways and may be used to prioritize pedestrians or bicyclists. These measures can have undesired network effects, so care should be taken to address diversion concerns (see Section 18.2.5, *Regional Roadway Network Impacts*.)

The toolbox includes the following physical obstruction traffic-calming measures:

- 18.5.12 – Diagonal diverter
- 18.5.13 – Right-in or right-out island
- 18.5.14 – Raised median through intersection
- 18.5.15 – Half closure with bicycle pass through

18.5.12 – Diagonal Diverter

Description and Purpose

Diagonal diverters are physical barriers that are placed diagonally across a four-way intersection to create two unconnected intersections. Diagonal diverters, also referred to as diagonal road closures and full diverters, are typically used to prevent unwanted through-traffic.

Cutouts or gaps in the diagonal diverters can be used to accommodate bicycle through-movements or permit emergency vehicle movements.

Exhibit 18.5.42 Example Diagonal Diverter



(Source: Pedbikesafe.org)

Exhibit 18.5.43 Example Diagonal Diverter



(Source: NACTO)

Exhibit 18.5.44 Diagonal Diverter Typical Application

DIAGONAL DIVERTER TYPICAL APPLICATION	
TRAFFIC VOLUMES	Appropriate where volumes are typically low. Cut-through traffic should be a significant percentage (i.e., greater than 25%) of the total daily volume. Additional context considerations should be documented.
SPEED	Maximum posted speed limit of 25 mph. Requires vehicles to navigate the sharp intersection curve without stop control on some approaches.
STREET FUNCTIONAL CLASSIFICATION	Appropriate on local and collector streets in non-rural locations. Diagonal diverters should not be used on arterial streets. Can be implemented on streets with or without bicycle infrastructure. A grid of parallel streets is typically beneficial to provide several alternative routes with minimal out-of-direction travel.
STREET WIDTH	Not dependent on the width of the street. Typically used on roads with curbs.
NUMBER OF TRAVEL LANES	Appropriate on one-way and two-way streets.
GRADE	Locations where grades exceed 8% are typically not recommended.
CURVES	Applicable on vertical curves, given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	Diagonal diverters are acceptable on urban core, urban, and suburban roadways. They are not relevant on rural roadways and additional context may be required for implementation in rural towns. Diagonal diverters are typically used in residential settings where undesired through traffic is present.

Exhibit 18.5.45 Advantages and Disadvantages of Diagonal Diverters

ADVANTAGES	DISADVANTAGES
• Manages traffic volumes by reducing cut through traffic. • May reduce conflict points for vehicles. • Improves bicycle and pedestrian safety and should be constructed to allow bicycle and pedestrian through movements. • Enhances neighborhood appearance through the inclusion of landscaping, green stormwater infrastructure, or added pedestrian infrastructure. • Minimizes drainage impacts. • Reduces traffic noise due to lower speeds and volumes.	• Provides limited speed reduction. • May create diversion to adjacent streets. • May delay emergency response times. • Impacts local access, typically requires local support. • Drainage may need to be modified if the diagonal diverter is integrated with existing sidewalks and curbs. • May impact snow removal efforts. • May restrict large vehicle mobility.

Effectiveness

The effectiveness of a diagonal diverter depends on the availability and relative appeal of alternate routes. The installation of diagonal diverters increases travel time for motor vehicles and reduces traffic volumes by 20 to 70% (with an average reduction of 35%). Diagonal diverters reduce 85th percentile speeds by an average of 1 mph.

Exhibit 18.5.46 Design Features and Typical Design Criteria of Diagonal Diverters

DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• The design should maintain full-lane widths on local roadways, with a minimum turning radius of 7.5 ft. • The recommended width of the narrowest point of the diverter is 4 ft. • The recommended radius of the corner of a curb cutout for pedestrians and/or bicyclists is 3 ft.
SPACING	• Spacing of landscaping, patterning, or flexible post delineators on diverters may vary. Recommended spacing is 5 ft to 6.5 ft wide to prevent vehicles from traversing the diverter (5-ft minimum width). Review Bulletin 15 (Publication 35) – *Qualified Products List for Construction* for prequalified materials. • A width of 14 ft may be allocated to allow emergency vehicles to pass through the diverter, although an evaluation should determine whether the route should prioritize emergency vehicles or whether alternative routes would suffice.
PAVEMENT MARKING	• Pavement markings can be used to improve safety and alert motorists of a curvature in the street.
LOCATION	• Must be installed at intersections. • Applicable with both one-way and two-way roads.
SIGNAGE	• W1-2R (Right Curve) and W1-2L (Left Curve) signs should be used in advance of the diverter. • No parking signs should be used in advance of diverter, through the curve, and at the diverter. • Any clear width for emergency vehicles should be marked as emergency use only.

Design Considerations and Context

- **Located at four-way intersections.** Diagonal diverters must be installed at four-way intersections, typically where curbs are present.
- **Multifunctional use.** Diagonal diverters can incorporate landscaping features and additional sidewalk pavement and be used to collect and filter stormwater.
- **Bicycle and pedestrian facilities.** Diverter design should provide a safe bypass for bicycles, pedestrians, and wheelchairs. Pedestrian crossings can be maintained with sidewalk extensions across the diverter. If a sidewalk is included in the diverter, the design must ensure that the width of the travel lanes is maintained.
- **Warning measures.** Single Curve and No Parking signs should be incorporated to alert users.

- **Emergency routes.** Diagonal diverters may be modified with gates, operable transponder-responsive removable bollards, flexible post delineators, or mountable curbs to allow emergency vehicle access.
- **Drainage.** Modifications should be considered if space is left between the curb, gutter, and diverter. Modifications may be necessary if the diagonal diverter connects to existing sidewalks.
- **Maintenance.** Landscaping should only be incorporated into traffic-calming devices where clear maintenance responsibilities have been established. PennDOT requires a maintenance agreement with local jurisdictions.
- **Materials.** Materials may consist of a landscaped island, walls, gates, side-by-side flexible post delineators, or any obstructions that disallow vehicle through-movements. Temporary materials may be installed as an interim treatment option.
- **Temporary measures.** Temporary materials may be used to introduce diverters. A 6-to-12-month trial period is recommended before a measure is made permanent.
- **Traffic diversion.** A series of diagonal diverters may be used to mitigate unwanted traffic diversion to other streets.
- **Legal implications.** Restriction of vehicles on public streets may lead to legal issues, including access to businesses or emergency routes.
- **Transit routes.** Diagonal diverters are not appropriate along transit routes.

18.5.13 – Right-In or Right-Out Island

Description and Purpose

Right-in or right-out islands are used to prevent left turns and through-movements to and from side streets at intersections with major streets. Right-in/right-out islands, also referred to as raised islands, channelization islands, pork chops, and forced turn islands, may be used as a less intrusive and less expensive version of a median through an intersection.

Right-in or right-out islands can reduce cut-through traffic on local streets. A right-in or right-out island is typically triangular and placed at the mouth of an intersection.

Exhibit 18.5.47 Example Right-In or Right-Out Island





Exhibit 18.5.48 Right-In or Right-Out Island Typical Application

RIGHT-IN OR RIGHT-OUT ISLAND TYPICAL APPLICATION	
TRAFFIC VOLUMES	There is no maximum volume requirement for side streets configured with right-in or right-out islands. Some jurisdictions require a percentage of cut-through traffic (such as 25% or more of total daily street volume) to warrant treatment.
SPEED	Maximum posted speed limit of 25 mph on side street.
STREET FUNCTIONAL CLASSIFICATION	Appropriate on local, collector, and arterial roads. Appropriate on local streets at intersections with arterials and major collectors.
STREET WIDTH	Not dependent on street width. Typically found on roadways with urban cross sections.
NUMBER OF TRAVEL LANES	Appropriate on single-lane, one-way streets, and two-lane, two-way streets.
GRADE	Maximum grade should comply with local standards and criteria.
CURVES	Applicable on vertical curves, given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	Acceptable in all land use contexts.

Exhibit 18.5.49 Advantages and Disadvantages of Right-In or Right-Out Islands

ADVANTAGES	DISADVANTAGES
• Manages traffic volumes by reducing cut through traffic and reducing unwanted turning movements. • Reduces conflict points and crash severity by eliminating left turns or through movements. • Improves pedestrian safety by reducing crossing distances and providing refuge areas. • Improves bicyclist safety by reducing vehicle volume. • Enhances neighborhood appearance. • Drainage impacts along curb lines are negligible.	• Provides limited impact on speeds. • May restrict residential access. • Restricts emergency vehicles from passing straight through the intersection or turning left from and into a minor street. • May divert traffic to other parallel roads. • Impacts snow removal. • Limits turning movements and reduces overall street connectivity.

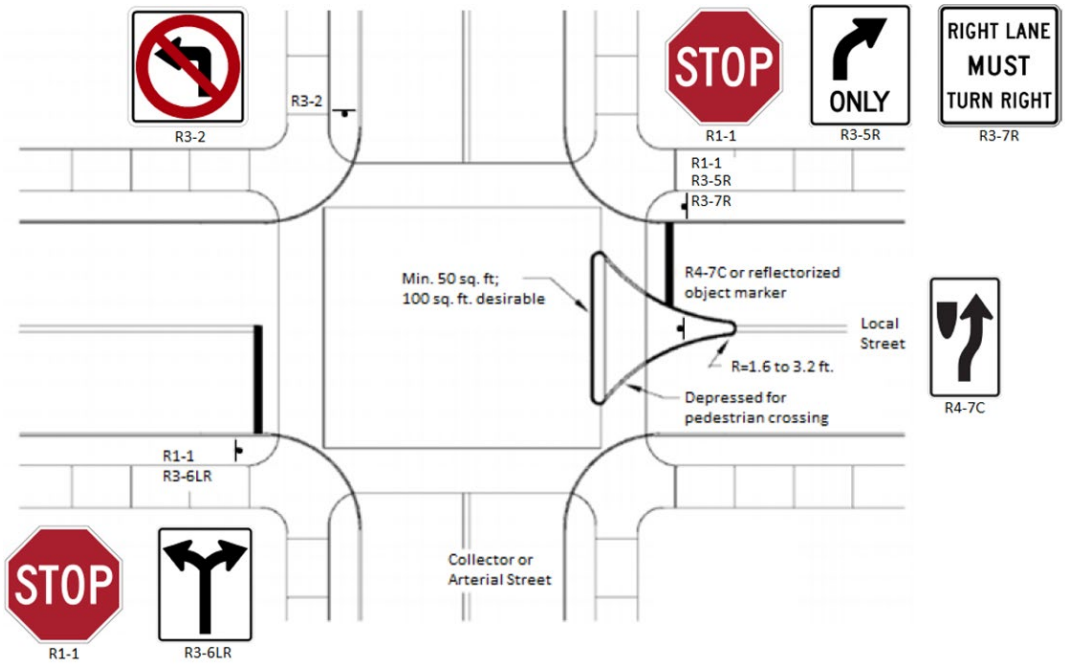
Effectiveness

Studies have shown treatments may reduce volumes by 20 to 60%. Volume reduction improves when used in combination with other area-wide measures.

Exhibit 18.5.50 Design Features and Typical Design Criteria of Right-In or Right-Out Islands

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• The recommended island dimension is 50 to 100 square ft. • The radius of the tip of the island should be 1.6 to 3.2 ft. • Minimum width of the island should be 6 ft to accommodate pedestrians.
PAVEMENT MARKINGS	• No additional pavement markings are required unless crosswalks are routed through the island.
SIGNAGE	• Stop signs or Yield signs should be used when appropriate. Other signs include Right-Turn Only (R3-5R), Keep Right (R4-7c), and Optional Movement Left or Right (R3-6LR).
EMERGENCY ACCOMMODATIONS	• Designs can include mountable curbs to accommodate large vehicles.

Exhibit 18.5.51 Right-In or Right-Out Island Dimension Details



Design Considerations and Context

- **Located at intersections.** Right-in or right-out islands are typically used at intersections with a minor and major approach. Traffic turning restrictions are like those of a median.
- **Located at access points.** Right-in or right-out islands may be appropriate for access points to and from businesses.
- **Multifunctional use.** A right-in or right-out island of sufficient width (6-ft minimum) can be designed to provide a pedestrian refuge for crossing the appropriate leg of the affected intersection.
- **Area-wide traffic calming.** Right-in or right-out islands are most effective when used in conjunction with nearby traffic calming and volume reduction treatments. This treatment is often used in sets to reduce cut through traffic in neighborhoods.
- **Bicycle facilities.** Right-in or right-out islands should be constructed to maintain or improve bicycle safety and mobility. Facilities, such as bicycle lanes, should be provided to separate bicyclists from vehicles.
- **Safety.** Right-in or right-out islands may be warranted by crash history. Right-in or right-out islands prevent left turning and through-movements, reducing conflict points.
- **Maintenance.** Landscaping should only be incorporated into traffic-calming devices where clear maintenance responsibilities have been established. PennDOT requires a maintenance agreement with local jurisdictions.

18.5.14 – Raised Median Through Intersection

Description and Purpose

Raised medians though intersections, also referred to as intersection barriers, intersection diverters, island diverters, and median diverters, incorporate raised islands along the centerline of a street that prohibit left turns.

The width of raised medians varies widely, depending on the total road width. Raised medians discourage through-traffic in residential areas by restricting turning movements. They may also be used for speed and volume reduction purposes.

Exhibit 18.5.52 Example Raised Median Through Intersection without and with Pedestrian Refuge Island



(Source: James R. Barrera, FHWA)



(Source: Steven Vance, FHWA)

Exhibit 18.5.53 Raised Median Through Intersection Typical Application

RAISED MEDIAN THROUGH INTERSECTION TYPICAL APPLICATION	
SPEED	Posted speed limit up to 45 mph, assuring adequate shy distance between the median and lane.
STREET FUNCTIONAL CLASSIFICATION	Appropriate on local, collector, and arterial roads in urban and suburban settings.
STREET WIDTH	Must maintain adequate lane width for design vehicle.
NUMBER OF TRAVEL LANES	Appropriate on two-lane, two-way streets.
GRADE	Locations where grades exceed 6% are typically not recommended.
CURVES	Applicable on vertical and horizontal curves, given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	Acceptable in all land use contexts.

Exhibit 18.5.54 Advantages and Disadvantages of Raised Medians Through Intersections

ADVANTAGES	DISADVANTAGES
• Reduces conflicts and head on collisions. • Manages traffic volumes by reducing through traffic and preventing unwanted turning movements. • Improves pedestrian and bike safety: narrows lane width which results in slower vehicle speeds. • Enhances neighborhood appearance. • Drainage impacts along curb lines are negligible. • Reduces traffic noise because of lower speeds and volumes.	• Provides limited impact on speeds. • Restricts access for emergency response and heavy vehicles. • May divert traffic volumes to parallel routes. • Impacts snow removal. • The addition of the median may require the removal of on-street parking to maintain appropriate lane width and turning radii. • Due to the potential to limit access, local community support is necessary.

Effectiveness

Raised medians through intersections are designed to reduce cut-through motor vehicle volumes by restricting specific movements. The design of median barriers should accommodate bicycle and pedestrian crossings.

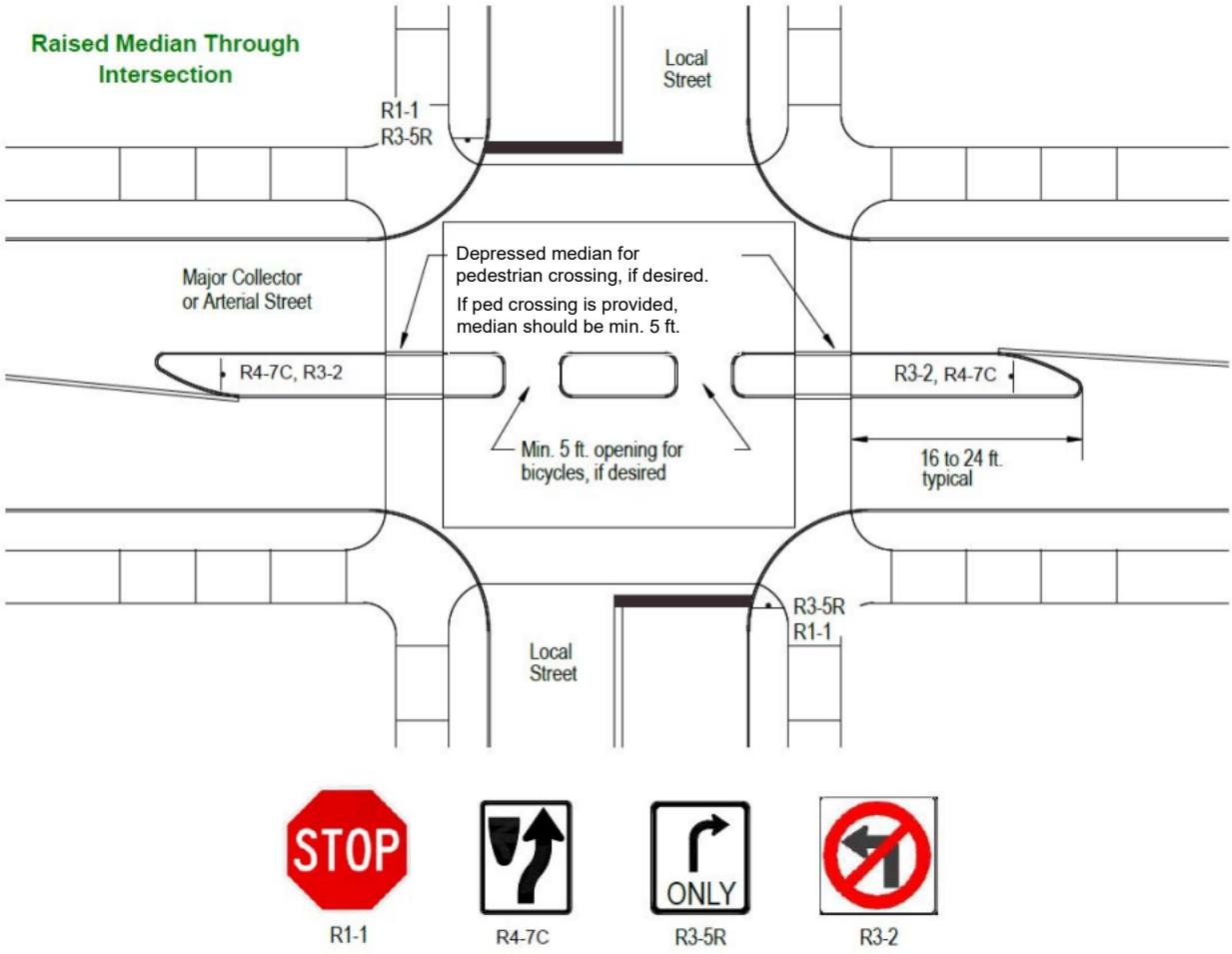
There are generally not significant impacts on speeds around or near the median application. However, speed reductions range from 2 to 3 mph on average depending on lane widths, and some research demonstrates reductions as great as 8 mph.

Median barriers can reduce volumes on local streets up to 70%.

Exhibit 18.5.55 Design Features and Typical Design Criteria of Raised Medians Through Intersections

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• No requirement for median width. • May be designed to include pedestrian refuge islands (Refer to Chapter 13) which would require 6-ft minimum width in the direction of pedestrian travel with an opening of 5-ft wide minimum (or as wide as the crosswalk.)
SPACING	• The median should divide the entirety of the intersection, with potential cutouts for pedestrians and bicyclists, and extend 15 to 25 ft beyond the intersection to prevent violations.
PAVEMENT MARKING	• Shared lane pavement markings may be necessary if bicyclists and vehicles are forced to share the lane.
LOCATION	• Raised medians must be installed through intersections. Raised medians may extend beyond the intersection extents.
SIGNAGE	• Recommended signage includes R6-1, R4-7, and R7-4.

Exhibit 18.5.56 Raised Medians Through Intersections Dimension Details



Design Considerations and Context

- **Multifunctional use.** Raised medians through intersections can incorporate landscaping features, on-street parking, additional sidewalk pavement, and can be used to collect and filter stormwater.
- **Design considerations for safer pedestrian and bicycle facilities.** The design of raised medians through intersections with pedestrian refuges can increase safety for pedestrians and bicyclists.
- **Maintenance.** Landscaping should only be incorporated where clear maintenance responsibilities have been established. PennDOT requires a maintenance agreement with local jurisdictions.
- **Materials.** Short-term materials, such as flexi-posts, planters, and other street furniture, may be used as interim treatment options.

- **Emergency routes.** Raised medians through intersections are not recommended on primary emergency response routes. Mountable barriers can be used to allow emergency vehicles and discourage non-emergency vehicles.
- **Local driveways.** The designer should avoid placing median barriers at or near local home or business driveways.

18.5.15 – Half Closure with Bicycle Pass Through

Description and Purpose

Half closures are intended to reduce traffic volumes by limiting vehicular traffic movements and creating a one-way roadway with a contraflow bike lane at the point of construction.

Half closures (also referred to as semi-diverters or partial diverters) use a physical barrier to block vehicle travel in one direction on an otherwise two-way street. Barriers are typically located near intersections to obstruct selected traffic movements to or from the intersection.

A bicycle pass-through provides a separate right-of-way that maintains bicycle accessibility and improves bicycle safety.

Exhibit 18.5.57 Example of Half Closure with Bicycle Pass Through



Note: The orange one-way sign is not standard.
(Source: Adam Fukushima)



(Source: NACTO)

Exhibit 18.5.58 Half Closure Typical Application

HALF CLOSURE TYPICAL APPLICATION	
TRAFFIC VOLUMES	Appropriate on low to moderate volume roadways. Additional context considerations should be documented.
SPEED	With appropriate advanced warning, speed limit is not constrained.
STREET FUNCTIONAL CLASSIFICATION	Appropriate at intersections with local roads and minor collectors intersecting with a collector or arterial to accommodate diverted traffic.
NUMBER OF TRAVEL LANES	Appropriate on two-way streets with an urban cross section (curb).
GRADE	Locations where grades exceed 6% should be avoided.
CURVES	Applicable on vertical curves, given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	Acceptable on urban core, urban, and suburban roads. Not acceptable on rural roadways; additional context may be required for implementation in rural towns. Typically used in residential settings where undesired through-traffic is present.

Exhibit 18.5.59 Advantages and Disadvantages of Half Closures

ADVANTAGES	DISADVANTAGES
• Manages traffic volumes by reducing cut through traffic. • Improves pedestrian and bicyclist safety through a reduction in conflict points and should be constructed to allow pedestrian and bicycle through movements. • Enhances neighborhood appearance. • Negligible drainage impacts along curb lines. • Reduces traffic noise due to lower speeds and volumes.	• May result in the loss of some on-street parking but unlikely to impact parking at intersections due to street design standards. • Challenges heavy vehicles; however, may provide greater access than full closures for emergency vehicles, if designed appropriately. • Impacts snow removal. • Impacts to local access, requires strong community support. • Half closures preventing motor vehicle exits are more likely to be violated. Drivers are also more likely to violate the closures at night and on low-volume roadways. Increasing the length of the closure can reduce violations.

Effectiveness

Half closures have a small impact on speed reduction, but a significant impact on volume reduction. Half closures with bicycle pass-throughs have varying levels of effectiveness for speed and volume reduction.

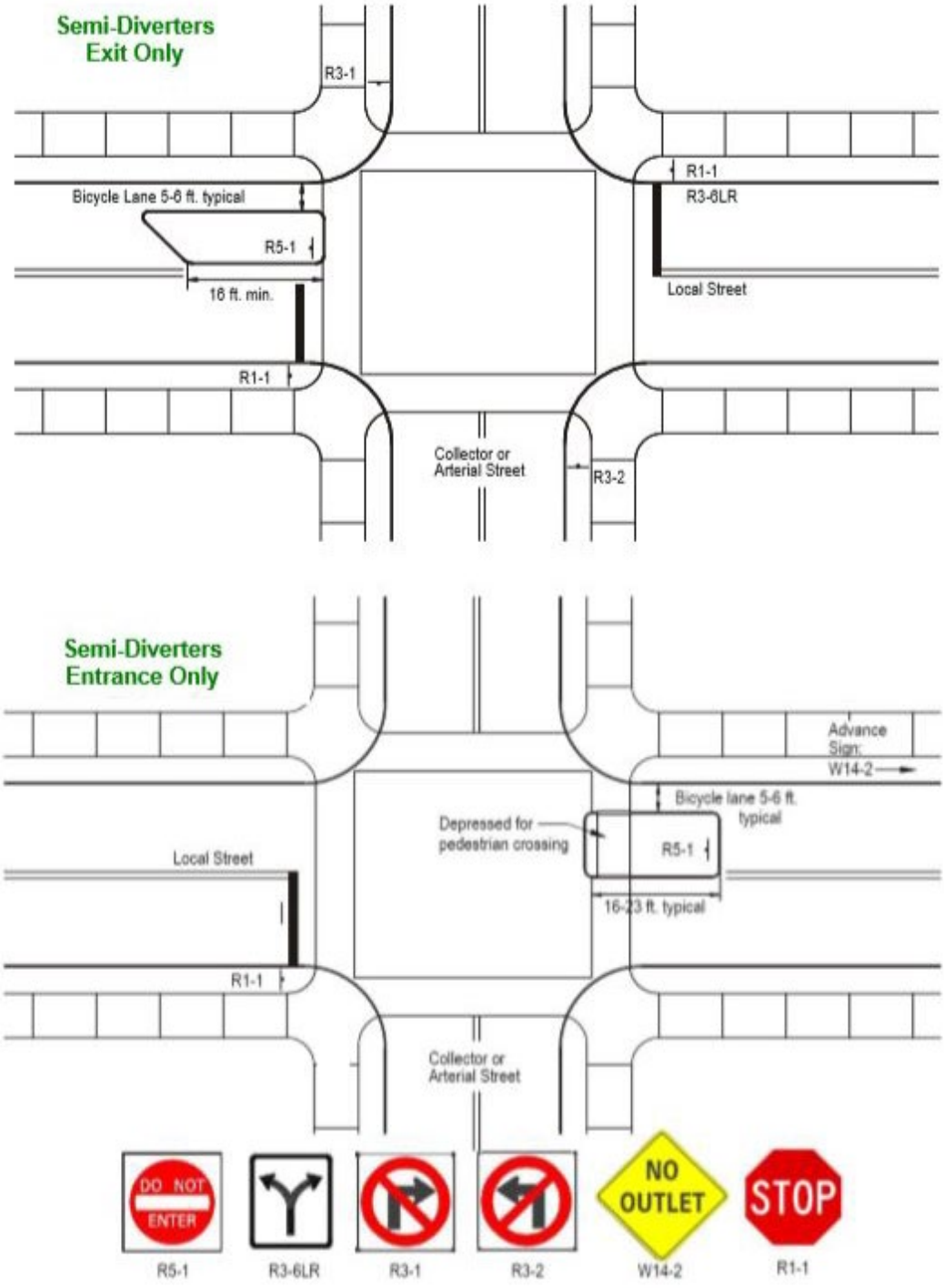
Effective half closures deter speeding cut-through vehicles from passing through a neighborhood or Slow Zone. Speeds may be reduced by 2 to 5 mph. Research shows that the 85th percentile speed reduction is 6 mph.

Half closures reduce volumes by at least 40%, with some reductions of 60%. They add protection for bicyclists and have limited impact on the mobility of emergency vehicles.

Exhibit 18.5.60 Design Features and Typical Design Criteria of Half Closures

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Recommended length is 16 to 30 ft. May be longer to prevent violations. • Should maintain the full width of the opposing travel lane and provide a sufficient curb radius for turning vehicles. • Bicycle pass-throughs should maintain the width of a bicycle lane and gutter (typically 5 to 6 ft). If rolled curbs are used, then the width may be reduced to 4 ft. • Should have vertical curbs, especially on the outer edges of the closure, to discourage vehicles from mounting the half closure. However, closures can be mountable to allow emergency vehicles to use the route.
SPACING	• Spacing of landscaping, patterning, or flexible post delineators may vary to prevent drivers from traversing the closure.
PAVEMENT MARKING	• There are no specific pavement markings for this treatment.
LOCATION	• Installed at intersections and mid-block locations. They are typically located at intersections to reduce cut-through traffic. These closures are less restrictive than diagonal diverters or full closures.
SIGNAGE	• Adequate signing should be used before the half closure on main and minor roadways. Signage can also be used on the half closure. • Suggested signs include R5-1, R3-6LR, R3-1, R3-2, W14-2, R3-7bP, and R1-1. • Do Not Enter signs should be used for exit-only closures.

Exhibit 18.5.61 Half Closure with Bicycle Pass Through Dimension Details



Design Considerations and Context

- **Multiple closures.** To prevent the generation of unwanted traffic on other local roads, multiple closures should be used to eliminate cut-through traffic throughout the entire area.
- **Multifunctional use.** Treatments may incorporate landscaping features and additional sidewalk pavement and can be used to collect and filter stormwater.
- **Bicycle facilities.** Half closures provide a safe bypass and physical barrier to protect bicyclists at the intersection. Pedestrian crossing distance is reduced with the addition of a half closure.
- **Warning measures.** Signs should be used to inform drivers of the one-way roadway.
- **Drainage.** Modifications should be considered, depending on the location of the bicycle pass-through and any changes to the curb geometry.
- **Maintenance.** Landscaping should only be incorporated into traffic-calming devices where clear maintenance responsibilities have been established. PennDOT requires a maintenance agreement with local jurisdictions.
- **Materials.** Short-term materials, such as flexible post delineators, planters, and other street furniture, may be used as interim treatment options.
- **Trial period.** A 6-to-12-month temporary trial period is recommended before permanent installation.
- **Transit routes.** Half closures are not recommended along transit routes where transit operations are impacted but they may be suitable on side streets which intersect a transit route.

18.5.16 – Signing and Pavement Markings

Signs and pavement markings can be used as traffic-calming measures that regulate traffic movements in lieu of physical changes to the roadway. In certain applications, these measures may produce the same effect as the physical traffic-calming measures. However, police enforcement is often required to ensure motorist compliance. These measures may be made permanent with physical changes in future road reconstruction projects.

The MUTCD and Publication 236 should be used for all standard signing and all standard pavement markings.

The toolbox includes the following signing and pavement marking traffic-calming measures:

- 18.5.17 – Travel Lane Width
- Bicycle Facilities – Reference Chapter 14, *Bicycle Facilities*.

- 18.5.18 – Lane and Parking Configuration Changes
- 18.5.19 – Lane Reduction and Road Diet
- 18.5.20 – Yield to Pedestrian Channelizing Devices

18.5.17 – Travel Lane Width

Description and Purpose

Travel lane width influences driver comfort, operations of the roadway, and the likelihood of crashes. Narrower travel lanes promote slower vehicular speeds, which can also reduce crash severity. Lane-width design decisions should consider traffic-calming goals while also providing adequate space for trucks and buses.

Refer to Chapters 3, 4 and 5 for required minimum lane widths. Information on the effect of lane width on capacity and level of service is provided in the *Highway Capacity Manual* (*HCM*). Travel lane width considerations are appropriate within other categories of traffic-calming measures, not just pavement markings.

Exhibit 18.5.62 Advantages and Disadvantages of Narrowing Travel Lane Widths

ADVANTAGES	DISADVANTAGES
• Narrows travel lanes. • Improves pedestrian safety by reducing pedestrian crossing distance and exposure to motor vehicle traffic. • Ability to provide more lanes in constrained right-of-way. • Lower construction cost. • Research has shown narrowing travel lane widths may reduce vehicle speeds on roadways. • Redistributes roadway space for other modes of transportation (e.g., bicycle facilities), network users, or other features (e.g., medians, sidewalks.).	• Challenges for larger vehicles if adequate space is not provided. • May slightly increase travel time.

Effectiveness

Physically narrowing the roadway tends to have a greater impact than using pavement markings to narrow lane widths. Wider longitudinal pavement markings may not directly affect speeds, but

they may increase driver awareness, although for this application there is no conclusive data showing a reduction in crashes associated with these treatments.

The designer can refer to NCHRP's *Report 613, Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections, Section 4.11.4: Speed Effects,* and *Section 4.11.5: Safety Effects,* for more information regarding reduced lane widths.

Design

Applicable design tools include:

- **Roadway narrowing with edge lines.** Applying pavement marking edge lines and centerlines to create 9-to-10-ft lanes (check that this meets minimum lane width requirements in Chapters 3, 4 and 5). This reduces speeds by approximately 1 to 2 mph and up to 5 mph in some locations.

  Roadway narrowing with edge lines is generally applicable on local roadways and low-volume minor collectors. Documented uses of reduced lane widths include work zones, low-speed urban and residential locations, and rural two-lane highways.

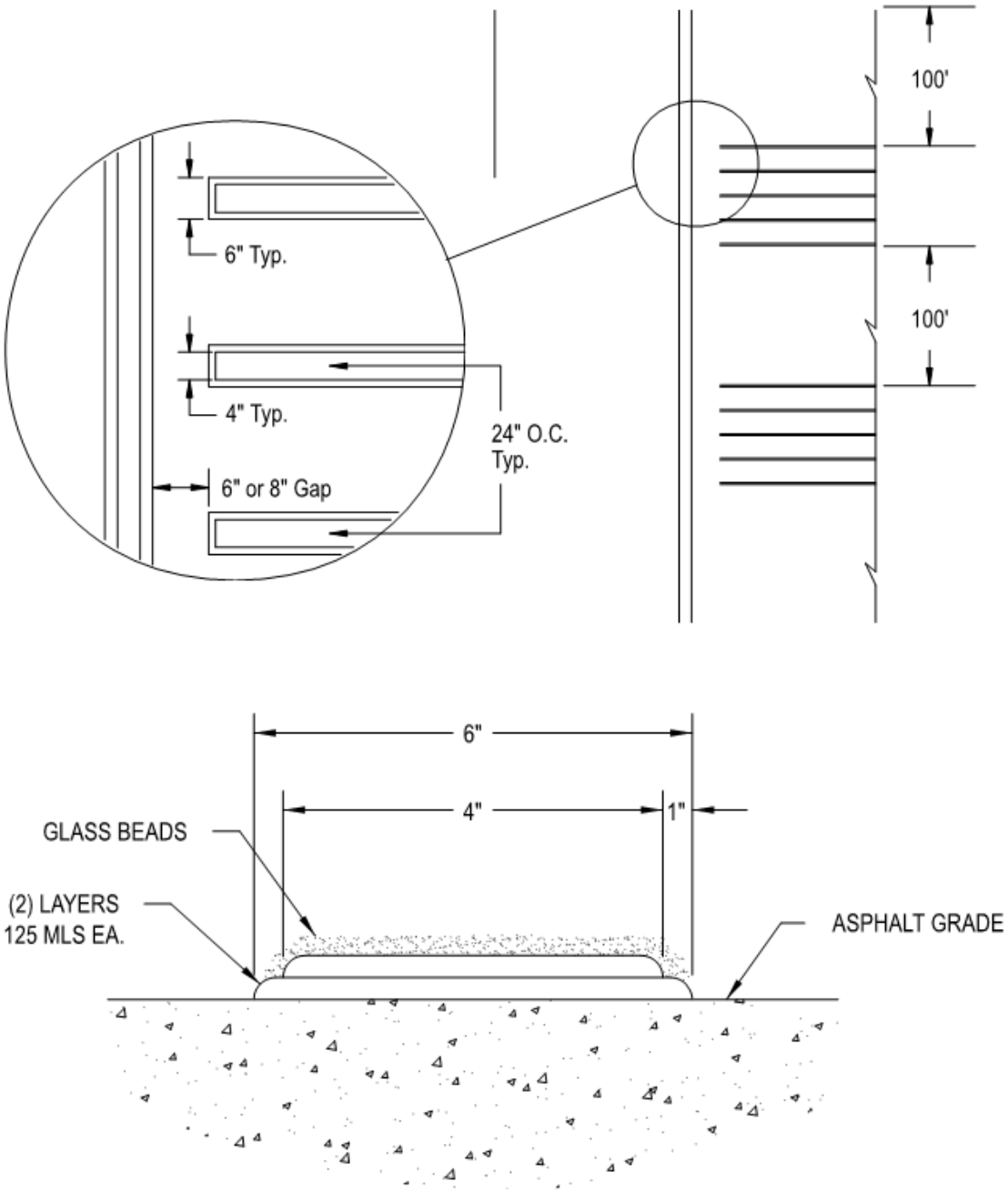
  The designer can refer to NCHRP *Report 613, Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections*, Section 4.11: Reduced Lane Width, for more information.

- **Wider longitudinal pavement markings.** The application of wider-than-normal line striping (i.e., 6 inches instead of 4 in) on roadways improves the visibility of travel lanes, demarks the intersection influence area, and calms traffic. Documented uses of wider longitudinal pavement markings include locations with a crash history involving curves, hills, roadway cross sections, and work zones.

  The designer can refer to NCHRP Report 613, *Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections*, Section 4.6: Wider Longitudinal Pavement Markings, for more information.

- **Transverse markings.** Double-thick thermoplastic transverse pavement markings can slow traffic in areas such as school zones, hospitals, approaches to severe curves, and stop signs. As illustrated in **Exhibit 18.5.63**, these markings typically consist of five transverse, 6-in-wide stripes, installed 2 ft on center, repeated every 100 ft. Depending on conditions, three to five sets of clusters are installed per approach. It is estimated that each cluster reduces approach speeds by 1 to 3 mph. As vehicles travel over these markings, the noise and vibration alert the driver. However, it may be inappropriate to use this application in locations with nearby residents, because of the noise generated. Avoid installing in shoulders.

Exhibit 18.5.63 Transverse Pavement Markings



Design Considerations and Context

- **Target operating speed.** Target operating speeds in urban districts are generally 35 miles per hour or 25 miles per hour in a residential district if the roadway is not a numbered traffic route and is classified as a local highway. Therefore, lane widths generally range from 10 to 12 ft on arterials and 10 to 11 ft on collectors. When target

operating speeds are below 30 mph, lane widths are typically 10 to 11 ft on arterials and 10 ft on collectors unless other design elements warrant a wider travel lane. Refer to Chapters 3, 4 and 5 for minimum required lane widths.

- **Multi-lane roadways with transit and freight.** On multi-lane roadways, a wider travel lane width may be provided as an outside lane (adjacent to the curb) for transit and freight, with inside lanes designed to a narrower width. A 20-ft clear distance is typically provided for fire truck access.
- **Urban areas.** In urban areas, travel lane widths of 10 ft typically provide adequate safety, slowing traffic without otherwise impacting traffic operations. For truck or transit routes, 11-ft designated lanes are typically provided.
- **Right-of-way.** The design should incorporate narrow lane widths for motor vehicles, reallocate roadway width, and prioritize space for bicyclists and pedestrians to maximize the use of right-of-way. Where capacity constraints exist, alternatives to widening street width or lanes, such as two-way to one-way conversions, should be considered.
- **Safety.** The designer should consider the safety of all users when designing with minimum-width travel lanes. Using minimum widths for adjacent street elements, such as travel, parking, and bicycle lanes, should be avoided, as minimum widths may reduce vehicle-bicycle or vehicle-pedestrian separation. The designer should consider widening the bicycle lane first to provide adequate separation. The designer can refer to Chapter 14, *Bicycle Facilities*, for information about bicycle facility selection and considerations for physically separated bike lanes.

18.5.18 – Lane and Parking Configuration Changes

Description and Purpose

On-street parking causes the visual perception of narrowing the roadway travel lanes. Parking may be allocated on alternate sides of a roadway to create a chicane effect but must be occupied with parked vehicles to effectively promote traffic calming.

On-street parking may be parallel, front-in, or front-out angled. Additionally, on-street parking may be combined with other physical treatments, such as curb extensions, mid-block chokers, chicanes, or road diets to have a greater traffic-calming impact.

The designer can refer to Section 19.2, *On-Street Parking Guidelines*, for more information about on-street parking design.

Exhibit 18.5.64 Examples of Lane and Parking Configuration



(Source: Google Maps)



(Source: Google Earth)

Exhibit 18.5.65 Lane and Parking Configuration Changes Typical Application

LANE AND PARKING CONFIGURATION CHANGES TYPICAL APPLICATION	
TRAFFIC VOLUMES	Appropriate to consider at all levels of traffic volume.
SPEED	Applicable on any common urban speed limit, provided an adequate shy distance is provided between the travel lane and parking lane.
STREET FUNCTIONAL CLASSIFICATION	Appropriate on all roads in rural towns, suburban, urban, and urban core contexts. Not applicable on rural roadways.
STREET WIDTH	On-street parking is preferable on streets with an urban cross section (curb). Can be applied both with and without a bicycle facility. The incorporation of bicycle facilities may require additional roadway width to protect bicyclists from dooring. (Refer to Section 14.3.4a for recommended bike lane buffer widths.)
NUMBER OF TRAVEL LANES	Appropriate on single-lane, one-way streets, and two-lane, two-way streets.
GRADE	Maximum grade should comply with local standards and criteria.
CURVES	Applicable on vertical curves, given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	Works well in downtown areas and near pedestrian generators or high levels of pedestrian activity. Also applicable in mixed-land uses, including residential areas and community places (e.g., transit stop, school, library, park). Not applicable in rural contexts. May be applicable in rural towns.

Exhibit 18.5.66 Advantages and Disadvantages of Lane and Parking Configuration Changes

ADVANTAGES	DISADVANTAGES
• May reduce vehicle travel speeds. • Improves pedestrian safety as parked vehicles provide a buffer between traffic and pedestrians on sidewalks. • Enhances neighborhood appearance. • Negligible drainage impacts. • Reduces traffic noise due to lower speeds and volumes. • Design can retain sufficient width to allow for transit and emergency vehicles. • Can be combined with other traffic-calming measures such as road diets, chicanes, curb extensions, and chokers, to further reduce speed. • Minimal impacts on motorist comfort.	• May create visibility issues by reducing driver visibility of pedestrians, or limiting sight distance at driveways, alleys, or intersections. (Unless combined with other measures such as curb extensions or daylighting.) • In high demand areas, may result in additional circulating trips as vehicles locate parking spots.

Effectiveness

The effectiveness of on-street parking on speed reduction depends on its demand. If half or more of the block face is not occupied by parked vehicles, the effect on vehicle speeds lessens and may be negligible.

Research has shown that on-street parking can slow speeds by 1 to 5 mph, with a 2 to 3 mph reduction most common. The most pronounced effect on speed occurs on a narrow two-way street with parking on both sides. Studies have shown that reducing the lane width with markings reduced 85th percentile speeds by about 1 mph.

On-street parking has little effect on traffic volumes. It also has limited effect on the number and severity of pedestrian-vehicle conflicts, except for the movement of persons to and from a parked vehicle.

Exhibit 18.5.67 Design Features and Typical Design Criteria of Lane and Parking Configuration Changes

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Typically, the recommended minimum width for a parking lane is 7 ft. See Exhibit 19.2.1 for more information about the recommended minimum parking lane width. • Refer to Section 14.3.3 for bike lane widths due to parking configuration.
PAVEMENT MARKING	• Exhibit 19.2.2 provides recommendations for parallel parking lane markings. • Refer to section 19.2.3, *Angled Parking*. Section 19.2.3.a describes the recommended design parameters for head-in angled parking and Section 19.2.3.b describes back-in angled parking. • May be designated using pavement markings, which may also be used to designate space where parking is not permitted. • When using pavement markings, parking facilities must be designated with a 4-in solid white-line edge. Parking lane surfaces will generally match adjacent streets.
LOCATION	• May be permitted between intersections. • Vehicle Code Title 75 §3353 - This section identifies parking restrictions, such as within 20 ft of a crosswalk per 3353(2)(iii), or within 30 ft of the approach to a stop sign or traffic signal per 3353(2)(iv). • Parking should not be permitted within 5 ft of driveways.
SIGNAGE	• Signs should indicate where parking is and is not permitted. • Signs should inform drivers of permitted and prohibited parking times.

Design Considerations and Context

- **Parallel and Angle Parking.** Angle parking has the potential to cause more crashes than parallel parking and is generally not recommended to achieve speed reduction. See Publication 46*, Traffic Engineering Manual,* Section 11.6, *Angle Parking*, or Chapter 19, for more information.

- **Demand.** Impact is directly affected by demand; there must be parked vehicles present to encourage traffic calming. For lower-demand locations, curb extensions may be used to further provide road narrowing features.

- **Pedestrian Accommodations.** On-street parking design should include curb extensions at intersections where pedestrians are expected to cross or where visibility is poor. The designer can refer to PennDOT's Publication 46*, Traffic Engineering Manual,* Section

11.6, *Angle Parking*, and Section 11.9, *Unsignalized Midblock Crosswalks,* for more information.

- **Restrictions.** On-street parking should be restricted at least 20 ft on both approaches to marked and unmarked crosswalks.
- **Multifunctional use.** The space resulting from lane and parking configuration changes can serve multiple uses. For example, the space can incorporate landscaping features, on-street parking, additional sidewalk pavement, transit stops and can be used to collect and filter stormwater.
- **Bicycle facilities.** Refer to Section 14.3.3 and 14.3.4 for information regarding bike lane widths with parking configurations.
- **Maintenance.** Landscaping should only be incorporated into traffic-calming devices where clear maintenance responsibilities have been established. PennDOT typically requires a maintenance agreement with municipalities for maintenance responsibilities.
- **ADA accessibility.** Accessible parking should be provided and located as close as possible to an available curb ramp. See Section 19.2.4, *Accessibility (ADA) for Parallel and Angled Parking – On Street*.
- **One-way to two-way conversion.** Depending on context, converting a multi-way one-way street to a two-way street can reduce vehicle speeds, and may provide improved pedestrian and bicycle access.

18.5.19 – Lane Reduction and Road Diet

Description and Purpose

A road diet involves removing vehicle lanes from a roadway and reallocating the space for other uses or modes, including bicycle infrastructure, wider sidewalks, landscaping, on-street parking, and transit facilities. The removal of through lanes may be reallocated to turn lanes. Road diets are also known as lane reductions and roadway reconfigurations. Relevant criteria for a road diet may include high crash rates for pedestrians and bicyclists, areas where speeding and frequent lane changes occur, desired changes to traffic flow, or to address intersection congestion.

The most common road diet configuration is the conversion of an undivided four-lane roadway into a three-lane undivided roadway, made up of two through-lanes and a center two-way, left-turn lane. (See Exhibits 8.1 and 8.2 for examples of Road Diet configurations.)

Refer to Chapter 8, *Road Diets,* for more information about the design of road diets. This chapter focuses primarily on the traffic-calming applications.

Exhibit 18.5.68 Example of Before and After Road Diet Configurations



Before



After

Exhibit 18.5.69 Lane Reduction and Road Diet Typical Application

LANE REDUCTION AND ROAD DIET TYPICAL APPLICATION	
TRAFFIC VOLUMES	• Varies depending on context. • 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. • See Section 8.2.5, *Average Daily Traffic (ADT)*, for more information.
SPEED	• Applicable for any common urban speed limits.
STREET FUNCTIONAL CLASSIFICATION	• Appropriate on arterial and collector roadways in rural areas and roads in rural town, suburban, urban, and urban core contexts.
STREET WIDTH AND NUMBER OF TRAVEL LANES	• Most common on a four-lane section, but also applicable on wide two-lane sections. Typical lane widths are 10 to 12 ft. • See Exhibit 8.0.2 for potential road diet configurations.
GRADE	• Must comply with local standards and criteria. • Maximum grades typically range from 5 to 12%. • See Section 8.6.2 for more information.
CURVES	• Applicable on vertical curves, given adequate stopping sight distance, appropriate lighting, and warning signs.
CONTEXT: LAND USE AND AREA	• Works well in downtown areas and near pedestrian generators or high levels of pedestrian activity. Also applicable in mixed-land uses, including residential areas and community places (e.g., transit stop, school, library, park). Not applicable in rural contexts except in rural towns.

Exhibit 18.5.70 Advantages and Disadvantages of Lane Reductions and Road Diets

ADVANTAGES	DISADVANTAGES
• Reduces speeds while maintaining throughput. • Improves pedestrian safety and comfort by reducing the number of conflict points and shortening crossing distances. • Improves bicyclist safety by reallocating roadway space for bicycle infrastructure. • Enhances neighborhood appearance. • Road diets that include center left-turn lanes may mitigate queues associated with left-turns. • If designed correctly, drainage impacts along curb lines are negligible. • Reduces traffic noise due to lower speeds. • May result in gain of on-street parking. • A low-cost solution.	• May result in the loss of on-street parking. • Challenges emergency response and heavy vehicles if not designed correctly.

Effectiveness

A road diet is an FHWA Proven Safety Countermeasure and provides safety and operational benefits. Road diets have operational benefits, including separating left turns, improving the safety for side-street traffic crossings, reducing speed, and enhancing mobility for all users.

Road diets have demonstrated a 3 to 5 mph speed reduction in 85th percentile speeds.

Studies show a 19 to 47% reduction in overall crashes when a road diet converts a four-lane facility to a three-lane facility. A road diet that incorporates elements of a Complete Street may also reduce collisions. Generally, road diets have shown a crash reduction of approximately 2%.

Design

Refer to Chapter 8.5.1, *Design Elements*, for more specific Road Diet design information.

Exhibit 18.5.71 Design Features and Typical Design Criteria of Lane Reductions and Road Diets

TRAFFIC-CALMING MEASURE DESIGN FEATURES	TYPICAL DESIGN CRITERIA
DIMENSIONS	• Roadway widths are described in Chapters 3 and 4. • Median design information is in Chapter 3.
CROSS SLOPE	• Generally, the highest point of the converted cross section is located at the center of the median or two-way, left-turn lane. • Cross slope design details are in Chapter 3.
BICYCLE FACILITIES	• Road diets that incorporate bicycle lanes must provide a minimum of 4 ft with no curb and gutter. Wider bicycle lanes should be considered when feasible. • Bicycle facilities may require additional attention within transition zones (entering and existing road diet segment.) • Refer to Chapter 14 for more information about the design of bicycle facilities.
LOCATION	• Applicable on roadway segments of varying lengths. • May be considered where road space may better be allocated to other modes, including bicycles, pedestrians, transit, or additional street furniture.
ON STREET PARKING	• Refer to Chapter 19, *Parking Facilities*, for the design of on street parking.
CROSS SECTION TRANSITIONS	• May require transitions entering and exiting the road diet segment. The design of these transitions is a function of the width of the lane to be dropped and the posted or design speed at lane-drop locations. • Taper lengths can be found in Chapter 3.

Design Considerations and Context

Refer to Chapter 8, *Road Diets*, Section 8.5, for more specific design considerations of Road Diets.

- **Area context.** Factors such as driveway access, transit and emergency routes, location of intersections, and operational characteristics of a corridor should be evaluated when considering a road diet. The FHWA and AASHTO established qualities that should be met when considering a road diet, including providing lasting community value and safe facilities, as well as preserving environmental, scenic, aesthetic, and historic values of the area.
- **Speeds.** When designing road diets, the design should match vehicle speeds to the context of surrounding land uses and road users.

- **Turning movements.** The volume and patterns of turning movements should be assessed when considering road diet conversions.
- **Service vehicles.** Roads that have a high volume of frequently stopping or slow-moving vehicles may not be well suited for a road diet. Queueing may result as delivery trucks, transit vehicles, and other service trucks stop along the roadway and prevent vehicles from passing. Applying curb management techniques may address frequently stopping or slow-moving vehicles.
- **Sight distance.** Road diets can be designed to improve sight distance for mid-block, left-turning drivers at entrances. Refer to Section 8.6.1.
- **Access management.** Access management should be analyzed during road diet conversions to mitigate site access issues. Access management considerations include potential conflicts with transit stops, driveway access use, property access, sidewalk continuity, and bicycle accommodations. Consolidating access points may simplify multimodal interactions and conflicts.
- **Maintenance.** Landscaping should only be incorporated into traffic-calming devices where clear maintenance responsibilities have been established. PennDOT typically requires a maintenance agreement with municipalities for maintenance responsibilities.
- **Materials.** Short-term materials, such as flex-posts, planters, and other street furniture, may be used as interim treatment options.

18.5.20 – Yield to Pedestrian Channelizing Devices

Description and Purpose

Yield to Pedestrian Channelizing Devices (YTPCD), R1-6 signs, offer a low-cost, effective solution for locations that have either an intersection with a documented car/pedestrian crash history or where pedestrians have difficulty crossing the street or roadway because motorists fail to yield to them lawfully.

The signs are designed to remind motorists of Pennsylvania law requiring the operator of a vehicle to yield the right-of-way to a pedestrian crossing a roadway within any marked crosswalk or unmarked crosswalk at an intersection where there are no traffic controls or traffic controls are not in operation. The designer can refer to Pennsylvania Statute *Title 75, Section 3542 (a)* for details.

YTPCD have both temporary and permanent applications. The temporary application is defined in this chapter. For details regarding permanent applications, the designer can refer to Publication 236*, Handbook of Approved Signs*.

Typical Application

The following eligibility criteria pertain to the temporary installation of YTPCD:

1) The units are intended for mid-block crossings or non-signalized intersections. However, if used at intersections, they must be placed slightly in advance of and as close to the crosswalk as feasible without interfering with the turning radius of motor vehicles.
2) Where YTPCD are considered, all crosswalks must be marked (i.e., no unpainted crosswalks). High visibility, continental crosswalks are recommended and preferred.
3) YTPCD are not intended as a permanent installation for traffic-calming purposes and should only be placed in the roadway during peak pedestrian activity. Experience using YTPCD in Pennsylvania indicate motor vehicles become accustomed to the presence of YTPCD and the installation becomes less effective at enhancing safety over time.

Design Considerations and Context

- **Using YTPCD as a gateway treatment.** YTPCD may be used alone by placing them on the double-yellow centerlines in the roadway or used as part of a gateway treatment. A gateway treatment can be constructed using a combination of three elements:
  - YTPCD mounted in the roadway on a temporary curb base.
  - YTPCD flush mounted on a curb in a median island or curb extension.
  - Flexible delineator post mounted on the white lane line.
- **Context and location.** YTPCD should not be used at an intersection approach that includes a stop control, either by sign or signal. It is for use at crosswalk locations where there are no traffic controls or traffic controls are not in operation.
- **Determining potential locations.** Potential locations for usage are determined by two methods.
  - Documented pedestrian crash locations in municipalities with significant numbers of pedestrian crashes.
  - High pedestrian-activity locations or locations near trip generators where motorists do not yield to pedestrians in crosswalks, resulting in community safety issues.

18.5.21 – Other

There are other engineering tools and techniques that can be used to achieve traffic-calming objectives. The toolbox includes the following other traffic-calming measures:

- 18.5.22 – Traffic Signal Timing and Phasing Modifications

- 18.5.23 – Automated Enforcement
- 18.5.24 – Leading Pedestrian Interval
- 18.5.25 – Intersection Control Spacing

18.5.22 – Traffic Signal Timing and Phasing Modifications

Description and Purpose

Traffic signal timing and phasing modifications can achieve traffic-calming goals that support the balanced movement of pedestrians, bicyclists, transit, and vehicles.

The designer can consider alterations to signal cycle length, signal phasing, and signal coordination. Signal timing parameters such as clearance intervals, detection location, and detection settings may also be altered to achieve safety related improvements at signalized intersections.

Design Considerations and Context

- **Shorten signal cycle lengths.** Shorter cycle lengths can minimize delay for all users and increase turnover at an intersection.
- **Minimize signal phases.** Where possible, minimizing signal phases can decrease wait times for all users. Providing additional phases has safety benefits for high vehicular-turning movements but may lead to increasing the signal cycle length. In urban areas, vehicular turn restrictions should be considered at key locations.
- **Prioritize walking, bicycling, and transit movements.** Signal priority techniques, such as leading pedestrian intervals, bicycle signals, and transit signal priority, are examples of tools used to establish priority for desired modes along a corridor.
    - Leading pedestrian intervals can be implemented to prioritize pedestrian movements at an intersection with a high volume of vehicle turning movements. Leading pedestrian intervals allow pedestrians to begin crossing the intersection before the turning vehicles receive a green indication.
    - Transit signal priority is a technique for coordinating transit headways for consistent transit routes.

    The designer can refer to Chapter 14 for information on bicycle signals.
- **Time signals to maintain desired travel speed.** Coordinated signal timing techniques can be used to maintain a specified travel time or average speed along a corridor. Low vehicle progression speeds can create a pedestrian-and-bicycle-friendly environment. Off-peak or weekend volumes should be considered when developing timing plans.

- **Use fixed time signalization versus actuated signalization.** In urban areas, fixed signals provide consistent and predictable opportunities for pedestrians to cross the street. Providing pedestrian recall at a signal can provide pedestrian phases every cycle, while still allowing vehicle demand to extend the green time beyond the pedestrian minimum time.
- **Meet accessible design regulations.** PROWAG and ADA regulations and guidelines can be met by incorporating audible indicators and pushbuttons (where applicable).

18.5.23 – Automated Enforcement

Description and Purpose

Automated enforcement is a tool used by states and agencies to reduce vehicles running red-lights and speeding, as both behaviors are major contributing factors to fatal crashes. Automated enforcement supplements traditional enforcement operations (in which violations are detected, identification information about the vehicle and driver is recorded, and citations are issued by mail). Both speed cameras and red-light-running cameras enable police to focus resources on other enforcement needs. Review Title 75 provisions to ensure compliance with the regulations.

For additional guidance and information regarding the implementation of red-light camera systems or speed enforcement camera systems, the designer can refer to *Red Light Camera Systems: Operational Guidelines* and *Speed Enforcement Camera Systems: Operational Guidelines* developed by the FHWA and the NHTSA. In addition, NCHRP's *Report 729: Automated Enforcement for Speeding and Red Light Running* provides guidelines for the operation of automated enforcement programs.

Exhibit 18.5.72 Advantages and Disadvantages of Automated Enforcement

ADVANTAGES	DISADVANTAGES
• Research indicates a reduction in speeds can be attributed to the implementation of automated enforcement, although the estimated reduction is difficult to quantify. • Improves safety by reducing speeding and speed related crashes. (Crashes occurring at lower speeds tend to be less severe.) • Allows police enforcement to reallocate resources to other needs. • Obtains quantifiable data on speed and red-light violations.	• May require further research into traffic flow changes and crash mitigation to non-enforced routes or segments.

Effectiveness

Studies documented in NHTSA's project, *Automated Enforcement: A Compendium of Worldwide Evaluations of Results,* reported reductions in speeds with automated speed enforcement. The estimated reduction is difficult to quantify due to the many factors associated with speeding and confounding factors related to differences in study designs.

Studies evaluated in NHTSA's project also reported a decrease in estimated injury crashes, all crashes, or speed-related crashes at project sites with automated speed enforcement. While key studies show a significant reduction in estimated crashes, only a few studies were well-controlled. The effects of regression to the mean, confounders, specific site characteristics, and behavior shifts (such as taking alternate routes) on the reduction in estimated crashes cannot be stated with certainty.

Factors contributing to red-light running include driver behavior, intersection design and operation, vehicle characteristics, and weather. Studies have shown evidence that red-light running camera systems improve safety at signalized intersections with high red-light running activity.

A variety of studies report a reduction in crash severity. Similarly, other reports document that red-light running camera systems contributed more to decreasing fatal, injury, angle and left-turn crashes than to decreasing property-damage-only or rear-end crashes. Crashes caused by red-light running tend to be more severe than other crashes that occur at signalized intersections.

Design Considerations and Context

- **Supplement to traditional tools.** Automated enforcement should supplement traditional engineering, enforcement, and education countermeasures, not just replace these measures.
- **Program qualities.** Beyond providing public transparency and awareness, automated enforcement offers other key program qualities. Their implementation is motivated by safety considerations, with legislation that provides the authority to operate the program. Further, automated enforcement is developed to be repeatable and monitored to evaluate performance and operation. As a result, automated enforcement can be deployed in locations such as on a high-injury network, or near school zones.

18.5.24 – Leading Pedestrian Interval

Description and Purpose

At signalized intersections with pedestrian signal indications, a leading pedestrian interval is a period of typically 3 to 7 seconds where the walk signal is provided to pedestrians in advance of vehicles receiving a green signal indication. The interval enables pedestrians to begin crossing an intersection to establish their presence in the crosswalk.

According to MUTCD, leading pedestrian intervals should be at least three seconds and timed to allow pedestrians to cross one lane of traffic or to be visible to vehicles before they receive a green indication. The duration of a green interval sometimes extends the pedestrian clearance time to provide turning drivers additional time to make turns after pedestrians completely cross the intersection.

Exhibit 18.5.73 Leading Pedestrian Interval Typical Application

LEADING PEDESTRIAN INTERVAL TYPICAL APPLICATION	
TRAFFIC VOLUMES	At a signalized intersection with high left-or-right-turning volumes.
INTERSECTION OR ROADWAY SEGMENT TYPE	At a signalized intersection.
CONTEXT: LAND USE AND AREA	In areas with high pedestrian activity.

Exhibit 18.5.74 Advantages and Disadvantages of Leading Pedestrian Intervals

ADVANTAGES	DISADVANTAGES
• Improves pedestrian safety (increases pedestrian visibility within the intersection, reduces pedestrian-vehicle crashes, and increases likelihood of vehicles yielding to pedestrians). • Low-cost improvement - can be incorporated into existing signal timing.	• May increase vehicle delay at signalized intersections operating at capacity. • Reduces green time for vehicle movements.

Effectiveness

The leading pedestrian interval is one of FHWA's Proven Safety Countermeasures based on the proven effectiveness of the safety improvement. This traffic-calming measure provides a 13% reduction in pedestrian-vehicle crashes at intersections.

One study demonstrated that the implementation of leading pedestrian intervals at ten intersections in Pennsylvania reduced pedestrian-vehicle collisions by up to 60%.

Design

MUTCD, *Pedestrian Intervals and Signal Phases* section, provides guidance and support about these measures. These include:

- Providing leading pedestrian intervals at intersections with high pedestrian volumes and high conflicting turning vehicle volumes.
- Using accessible pedestrian signals if intervals are implemented.
- Only applying leading pedestrian intervals when accessible features are also present, to avoid confusion.
- Prohibiting turns across the crosswalk during the interval.

The designer can refer to *NCHRP 812, Signal Timing Manual, Second Edition*, *Section 6.1.6.6 Additional Guidance on Pedestrian Intervals – Leading Pedestrian Interval*, for additional guidance.

Design Considerations and Context

- **Located at signalized intersections.** Leading pedestrian intervals can be implemented at intersections with current or desired high pedestrian volumes or intersections with long crossing distances.

- **Curb extensions.** Leading pedestrian intervals can be coupled with curb extensions to improve pedestrian visibility at intersections with conflicts, such as high left-or-right-turn volumes and reduce the amount of signal cycle time needed to complete the crossing.
- **Pedestrians with visual restrictions.** An audible signal should accompany the interval to accommodate pedestrians with visual restrictions.
- **Use of accessible pedestrian signals.** Accessible pedestrian signals should be considered.

18.5.25 – Intersection Control Spacing

Description and Purpose

Intersection control spacing impacts mobility, access, and connectivity within a network. Intersections should be analyzed as a part of a network rather than as an isolated feature and should be designed to result in operating speeds consistent with driver expectations and the function of the roadway.

NCHRP's *Report 613, Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections,* discusses the transition area between intersections and segments where drivers need to react and adjust their speed. The report also describes the intersection influence area as comprising geometric and operational areas. The geometric area includes typical section changes such as tapers for adding or dropping lanes. The operational area includes queuing, merging, lane changing, and acceleration and deceleration.

Design Considerations and Context

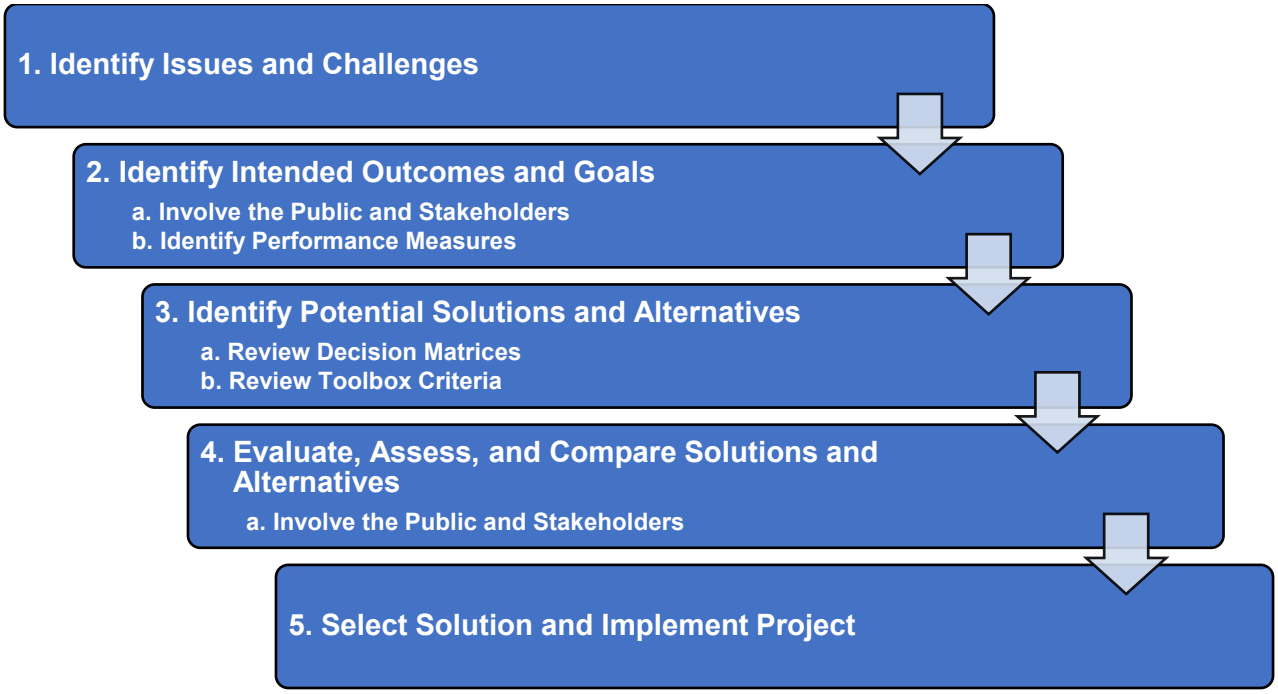
- **Traffic control type.** Driver operating speeds will vary with different traffic control types, due to various driver tasks required.
- **Long blocks between intersections.** Higher speeds tend to be associated with longer distances between intersections. Introducing elements of traffic control friction, such as vertical deflection, along long blocks can serve to calm traffic.
- **Large speed differentials.** When vehicle queues extend beyond an intersection or outside an intersection's approach sight distance, speed differentials along a segment can increase. This, in turn, increases the potential for severe crashes. When the difference in 85th percentile speeds exceed 10 to 15 mph in transition areas, crashes tend to be more severe. The relationship between speed and crash frequency is less clear.
- **Roadway characteristics.** Roadway and intersection geometric design characteristics, such as intersection spacing, travel lane width, turn lanes, and sight distance, can impact travel speed.

- **Pedestrian access.** The average intersection spacing for walkability is a maximum distance of 660 ft; less than 400 ft is desirable.
- **Transition area.** Intersection locating with respect to tangent segment could influence speeds.

Appendix 18A Traffic-Calming Study and Approval Process

Implementing a traffic-calming measure should be based on an established process. The process should start with the identification of a problem or issue within a given project or site context and continue through the implementation of an individual measure or series of measures. This procedure is for State highways, a local road with state or federal funding, or a federal aid roadway. PennDOT approval is not required prior to the installation of traffic-calming measures on a local road with local funding. See 67 Pa Code §212.5. Processes vary in their formal structure, but all effective decision-making incorporates the following key components displayed in **Exhibit 18.A.1**.

Exhibit 18.A.1 Traffic-Calming Study and Approval Flow Chart



As outlined in Chapter 2, the context will determine the design speed of a roadway. The context of the roadway could be defined through the planning process, the evaluation and review of existing conditions and proposed data, the involvement of stakeholders and the public, and data-driven analyses or processes.

A local authority can further define the context within its area through a data-driven screening process. This process allows a local authority to define and classify facilities under a more detailed and specific lens, potentially enhancing the resulting project. General approaches may include retrofitting existing roadway facilities with traffic-calming measures or designing new projects where geometrics and context lower speeds and criteria are aligned with design speed.

Traffic Engineering Form TE-125 is a step-by-step guide for documenting the project process and determining an appropriate traffic-calming measure. Documentation is an essential part of codifying all the research, outreach, and engineering judgments made during a project. A standardized traffic engineering form will also ensure consistency in how traffic-calming devices are deployed in Pennsylvania.

18A.1 – Tort Liability Considerations

Risk management best practices include keeping adequate documentation of engineering design decisions and assumptions made throughout a project. Elements that counteract potential liability concerns include the following:

- Public involvement.
- Documentation of design decisions made throughout a project.
- Documentation of the issues to address and the goals of the project.
- Design development that accommodates all users.
- Design development consistent with driver expectations.
- Provisions for adequate maintenance of the project features.
- Record retention.

Tort liability is addressed in Chapter 1; design documentation and exceptions are discussed in Chapter 2. Details pertaining to documentation and the process of design exceptions are outlined in Publication 10X, Design Manual Part 1X, *Appendices to Design Manuals 1, 1A, 1B AND 1C*, (DM-1X) *Appendix P,* Design Exceptions.

18A.2 – Identify Issues and Challenges

An engineering evaluation should be conducted when concerns about speed or safety arise. The evaluation may involve site observations, speed studies, conflict monitoring, community input, and available crash data and analysis information. The engineering evaluation should quantify and document the context considerations, such as existing site and project conditions, community feedback, environmental impacts, policy, and constraints.

The determination of traffic-calming measures might consider:

- Speeding issues, as documented through a speed evaluation of vehicles exceeding the posted speed limit or the operating speed intended for the context of the roadway.
- Concerns regarding speeding, poor visibility and impeded sightlines, and pedestrian safety.

- Crash data that documents pedestrian or bicyclist crashes, higher-than-expected vehicular crashes, intersection safety concerns, or specific crash types related to speeding.
- Land uses and context classification of an area that warrant implementation of traffic calming.

18A.3 – Identify Intended Outcomes and Goals

Once specific issues are identified, the stakeholders and community should be involved in developing the objectives and goals of traffic calming through implementation of priority concepts.

Outcomes and goals to increase the safety of users may include the following:

- Improve visibility for all modes of transportation.
- Reduce vehicle operating speeds.
- Reduce crash frequency and severity.
- Reduce crossing distance.
- Decrease all road users' exposure to crash risk.
- Increase pedestrian safety and comfort.
- Reduce conflict points.
- Improve visibility for pedestrians.
- Improve line of sight for pedestrians.
- Enhance multimodal connectivity and access.

18A.3.a – Involve the Public and Stakeholders

PennDOT's *Design Manual 1 (DM-1)* states that opportunities should be provided for more participation from agencies and the public at an early stage of the project and should continue throughout the duration of the project.

The designer can refer to *PennDOT Connects* and *DM-1* for best practices related to public involvement and stakeholder coordination. Avenues for soliciting feedback from stakeholders and the public include public comment periods, meetings and workshops, and online surveys.

18A.3.b – Identify Performance Measures

Once issues, challenges, outcomes, and goals are identified, performance measures should be developed to provide a framework for weighing alternatives and measuring progress. Performance measures can be linked to assessments of speed control, crash data, modal split, traffic volumes, and existing site-condition reviews.

18A.4 – Identify Potential Solutions and Alternatives

Once the issues are understood and the goals of the project are determined, the next step is to identify and prioritize solutions and alternatives to address the challenges. Maintenance considerations and public or stakeholder involvement should be a part of the decision-making process.

To find the optimal solution, the designer should assess the impacts of implementing traffic-calming measures and identify improvement opportunities. The designer should explore:

- The potential solutions and the variety of alternatives that can achieve the goals within the given constraints.
- The advantages and disadvantages of certain traffic-calming measures, and how project-specific performance measures and goals can be used in weighing solutions.

The path to implementing a traffic-calming measure may include education, enforcement, turn prohibitions, speed feedback signs, and pavement markings.

These tasks involve:

- **Education.** Advise and inform the public about the issues and challenges relating to safety and speed management within the transportation network for all transportation modes and users. Provide resources through community engagement efforts.
- **Enforcement.** Traffic and speed enforcement can be focused on key locations through data-driven processes to alter the behavior of drivers.
- **Turn prohibitions.** Implementing turn-prohibition signs (e.g., No Turn On Red signs, No Left Turns signs) may be useful in addressing operational concerns, safety implications, or cut-through traffic impacts. Installing signs to eliminate driver movements in full-time or restricted-time intervals may meet the goals of the project.
- **Speed feedback signs.** Installing speed feedback signs provides drivers with real-time information about how fast they are traveling and may encourage them to slow down.
- **Pavement marking solutions.** Implementing pavement markings to visually narrow the roadway to slow speeds, also known as roadway narrowing. Installing speed limit pavement marking legends to reinforce the speed limit.

18A.4.a – Preliminary Screening of Traffic-Calming Measures

Designers can use Exhibit 18.4.1 and Exhibit 18.4.2 to screen appropriate traffic-calming measures for a project. **Exhibit 18.4.1** shows the typical applicability of various traffic-calming measures to intended outcomes. **Exhibit 18.4.2** shows the five context classifications and posted speed ranges and the applicability of each traffic-calming measure within each context and each posted speed range.

18A.4.b – Review Toolbox Criteria

After a preliminary screening of traffic-calming measures, the next step is to review the toolbox criteria in Section 18.5, *Toolbox of Traffic-Calming Measures and Design Guidelines*, of this chapter for further details.

The criteria further narrow solutions and consider the advantages and disadvantages of potential traffic-calming measures by assessing impacts and opportunities, considering costs, and weighing outcomes.

18A.5 – Evaluate, Assess, and Compare Solutions and Alternatives

Evaluating, assessing, and comparing traffic-calming measures is an iterative process. The designer should consider applying multiple treatments within a network or area to achieve goals.

The design should provide efficiency in project implementation and identify low-cost solutions where applicable or effective, as well as descriptions or reasons why other considerations should be evaluated before undertaking a traffic-calming measure.

18A.5.a – Involve the Public and Stakeholders

The community can help identify concerns and can be involved in the solution process. The designer should incorporate the community vision and values in the selection of project alternatives and solutions. Designers should continue coordinating with affected stakeholders, such as residents and community members, public works, or PennDOT Maintenance, to discuss snowplowing or other challenges, such as drainage, utility, and other engineering implications.

The designer can refer to *PennDOT Connects*, DM-1, and Publication 295, *Transportation Project Development Process – Public Involvement Handbook,* for best practices for public involvement and stakeholder coordination.

Collaboration and partnership with PennDOT and other agencies throughout the duration of the project will help to ensure the success of traffic-calming measures on state-owned roadways or local roads on the Federal Aid System.

Early PennDOT Connects coordination with the Planning Region(s) and PennDOT District Staff, may help to identify planning concepts for a candidate project decision making process. Conversations with District staff in Design and Maintenance may also help to identify discretionary or Regional Long Range Transportation Program (LRTP) Funding opportunities for near and long-term solutions.

18A.6 – PennDOT Approval, Selection of Solution, Implementation of Project

PennDOT approval is required, prior to the installation of traffic-calming measures on a State highway, a local road with state or federal funding, or a federal aid roadway. PennDOT approval is not required prior to the installation of traffic-calming measures on a local road with local funding. See 67 Pa Code §212.5.

PennDOT approval of the selection and implementation of a traffic-calming project requires the following elements:

- Completed Form TE-125 (Traffic Calming Measure Engineering and Traffic Study) with appropriate signatures.
- HOP issuance (state-owned roadways only).
- Maintenance agreements.

Form TE-125 is to receive municipal approval, District Traffic Engineering approval if the project is a state roadway, and Assistant District Executive-Design Approval if the project is a PennDOT project.

Traffic calming is an evolving practice and data regarding certain traffic-calming measures is limited. Collecting before and after data on traffic-calming projects on both state and local roadways in Pennsylvania will help the department improve our policies and design criteria. Information on existing site conditions and intended outcomes will be documented using Traffic Engineering Form TE-125. It is strongly recommended to conduct a post-implementation analysis to: (1) assess the effect on measurable conditions including 85th percentile speeds and observed crashes; and (2) determine to what extent the intended outcomes were achieved. The findings should be reported to PennDOT Bureau of Operations for consideration and policy updates as applicable.

Appendix 18B Maintenance and Ownership

The justification for a traffic-calming device can originate as a stand-alone need for a specific location or as an integral part of a roadway project. Several different entities may be responsible for the various planning, design, construction, and maintenance stages of traffic calming.

When a local authority originates a project on a state road, close communication between the District and the local authority throughout the planning stage is recommended. The design and construction should be administered through PennDOT's Highway Occupancy Permit (HOP) program. Traffic calming can be integrated into the project scope, with PennDOT providing local support on the planning, justification, design, and construction. On a PennDOT construction project, PennDOT may issue an HOP to the local authority or complete a maintenance agreement identifying what aspects of traffic calming is the responsibility of the local authority Should the Permittee choose to make any future modifications to the traffic-calming measure, an HOP application must be submitted to PennDOT for review. **Exhibit 18.B.1** shows a typical breakdown of the responsibilities of local authorities and PennDOT.

Exhibit 18.B.1 Roles and Responsibilities of Local Authority and PennDOT

Task	Local Authority	PennDOT
Preliminary Assessment		
Process review	x	1
Site investigation	x	1
Data collection	x	1
Study development	x	1
Public and stakeholder involvement	x	
Municipal concurrence, associated cost, and future maintenance	x	
Application Submission		
Traffic-calming process adherence – conduct outreach with all stakeholders and coordinate with PennDOT Traffic Unit for determination and pre-approval	x	1
Department Application Review		
HOP submission process adherence – approve, deny or request additional information from the local authority		x

HOP issuance		x
Plan sheets development	x	1
Construction plans and specifications development	x	1
Construction		
Construction	x	1
Inspection	x	1
As-built drawings	x	1
Maintenance		
Budgeting	x	
Response and preventative maintenance	x	
Design modifications	x	

x = Entity responsible for task.
1 = The Department would generally perform this function for Department construction projects on state highways, but local authorities may be responsible for a share of the costs.

Appendix 18C: Form TE-125

TE-125 (11-24)

TRAFFIC-CALMING MEASURE ENGINEERING AND TRAFFIC STUDY

PLEASE TYPE OR PRINT ALL INFORMATION IN BLUE OR BLACK INK

pennsylvania
DEPARTMENT OF TRANSPORTATION
www.dot.state.pa.us

STEP 1: IDENTIFY CHALLENGES AND ASSESS ISSUES

A – LOCATION INFORMATION

COUNTY:	MUNICIPALITY:
STREET NAME:	
STATE ROAD #:	LOCAL ROAD #:
STUDY AREA: SEGMENT: OFFSET:	TO SEGMENT: OFFSET:
LOCATION:	TO LOCATION:

B – REFERENCE INFORMATION

REFERENCE: Chapter 212	SECTION(S): §212.9 Traffic Calming
REFERENCE: Design Manual 2	SECTION(S): Chapter 18 Traffic Calming
REFERENCE: PUB 46 Traffic Engineering Manual	SECTION(S):
REFERENCE:	SECTION(S):

C – STUDY ELEMENTS

FROM PUBLICATION 212 APPENDIX:

❑ Crash Analysis (1)	❑ Gap study for school children (7)	❑ Roadside Development (13)	❑ Speed Data (17)	❑ Other: _____
❑ Alternate Route (3)	❑ Geometric Review (8)	❑ Roadside Obstructions (14)	❑ Traffic Signals (19)	❑ Bicycle Volumes (X)
❑ Arr./Dep. hrs of students (5)	❑ Parallel Streets (9)	❑ School Route Plan (15)	❑ Type of Highway (21)	
❑ Capacity Analysis (6)	❑ Pedestrian Volumes (12)	❑ Sight Distance (16)	❑ Intersection Delay (22)	

D – EXISTING CONDITIONS DESCRIPTION

1. Is there a documented speeding problem? ❑ YES ❑ NO ❑ N/A

85th Percentile Speed: _____ Posted Speed: _____ Target Speed: _____

Remarks:

2. Have there been observed conflicts with vulnerable users or documented crashes? ❑ YES ❑ NO ❑ N/A

Remarks:

3. Are pedestrian/bicycle facilities present (i.e., sidewalks, curb ramps, crosswalks, pedestrian signals, trail, roadway)? ❑ YES ❑ NO ❑ N/A

Remarks:

Confidential – Traffic Engineering and Safety Study

(For Department Use Only)

This document is the property of the Commonwealth of Pennsylvania, Department of Transportation. The data and information contained herein are part of a traffic engineering and safety study. This safety study is only provided to those official agencies or persons who have responsibility in the highway transportation system and may only be used by such agencies or persons for traffic safety related planning or research. The document and information are confidential pursuant to 75 Pa. C.S. 3754 and 23 U.S.C. 409 and may not be published, reproduced, released or discussed without the written permission of the Pennsylvania Department of Transportation.

4. Are pedestrian facilities near the site? ❑ YES ❑ NO ❑ N/A

Remarks:

5. Has the land use context been defined per Design Manual 2? ❑ YES ❑ NO ❑ N/A

Remarks:

6. Has the functional street classification been defined? ❑ YES ❑ NO ❑ N/A

Remarks:

STEP 2: IDENTIFY INTENDED OUTCOMES OR GOALS FOR THE PROJECT

E – OUTCOME IDENTIFICATION

Identify outcomes/goals of traffic calming implementation to address site challenges.

- Reduced vehicle operating speed ❑ YES ❑ NO ❑ N/A
- Reduced crash frequency/severity ❑ YES ❑ NO ❑ N/A
- Reduced crossing distance ❑ YES ❑ NO ❑ N/A
- Decreased pedestrian exposure ❑ YES ❑ NO ❑ N/A
- Increased pedestrian safety and comfort ❑ YES ❑ NO ❑ N/A
- Reduced conflict points ❑ YES ❑ NO ❑ N/A
- Improved visibility of pedestrians ❑ YES ❑ NO ❑ N/A
- Improved line of sight for pedestrians ❑ YES ❑ NO ❑ N/A
- Enhanced multimodal connectivity and access ❑ YES ❑ NO ❑ N/A
- _____ ❑ YES ❑ NO ❑ N/A
- _____ ❑ YES ❑ NO ❑ N/A
- _____ ❑ YES ❑ NO ❑ N/A
- _____ ❑ YES ❑ NO ❑ N/A
- _____ ❑ YES ❑ NO ❑ N/A

F – OUTREACH EFFORTS

Has contact and discussion concerning traffic calming been made with the following groups/organizations?

- Municipality (s) ❑ YES ❑ NO ❑ N/A
- Transit Organization (s) ❑ YES ❑ NO ❑ N/A
- School District (s) ❑ YES ❑ NO ❑ N/A
- Public Meeting (s) ❑ YES ❑ NO ❑ N/A
- Emergency Services ❑ YES ❑ NO ❑ N/A
- Advocacy Groups ❑ YES ❑ NO ❑ N/A
- County Maintenance Service Providers ❑ YES ❑ NO ❑ N/A
- Other (s) ❑ YES ❑ NO ❑ N/A

Remarks/Comments from outreach efforts (specify which groups/organizations were involved in outreach efforts):

STEP 3: IDENTIFY POTENTIAL SOLUTIONS AND ALTERNATIVES

G – SITE INFORMATION FOR POTENTIAL ALTERNATIVES

DATE DATA COLLECTED:	PERSON CONDUCTING STUDY:	TITLE:

1. Traffic Volumes (ADT): .....

Remarks:

2. Posted Speed Limit (MPH): .....

Remarks:

3. Street Functional Classification: .....

Remarks:

4. Crash History: .....

Remarks:

5. Parking Information (i.e. Location, Capacity, Use, etc.): .....

Remarks:

6. Operating Speed (MPH): .....

Remarks:

7. Grade (percent) .....

Remarks:

8. Roadway Geometry (i.e. Curves, Intersection, Segment Type, etc.) .....

Remarks:

9. Number of Travel Lanes .....

Remarks:

10. What is the context, Land Use, and Area of the site/project? .....

Remarks:

11. What are the impacts on the project area and surrounding roadway network? .....

Remarks:

a. Is there a Transit Route/Transit Stops or Emergency Vehicle Route in the site/project vicinity? ..... ❑ YES ❑ NO

Remarks:

b. Have the impacts to larger vehicles been considered? ..... ❑ YES ❑ NO

Remarks:

c. Have noise impacts been considered ..... ❑ YES ❑ NO

Remarks:

This traffic engineering and safety study is confidential pursuant to 75 Pa. C.S. 3754 and 23 U.S.C. 409 and may not be disclosed or used in litigation without permission from PennDOT.

Step 3.1 - Preliminary Screening of Traffic-Calming Measures using Decision Matrices

1. Intended Outcomes of Traffic Calming Implementation, shows which intended outcomes are typically applicable with the implementation of various traffic-calming measures.
2. Posted Speed and Roadway Classification, shows the five context classifications and posted speed ranges along the top of the matrix. This matrix shows the applicability of each traffic-calming measure within each context and posted speed range.

Step 3.2 – Review Toolbox Criteria for potential Traffic-Calming Measures

STEP 4: EVALUATE, ASSESS, AND COMPARE ALTERNATIVES

H – EVALUTATION OF PROPOSED ALTERNATIVES

- Weighing the Advantages and Disadvantages associated with potential traffic-calming measures – document traffic-calming measure effectiveness in achieving intended outcomes.

- Considering Tradeoffs: safety, accessibility, cost, maintenance, multiple users, vehicles, and other modes of transportation.

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STEP 5: RECOMMENDATION OF A SOLUTION

I – RECOMMENDATION AND JUSTIFICATION OF PROPOSED SOLUTION

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J – APPROVALS FOR PENNDOT PROJECTS

Comments:

Completed by:

Name:	Agency/ Consultant:	Date:

MUNICIPAL APPROVAL
(Required for Local Roads)

Reviewed and Approved By (Print):	Title:	Date:

Reviewed and Approved By (Signature):

DISTRICT TRAFFIC ENGINEERING APPROVAL
(Required for State Roadways)

Reviewed and Approved By (Print):	Title:	Date:

Reviewed and Approved By (Signature):

ASSISTANT DISTRICT EXECUTIVE-DESIGN APPROVAL
(Required for Arterials and State Roads with Posted Speeds over 35 MPH; HDTD involvement required in the approval process)

Reviewed and Approved By (Print):	Title:	Date:

Reviewed and Approved By (Signature):

This traffic engineering and safety study is confidential pursuant to 75 Pa. C.S. 3754 and 23 U.S.C. 409 and may not be disclosed or used in litigation without permission from PennDOT.

Chapter 19 – Parking

In this chapter there are references to future chapters 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 19 – Parking

19.0 – Introduction

The size and location of parking facilities can have a significant impact on the overall operation of a roadway network, while also shaping overall land-use patterns. Accessibility for all parking facility users, for both arrival and departure and for navigating within a lot or exiting from an on-street parking space is important.



Parking is provided in several different ways, from street parking in cities, towns, and residential neighborhoods to serving the needs of specific land developments.

This chapter focuses on the design for accommodating parking within the State Highway right-of-way and at other PennDOT facilities.

The designer should ask these important context questions:

- Is there existing parking in the project area?
- Will installation of street parking negatively affect the operation or safety of the roadways or non-motorized transportation facilities (e.g., bike lanes, trails, and sidewalks)?
- For Park-and-Ride lots, are transit stops and stations coordinated with the parking arrangement to promote access to and safe circulation within the lot?
- What is the appropriate design vehicle for the facility?
- Will the access points to a Park-and-Ride lot or rest area create safety concerns and/or increase congestion on the road network?
- How easy is it to transition between buses and other modes of transportation?
- Parking is allowed along the curb or edge of any roadway in the Commonwealth, however, should parking be restricted under certain conditions as identified in Section 19.2.1 of this Chapter?
- How will parking affect the operating speed and width of the roadway?
- What are the special traffic control requirements for transit operations?
- How will ride-shares effectively pick up and drop off passengers at these facilities?

Key design components include:

- **Confirming Street Parking Will Not Negatively Impact Sight Distance and Other Modes.** Street parking is located curbside within communities containing businesses, bicycle and pedestrian facilities, and numerous cross-streets. Installation of street parking should not compromise sight distances for cross-streets or non-motorized users on bike lanes, trails, and sidewalks. The designer will have to balance this concern with a strong push from local businesses for as much on-street parking as possible. Removal of any spaces due to sight distance concerns should be coordinated with the municipality and local stakeholders. Parking design should balance safety needs for all users.

- **Sizing Facilities in Context with Surrounding Area.** On-street parking effectively narrows the roadway travel lanes by adding side friction to the travel flow, and it may be used to encourage traffic calming. The design should avoid using minimum parking and adjacent travel lane widths and turning radii in areas expecting significant numbers of truck deliveries or transit stops (if applicable). For rest areas and Park-and-Ride lots, the designer should ensure that lane widths are adequate and vehicle waiting areas are of sufficient width to allow larger vehicles (e.g., transit, maintenance vehicles, trash trucks, tow trucks, etc.) to navigate the parking facility without collision risks or detriment to internal circulation.

- **Providing Accessibility for Pedestrians.** ADA Guidelines dictate ratios of overall parking dedicated to users with disabilities. Accessibility must also be maintained for exiting vehicles and appropriate facilities. For street parking, the surrounding sidewalk design must allow users with disabilities ADA-compliant access from designated parking spots. For Park-and-Ride and rest area users, dedicated pedestrian paths with appropriate signage, detectable warning surfaces, and slopes in accordance with federal guidelines must be provided.



- **Considering Maintenance Operations in the Design of Parking Facilities.** For on-street parking, the type and location of parking can have a significant impact on snow-placement operations and lead to maintenance issues for other facilities (e.g., sidewalks and bike lanes) adjacent to the parking lane. Local coordination during design, especially where the local municipality leads snow removal efforts, is critical. For Park-and-Ride

and rest areas, the design should consider ancillary areas for snow removal, as well as potential constraints in providing adequate room to operate snow-removal equipment.

- **Parking is in Accordance with Regulatory Requirements.** See Vehicle Code Title 75 Section 3353. This section identifies parking restrictions, such as within 20 feet of a crosswalk per 3353(2)(iii), or within 30 feet of the approach to a stop sign or traffic signal per 3353(2)(iv).

19.0.1 – References and Resources

- AASHTO, *Guide for Development of Rest Areas on Major Arterials and Freeways*, 2001.
- AASHTO, *Guide for the Design of Park and Ride Facilities*, 2004.
- FHWA, *Commercial Driver Rest Area Requirements: Making Space for Safety*, 1996.
- FHWA, *On-street Motor Vehicle Parking and the Bikeway Selection Process*, 2021.
- National Association of City Transportation Officials (NACTO), *Urban Street Design Guide*, 2014.
- PennDOT, Publication 46, *Traffic Engineering Manual*.
- PennDOT, Publication 111, *Traffic Control-Pavement Markings and Signing Standards*.
- PennDOT, Publication 212, *Official Traffic Control Devices*.
- PennDOT, Publication 236, *Handbook of Approved Signs*.
- United States Access Board, *Guidelines and Standards*, 2017.
- United States Access Board, *Public Rights-of-Way Accessibility Guidelines (with SUP)* (PROWAG), 2013.
- United States Department of Justice, *ADA Standards for Accessible Design*, 2010.

19.1 – Required Agency and Stakeholder Coordination

The design team must coordinate with the local municipality on parking-related aspects of a project. The municipality often has standards and ordinances related to parking within their community, including alignment, placement, setback requirements, metering needs, and other items related to the design.

Through this coordination, the designer can ensure that parking is in accordance with local ordinances and/or preferences and can accommodate any future projects such as streetscape or pedestrian improvements. For Park-and-Ride lots, many of these same standards and ordinances may apply. Therefore, additional coordination should take place with local transit agencies to confirm that the design can accommodate both current and future service to the parking lot.

Stakeholders may have information on the types of vehicles they commonly see in their rest areas. For Park-and-Ride facilities, coordination with local stakeholders will also allow for determination of appropriate design vehicles for lot dimensions and arrangement.

For PennDOT projects, general guidance for which agency has precedence is as follows:

- Project designers should send the municipality an initial letter or e-mail asking if ordinances might apply, while stating PennDOT does not need to comply. PennDOT projects within the state highway right-of-way do not need municipal approvals or variances. Project designers should make a good-faith effort to accommodate municipal design practices. PennDOT design criteria will take precedence over municipal design criteria if they conflict.
- For facilities such as Park-and-Ride lots and rest areas outside of state highway right-of-way, local and municipal ordinances may apply. There are exceptions to this policy for certain circumstances. For questions related to these types of facilities, confirm with both the regional PennDOT District Office and they will coordinate with Office of Chief Counsel as necessary.

Generally, for non-PennDOT projects on non-expressways and non-freeways, PennDOT does not approve municipal installations, revisions or removals of parking as defined in Title 67 PA Code § 212.5(b)(iv), except written Department approval is required prior to creating new angle parking within state highway right-of-way.

19.2 – On-Street Parking Guidelines

On-street parking is a valuable resource in many communities because it provides access to residents and to local businesses, which generate revenue, and it slows adjacent traffic. State or local jurisdictions' legal rights-of-way often provide for on-street parking. Many local municipalities have ordinances and guidance that directs the type of parking installed (e.g., parallel versus angled) and minimum dimensions on stalls and markings.

19.2.1 – Placement Guidelines

Publication 212, *Official Traffic Control Devices,* Section 114, provides requirements on where parking is restricted, based on road width, operational characteristics, and other factors that would negatively affect the operation and safety of the state highway.

Per Publication 212, *Official Traffic Control Devices,* Section 114, parking may be restricted when:

1) The distance between the center of the centerline pavement markings (or the center of the roadway if centerline pavement markings are not present) and the curb or edge of the roadway is less than 19 feet on major arterial highways or less than 18 feet on other roadways.

2) The street width is such that, if vehicles are parked along one or both curb faces or edges of the roadway, two vehicles cannot move abreast of one another in the same direction or cannot pass one another in opposite directions (without one yielding to the other).
3) A capacity analysis indicates that parking should always be removed or during certain hours to accommodate the traffic volume.
4) The available corner sight distance for a driver at an intersection of a minor road is less than the necessary minimum-stopping-sight distance value for a driver on a through-roadway.
5) An analysis of vehicle crashes indicates that at least three crashes during the previous three-year period have been directly or indirectly attributed to one of the following primary causes:
    (i) Vehicles parking on the roadway.
    (ii) Vehicles entering or leaving the parked position.
    (iii) Drivers or passengers getting out of parked vehicles on the street side.
    (iv) Reduced sight distance due to parked vehicles.
6) The area is designated as a bus stop or as a loading and unloading zone.
7) The area is adjacent to or opposite a fire-station driveway or any other type of driveway or intersection where turning maneuvers would be restricted if parking were present.
8) The width of the shoulder is not sufficient to allow a vehicle or its load to park completely off the roadway.
9) Vehicles are allowed to use the berm or shoulder as a clear recovery area along roadways having three or more lanes and speed limits of 40 mph or above.

Due to potential dooring risk (e.g., when a moving vehicle or bicycle is struck by an opened door from a parked vehicle) and the safety of pedestrians entering and exiting the vehicle, street parking is not recommended along roadways with a posted speed above 35 mph, unless a buffer between the parking lane and travel lane is provided. When considering street parking adjacent to any roadway, issues such as exhibited demand, surrounding land use, and development plans for the local community, should factor into determining placement. See Chapter 14, *Bicycle Facilities*, for more information pertaining to bike lanes adjacent to parallel and angle (or diagonal) parking.

19.2.2 – Geometric Guidelines for Parallel Parking

For parallel parking, the recommended minimum width of a lane denoted for parking should be 8 feet. Passenger car and passenger truck body widths range from 5.2 feet to 7.2 feet. The maximum legal body width for all vehicles is 8.5 feet. Where constrained by right-of-way or other obstructions, the recommended minimum parking lane width per the Green Book's section on

On-Street Parking depends on roadway typology and surrounding land use as shown in **Exhibit 19.2.1**.

Exhibit 19.2.1 Green Book Recommended Widths for Parallel Parking Lanes for Various Roadway Typologies

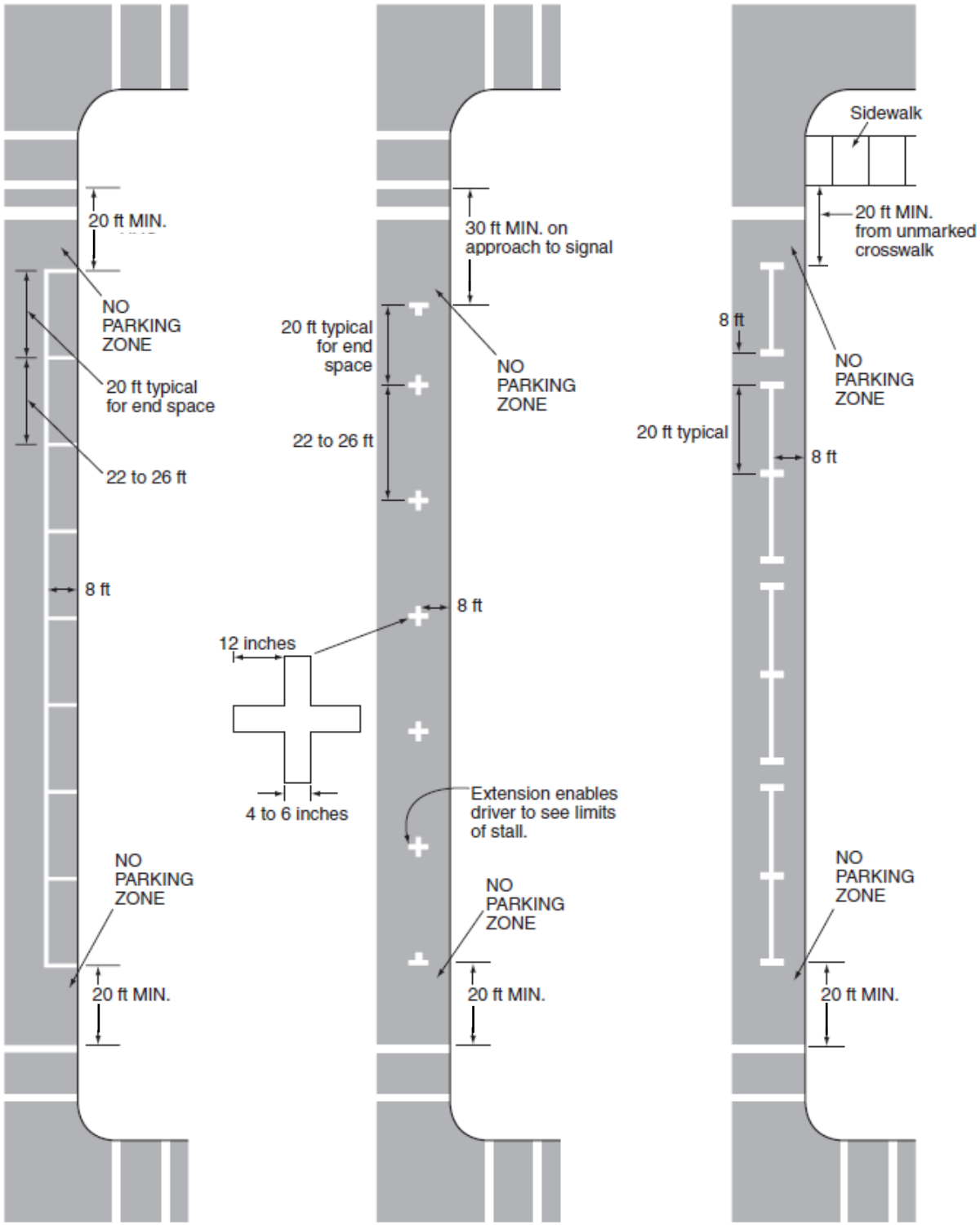
Roadway Typology	Surrounding Land Use		
	Residential	Industrial/ Commercial	Adjacent to Bike Lane
Local Roads and Streets	7’	8’	8’*
Collector Roads and Streets	7-8’	8-10’	8-10’*
Arterial Roads and Streets	7-10’	7-10’	12-14’
*In high volume bike or parking turnover areas, and where feasible, increase these dimensions to reduce the potential for dooring.			

The designer should consider greater parking lane widths in areas of observed larger vehicle (e.g., buses, three and/or more axle trucks) usage of parking lanes. Minimum lane widths in accordance with Chapters 3, *New Construction and Reconstruction – Change in Road Type,* and Chapter 4, *Reconstruction - No Change In Road Type; Resurfacing, Restoration, and Rehabilitation (3R), and Pavement Preservation Projects*, should be provided if the parking lane will serve as a travel lane during peak periods or intended for future use as a through-travel lane.

The selection of lane width and configuration fit into the context of the surrounding land use and in concert with the surrounding land use and operation of the roadway. For example, when parking lanes are provided on the approaches for a bridge, the design should consider extension of the parking lanes across the bridge. For curbside parallel parking, spaces should be 22 feet to 26 feet in length in accordance with the Green Book; however, this should be confirmed with local ordinances and guidelines. Designers should attempt to meet local requirements when they are defined and applicable. For lane buffer dimensions, refer to Chapter 14, *Bike Facilities*, for more information.

Pavement markings are recommended but not required; however, accessibility pavement markings are required. In areas where curb extensions are used, the extension should be 1 foot less than the width of the parking lane. When transitioning from parking lanes to the curb extension, the design should provide a 20-foot buffer space where parking is prohibited in advance of an 8-foot curb transition from parking lane to curb line. The Green Book, MUTCD, and the PA Vehicle Code (Title 75) Chapter 33, Subsection E, provides details and guidance on dimensions for curb and parking lane transitions at intersections. In many jurisdictions, local ordinances and standards have a prohibition of parking and appropriate spacing from such items as intersecting streets, fire hydrants, driveways, crosswalks, railroad grade crossings, and school zones. For information on the requirements at these locations, refer to PA Vehicle Code (Title 75) Section 3353. Restrictions at bus stops can be found in Chapter 15, *Transit Facilities*. **Exhibit 19.2.2** provides recommendations for on-street parking pavement markings.

Exhibit 19.2.2 Recommendations for Parallel Parking Lane Markings



For roadways accommodating bus and delivery vehicles, the designer can use turning templates for the appropriate vehicle to confirm that there is room to maneuver around marked parking stalls. The design must also ensure that emergency vehicles (fire, police, Emergency Medical Services) have access to facilities for their response (fire hydrants, etc.) and the ability to mobilize forces into buildings as needed.

See Chapter 14, *Bicycle Facilities*, for more information pertaining to bike lanes adjacent to parallel parking.

19.2.3 – Angled Parking

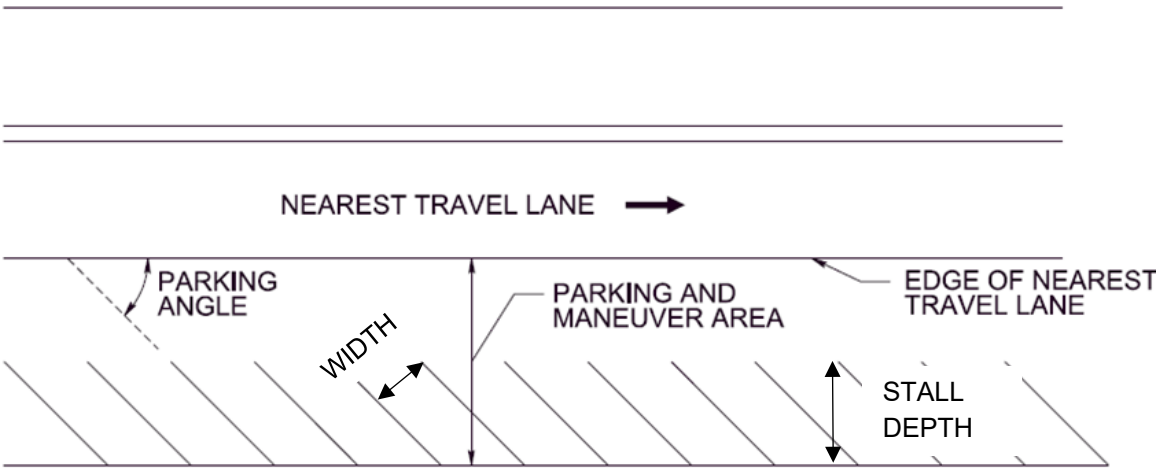
Parallel parking is usually the preferred installation when parking is permitted adjacent to a state highway, due to reduced space requirements and ease of ingress and egress to the roadway. Angled or diagonal parking, on lower speed roadways with more cross-sectional room, allows for better visibility of pedestrians and bicycles. As with parallel parking, appropriate numbers of ADA-accessible parking spaces must be provided (as presented in **Exhibits 19.2.8, 19.2.9 and 19.2.10**). Local authorities can permit angle parking where a study shows "sufficient width," but must get PennDOT approval before installing it on a state highway.

Angled parking may be considered where:

- Bicycle and pedestrian activity are of a high enough level that interactions with vehicles parking in the street are common.
- There is available right-of-way to provide the parking and/or maneuver area.
- Speeds are low enough to permit installation of the parking.

19.2.3.a –Head-In Angled Parking

Exhibit 19.2.3 sets the design parameters for the permissible use of angled parking. Space widths exceeding the minimum 8.5 feet widths are recommended.



Parking Angle (degrees)	Minimum Parking and Maneuver Area (feet)	Minimum Width of Space (feet)	Minimum Stall Depth (feet)
30	26	8.5	16.4
45	30	8.5	18.7
60 (preferred)	37	8.5	19.8
90	43	8.5	18

Exhibit 19.2.3 Parking Dimensions for On-Street Head-In Angled Parking

Other considerations for angle parking include checking that:

- Parked vehicles do not adversely affect the available intersection sight distance.
- Additional travel lanes are not required for existing traffic volumes to achieve a satisfactory level of operation.
- Parking stalls are adequately marked and spaced.
- Pedestrian activity is minimal within the parking maneuver area.

As with any parking installation, widths, and lengths of lanes, along with arrangement and angle, should attempt to conform to local ordinances. Minimum stall dimensions shown in Exhibit 19.2.3 are based on a standard car and moderate roadway travel speed and width. Consideration should be given to typical vehicle types accessing angled parking, as longer vehicles may encroach on the traveled way or interfere with sidewalks, off-street utilities, or

other items prone to overhangs. Wheel stops can be considered to minimize encroachment on pedestrian paths. Adjacent land use (high-volume shopping, etc.), parking stall user (commercial delivery vehicles, etc.) and roadway type/volume/speed may also influence a desired width of stall. As with parallel parking, head-in angled parking is not recommended adjacent to state roadways with a posted speed above 35 mph, unless a buffer (the area between the markings for the parking and the travel lane) is provided. Refer to Section 19.2.2 for consideration of wider parking widths.

See Chapter 14, *Bicycle Facilities*, for more information pertaining to bike lanes adjacent to angled (or diagonal) parking.

19.2.3.b – Back-In Angled Parking

Back-in angled parking can be considered, provided the back-in maneuver can be made without disrupting operations on the adjacent roadway. In some cases, back-in parking may be an easier maneuver than parallel parking. Back-in parking also allows the driver better sight distance when exiting the parking spot. Back-in angled parking considerations include typical vehicle types accessing parking, as longer vehicles may encroach on the traveled way, bike lanes or interfere with sidewalks and pedestrians, off-street utilities, or other items prone to conflict with vehicle overhangs. While not preferred in high-volume areas, back-in angled parking may be an appropriate application in urban areas with sufficient width and areas with a high demand for parking. As with head-in parking, back-in angled parking is not recommended adjacent to state roadways with a posted speed above 35 mph, unless a buffer (the area between the markings for the parking and the travel lane) is provided.



Back-in angled parking may have certain advantages over front-in angled parking, such as:

- The backing maneuver takes place into an empty stall, not into live traffic.
- There is no backing blind into traffic. Back-in angled parking provides better eye-to-eye contact between drivers, bicyclists, and other road users, especially if the parked vehicle is next to a larger parked vehicle.
- Trunks and tailgates are safely accessible at the sidewalk.
- Children are better protected because the open car door directs them away from traffic and toward the sidewalk.
- Studies have consistently shown that back-in angled parking reduces the likelihood of crashes.

Guidance for Back-In Angled Parking

- Ensure adequate clear roadway width between the end of the parking stall and the face of the curb or parking stall on the opposite side of the street. Confirm adequate turning space with a turning template analysis. This is illustrated in **Exhibit 19.2.6**.
- Appropriate signage is in important for back-in angled parking. Approved signage is shown below in **Exhibit 19.2.4** and **Exhibit 19.2.5** from Publication 236**.**
- The preferred angle for reverse angle parking is 60 degrees.
- The minimum stall width is 8.5-feet wide (W) and 18-feet long (L), but wider spaces are recommended. Exhibit 19.2.6 provides dimensions for back-in angled parking.
- Parking barriers and/or extended shy zones in the landscape/buffer zone are desirable to ensure vehicles with long rear overhangs do not reduce pedestrian access routes or strike furnishings and other street side elements.

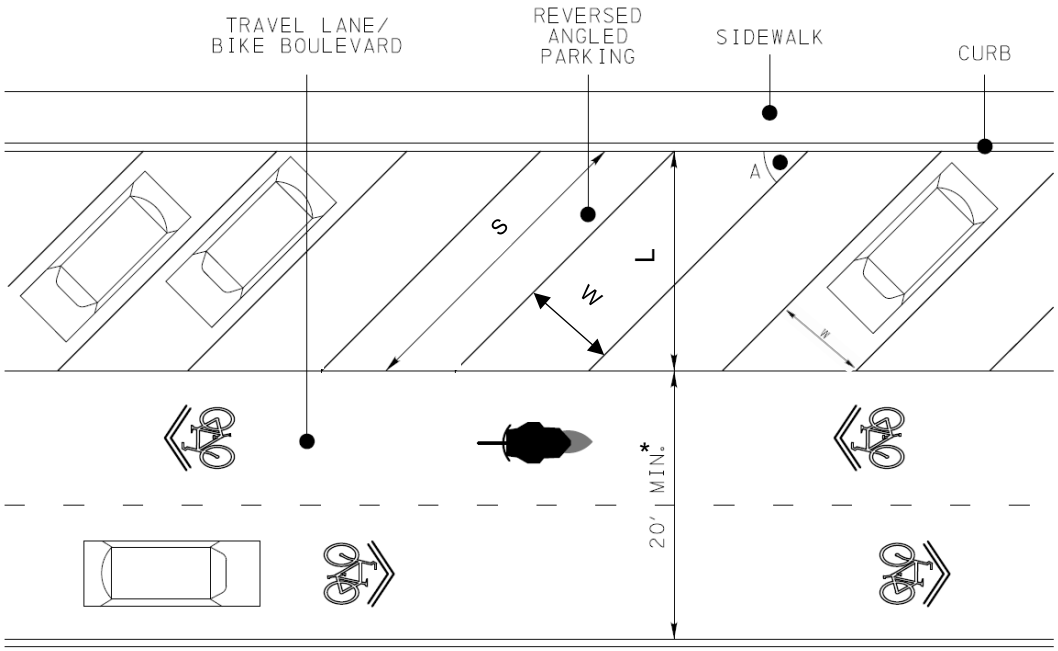


Exhibit 19.2.4 Back-In Parking Only



Exhibit 19.2.5 Back-In Parking Only with Arrow

Exhibit 19.2.6 Dimensions for Back-in Angle Parking Stalls



*For one-way streets, please use a minimum adjacent travel lane width of 10’ and any additional width needed for the design vehicle turning template.

Angle (A)	Minimum Stall Length (S)	Minimum Width (W)	Minimum Stall Depth (L)
30°	32.7’	8.5’	16.36’
45°	26.5’	8.5’	18.7’
60° (preferred)	22.9’	8.5’	19.5’
75°	20.3’	8.5’	19.6’

These stall dimensions are based on a standard car and moderate roadway travel speed and width. Adjacent land use (high-volume shopping, etc.), parking stall user (commercial delivery vehicles, etc.) and roadway type/volume/speed may also influence a desired width of stall. Refer to Section 19.2.2 for consideration of wider parking widths.

19.2.4 – Accessibility (ADA) for Parallel and Angled Parking - On Street

Where on-street parking is provided on the block perimeter and the parking is marked or metered, accessible parking spaces complying with the *Public Rights-of-Way Accessibility Guidelines* (PROWAG) shall be provided in accordance with **Exhibit 19.2.7**. Where parking pay stations are provided and the parking is not marked, each 20’ of block perimeter where parking is permitted shall be counted as one parking space. However, accessible parking is not

required for residential only parking spaces, regardless of if they are marked/metered. For marked/metered parking that serves both residential and business units, on street parking shall comply with PROWAG.

Evaluate accessible parking during new construction and alterations (resurfacing, etc.) to the facility, i.e., parking space. All resurfacing projects are considered an alteration to the street and require an evaluation of the number and location of accessible parking spaces on the affected block(s). Refer to Chapter 13, *Pedestrian Facilities*, for more information on alterations. All resurfacing projects are considered an alteration to the street and require an evaluation of the number and location of accessible parking spaces on the affected block(s).

Accessible parking spaces must be identified by signs displaying the International Symbol of Accessibility and should be located where the street has the least crown/grade and close to key destinations. In addition, Vehicle Code Title 75 Section 3354(d)(2) allows a resident with a disability to request an accessible parking space. At parallel parking spaces, curb ramps and blended transitions should be located so that a van side-lift or ramp can be deployed to the sidewalk and the vehicle occupant can transfer to a wheelchair or scooter (see Exhibit 19.2.8). Parking spaces at the end of the block face can be served by curb ramps or blended transitions at the pedestrian street crossing. Detectable warning surfaces (DWS) are not required on curb ramps and blended transitions that connect the access aisle to the sidewalk, including where the sidewalk is at the same level as the parking spaces, unless the curb ramps and blended transitions also serve pedestrian street crossings.

At accessible parallel parking spaces, parking meters shall be located at the head or foot of the parking space. Locating parking meters at the head or foot of the parking space permits deployment of a van side-lift or ramp or the vehicle occupant to transfer to a wheelchair or scooter. If pay stations are used instead of parking meters, they shall be located at the head or foot of the parking space they are adjacent to. Operable parts shall comply with PROWAG R403. Displays and information shall be visible from a point located 3.3 ft maximum above the center of the clear space in front of the parking meter or parking pay station.

If the Department is unable to provide accessible parking or the spaces are not fully compliant, a Technical Infeasibility Form should be submitted for review. This form is available through PennDOT's Americans with Disabilities Act (ADA) and Pedestrian Accommodations website, as well as through the District ADA coordinators. Completion of this form involves submission of site photos, as well as justification for not providing a fully compliant curb ramp. In these cases, coordinate with the District ADA Coordinator.

19.2.4.a – Minimum Required Number of Accessible (ADA) Spaces

The United States Access Board's *Public Rights-of-Way Accessibility Guidelines* (PROWAG) provides guidance on the minimum number and location of spaces for accessible parking spaces based on the total number of parking spaces provided on the entire perimeter of the block. When providing these spaces, the design must offer appropriate pedestrian

accommodations that allow the user to exit and subsequently access their vehicles. The values included in Exhibit 19.2.7 apply to both parallel and angle street parking.

Exhibit 19.2.7 On-Street Parking Spaces

On-Street Parking Spaces	
Total Number of Marked or Metered Parking Spaces on the Block Perimeter	**Minimum Required Number of Accessible Parking Spaces**
1 to 25	1
26 to 50	2
51 to 75	3
76 to 100	4
101 to 150	5
151 to 200	6
201 and over	4% of total

(Source: PROWAG)

19.2.4.b – Parallel Parking Accessible Spaces

For resurfacing projects, when the sidewalk is not being altered, locate the accessible spaces at the end(s) of the block face, unless a mid-block ADA compliant parking with an access aisle already exists. Curb ramp upgrades done as a routine part of resurfacing project are not considered sidewalk alterations.

When the street and sidewalk are both being altered as part of the project, the width of the adjacent sidewalk and available Right-of-Way* determine space needs adjacent to accessible parallel parking spaces. As per PROWAG, design features for these spaces fall into the following categories:

- **Wide Sidewalks.** Where the width of the adjacent sidewalk or available right-of-way* exceeds 14 ft, an access aisle with a minimum of 5 ft wide shall be provided at street level the full length of the parking space and shall connect to a pedestrian access route.

- **Narrow Sidewalks.** An access aisle is not required where the width of the adjacent sidewalk or the available right-of-way* is less than or equal to 14 ft. When an access aisle is not provided, the parking spaces shall be located at the end of the block face.

  *The width of available right-of-way depends on the scope of the project. The scope of the project will determine what must be done to make any available, but currently unusable, right-of-way accessible. Utilities, drainage, terrain, etc. may present conditions that prohibit construction of accessible aisles. Refer to Chapter 13, *Pedestrians Facilities*, for more details on how the scope of the project determines ADA requirements.

For the Wide Sidewalk category, two accessible parallel parking spaces can share a perpendicular access aisle. The parking stall must have a minimum width of 13’ which will allow a 5’ access aisle on either side. Curb ramps or blended transitions complying with ADA requirements shall connect the access aisle to the pedestrian access route. Curb ramps shall not be located within the access aisle and shall not encroach on the vehicular travel lane. Exhibits 19.2.8, 19.2.9 and 19.2.10 illustrates accessible parallel parking options.

Exhibit 19.2.8 Accessible Parallel Parking with Sidewalks (Or Available Right-of-Way) Greater Than 14 Feet with Street and Sidewalk Modifications

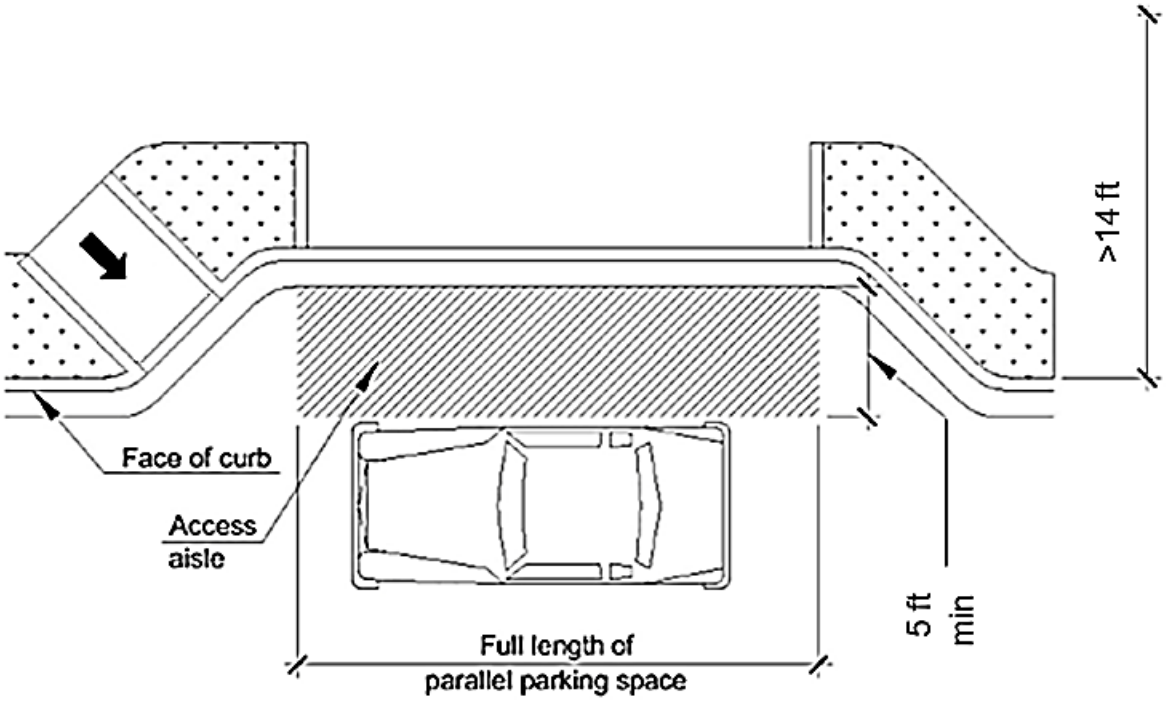


Exhibit 19.2.9 Accessible Parallel Parking with Sidewalks (Or Available Right-of-Way) Greater Than 14 Feet with Street and Sidewalk Modifications – Multiple Spaces

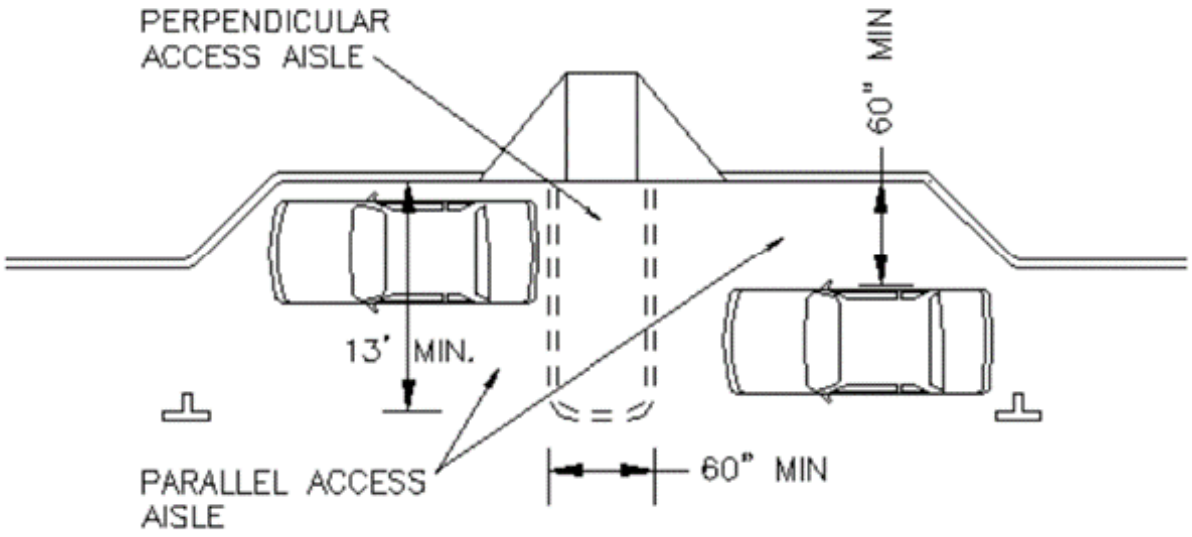
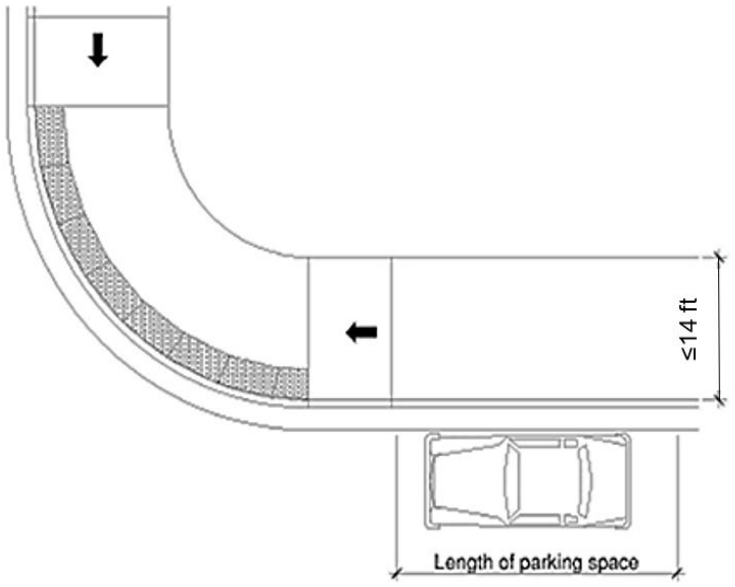


Exhibit 19.2.10 Accessible Parallel Parking with Sidewalks (Or Available Right-of-Way) Less Than 14 Feet with or without Street and Sidewalk Modifications



Regarding general accessibility from parallel parking spaces, the PROWAG states:

> "The sidewalk adjacent to accessible parallel parking spaces should be free of signs, street furniture, and other obstructions to permit deployment of a van side-lift or ramp or the vehicle occupant to transfer to a wheelchair or scooter. Accessible parallel parking spaces located at the end of the block face are usable by vans that have rear lifts and cars that have scooter platforms."

19.2.4.c – Angle Parking Accessible Spaces

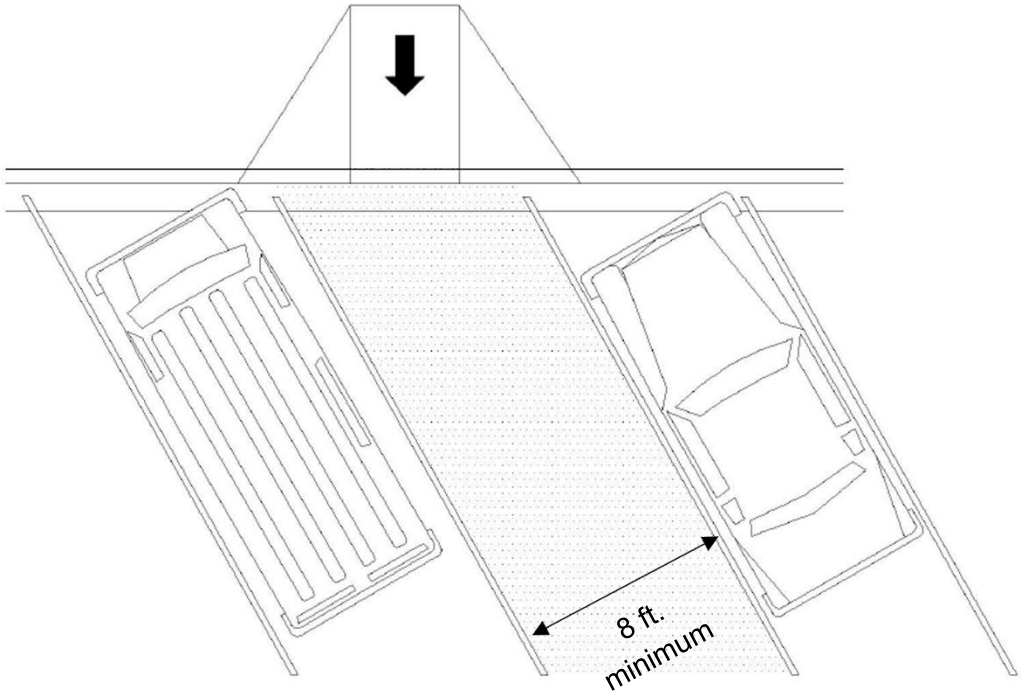
For angled or perpendicular street parking, the Access Board provides the following guidance:

> "Where perpendicular or angled parking is provided, an access aisle 8.0 feet wide minimum shall be provided at street level the full length of the parking space and shall connect to a pedestrian access route. Two parking spaces are permitted to share a common access aisle."

Also, access aisles should be provided on the passenger side, if possible, should extend the full length of the space, be marked, and not project into the travel lane.

Exhibit 19.2.11 illustrates accessible angle parking to the sidewalk.

Exhibit 19.2.11 Example Angle Parking Spaces Accessible to Sidewalk



19.2.5 – Removal of On-Street Parking

Removing existing parking along roadways should be considered when parking spaces create safety or operational issues for adjacent roadway users (e.g., sight distance concerns, pedestrian, and bicycle conflicts, or impacts on through-traffic on the roadway). Section 3353(d) of the vehicle code requires an engineering and traffic study that demonstrates a hazard (or that traffic is "unduly interfered" with) before restricting parking. When parking has been removed, and where parking is always prohibited or at specific times, NO PARKING signs should be installed following the requirements of Publication 236, *Handbook of Approved Signs*.



R8-3

(Source: Publication 236, *Handbook of Approved Signs*)

Publication 212, *Official Traffic Control Devices,* Section 114 (h), provides additional requirements on when it is permissible to remove parking on state highways, as follows:

> "Local authorities may establish, revise, or remove stopping, standing, or parking restrictions on State-designated highways within their physical boundaries, except Department approval is required prior to revising or removing any of the following:
>
> (1) Established in conjunction with a State or Federal aid project.
>
> (2) Requested or posted by the Department for safety or capacity reasons.
>
> (3) Included as a condition on a traffic signal permit."

Local ordinances and standards may also provide direction for removal of on-street parking. Section 2B.47 of the MUTCD provides additional guidance on prohibiting parking for a specific period or within a particular location.

19.3 – Park-and-Ride Parking Lots Design Guidelines

Park-and-Ride lots are valuable transportation facilities and can be key features of a multimodal transportation network. These facilities serve a broad range of use, from a small, simple place to park a few vehicles temporarily to an upscale, major multimodal hub. Park-and-Ride facilities are mainly utilized by commuters as a convenient means to pursue ridesharing/carpooling, vanpooling, bus, bike, or rail transit to reach their destination. Designers should consider the queueing when creating the design, especially at major Park-and-Ride locations.

These parking lots can promote non-automobile usage in several ways. Bus stops can be provided within a Park-and-Ride lot. Many buses are equipped with bicycle racks to transport both passengers and bicycles, allowing for bike commuters to utilize bikes on both ends of their transit usage. Park-and-Ride lots can be connected to trails and bike paths and have on-site bicycle storage facilities to encourage their use.

Park-and-Ride lots can be incorporated into ITS 'Smart' transportation technology applications such as multi-modal notification applications using on-site cameras, electronic message boards,

etc. Designers should consider incorporating ITS 'Smart' technology features into Park-and-Ride lots where Department ITS applications and other transportation mode provider applications support it.

The Park-and-Ride facility design can also include attractive landscaping that meets the architectural standards of a given community, while supporting local art with area-specific designs interwoven into the facility. Park-and-Ride landscaping may require maintenance agreements to establish maintenance responsibilities.

In summary, appropriate design choices can make Park-and-Ride facilities a pleasant place for people to have an intermediate meeting place and encourage users to consider non-automobile transportation or carpooling.

Note: Projects outside the highway right-of-way may be required to comply with local ordinances, including zoning ordinances. For questions regarding which standards govern on a particular project, please contact Office of Chief Counsel.

19.3.1 – Location and Layout

Locating and developing plans for Park-and-Ride facilities require analysis of several factors to determine where the facility will best serve both commuters and transit agencies. Situating the Park-and-Ride facility will depend on the availability of sites, locations of other Park-and-Ride facilities, topography, the surrounding roadway network, land use, and other elements. The layout must incorporate appropriately sized facilities that provide the proper mix of parking capacity, internal circulation for all users, and accessibility. It is important to recognize that Park-and-Ride lots are appropriate for both rural and urban conditions along corridors that provide commuter service to large employer bases.

Exhibit 19.3.1 provides general guidance for Park-and-Ride facilities.

Exhibit 19.3.1 General Park-and-Ride Guidance

Lot Type	Description	Typical Lot Features	Considerations
Remote or Rural Facilities	Remote lots are located in areas with low population growth and are not expected to grow excessively. Lots are generally located outside the urban area in a rural or small-town setting. Trip lengths for home-to-lot and lot-to-work tend to be longer than for other lot types.	• Between 20-60 miles from employment centers • More than 20,000 employees at trip end • Publicly owned right-of-way (ROW) already available • Less than 1 mile from a primary commuter route (arterial or freeway)	The success of a remote lot is dictated by the level of employment located at the destination and the distance traveled. Lots should be centrally located to the service area population. Usage will be greater if located near a major commuter route.
Urban Fringe Facilities	Urban fringe lots are located at the edge of urban development. Trips tend to originate outside or at the outer limits of the urban area while the destinations may be concentrated or dispersed within the urban area.	• Trip destination patterns may be concentrated or dispersed within the urban area • Located along arterial roadways with 4 lanes or more • Minimum of 10,000 employees per square mile to support the formation of carpools • Located in the vicinity of an urban area boundary • More than 3/4 mile from primary commuter route (arterial or freeway)	Service area demand and concentration of employment are factors that determine the usage of an urban fringe lot. Locations near a roadway with 35,000 Average Daily Traffic (ADT) is recommended to be used as a guideline for lot consideration.

Lot Type	Description	Typical Lot Features	Considerations
Peripheral Facilities	Peripheral lots are typically located on the edge of an intensely developed, highly congested or access-restrained activity center. These lots are designed to supplement parking deficiencies and include facilities that service activity centers with limited parking and/or auto access such as auto-free zones, colleges, and universities.	• Adjacent to areas which are congested or have restricted access • On a primary commuter route (arterial or freeway) • Insufficient parking facilities in the area • Distances from residential areas generally longer than other Park-and-Ride facilities, while distances to the activity center are usually shorter	Consider: • Parking demand/supply • Activity center circulation • Activity center access routes • Existing parking facilities
Urban Corridor Facilities	Urban corridor lots are located along a major commute route within an urban area, typically served by bus, urban rail, or commuter rail services. Trip origins tend to be disbursed along the corridor; destinations are usually concentrated in a Central Business District (CBD) or employment center.	• Often close to corridor with Level-of-service E or worse • Often close to a corridor with over 50,000 ADT • In areas with more than 2,000 dwelling units within 2 miles of lot • Lots usually located more than 10 miles from employment center	Identify areas in highly congested corridors. Prime corridors are operating at Level-of-Service (LOS) E or worse. It is better to locate a lot closer to trip origins.

19.3.1.a – Site Selection

The location of Park-and-Ride facilities are often determined by agencies outside of, but in coordination with, PennDOT, including transit agencies, planning agencies, and local stakeholders. PennDOT frequently serves as a stakeholder in the process since these facilities are often adjacent to and likely to impact state highways. PennDOT also serves as the primary owner for many Park-and-Ride lots along the state highway system.



Site selection is driven by the availability of an appropriately sized lot relative to the demand, necessary borders, landscaping, drainage, transit stations and stops, and other amenities. Public input also plays a role in site selection, as traveler demand and convenience are of the highest importance. Site selection should also consider expected service providers, incorporating both existing and planned transit operations.

Taking into consideration the needs of end users and service providers creates a framework for identifying areas where Park-and-Ride lots may be practical. Although this may largely be a common-sense approach, it is also based on long range planning, as well as existing and projected transportation, land use, and economic conditions including, but not limited to:

- Existence of informal Park-and-Ride activity
- Transit service
- Site visibility and accessibility
- Proximity to other major corridors or critical junctions
- Intensity, concentration, and location of employment centers
- Density and location of residential areas
- Distance between major residential areas and employment or activity centers
- Current and future levels of service on sub-area and corridor-level roadways
- Existing and future transportation-related improvement plans and programs
- Anticipated future development activity at both trip origin and destination points
- ROW acquisition costs

19.3.1.b – Site Sizing

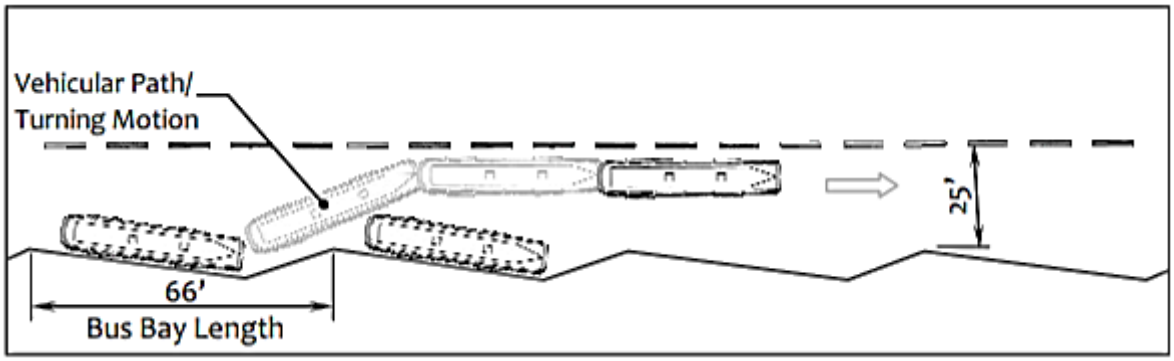
For sizing a parking lot relative to demand, several resources provide guidance for determining expected usage. AASHTO's *Guide for the Design of Park and Ride Facilities* provides a list of characteristics and analyses to be considered in determining the siting and size of the facility. AASHTO also provides assistance on the anticipated catchment area of the facility, as well as other factors, such as proximity to other Park-and-Ride locations and frequency of transit service. Additionally, the Institute of Transportation Engineer's *Trip Generation Manual* denotes Park-and-Ride lots as a recognized land use with trip generation rates based on a variety of lot characteristics.

19.3.2.c – Transit Terminal Facilities

Transit terminal facilities is a general term referring to the location where passengers board and alight from the transit vehicles. The design of transit transfer terminals within a Park-and-Ride facility comprises of two components: the transit vehicle and the passenger. The terminal area should be designed to provide for safe and easy bus operations. Large turning radii should be provided for buses to avoid acute angles when entering and exiting the site. Circulation roadways in the terminal area should be two lanes and operated in one direction of travel.

A saw-tooth design, shown in **Exhibit 19.3.2**, for the bus loading area provides for the easiest operation of buses, but is only required for larger terminals with extensive bus service. Reinforced pavement is recommended for the terminal area because of the large wheel loads, higher temperatures, and friction caused by buses stopping and starting.

Exhibit 19.3.2 Example Saw-Tooth Bus Parking Design



At a minimum, passenger amenities to consider for terminal areas are shelters, benches, and transit information. Designers should consider the need for maintenance of passenger amenities during the planning and design process.

Shelters should be provided where large numbers of passengers load buses or access other forms of transit, where transit is promoted, where waiting occurs, and where the site allows for such amenities. Generally, the need for a shelter increases with the demand and the headway between transit vehicles.

The size of a shelter required at a Park-and-Ride facility depends on the maximum accumulation of users at the transfer terminal. For conceptual design, the shelter size requirements can be assumed to be 25 square feet per 100 space facility. This is based on the following assumptions:

- An area of 80 square feet per shelter user.
- The number of kiss-and-ride drop offs is equivalent to 0.20 times the parking spaces in the facility.
- The average wait time is ten minutes.

Design decisions should be based on the number of vehicles parked at one time, the number of passengers, bus frequency, and funding. Shelters should be of contemporary design, constructed of highly durable materials, highly visible and providing ample weather protection, with minimal installation and maintenance costs. Clear zone and line-of-sight requirements must be kept in mind when placing shelters. They should not block the sidewalk and should allow for at least the minimum width required by ADA standards for passing on the sidewalk without interfering with the shelter. The characteristics of shelter design should include:

- **Visibility and Lighting.** Visibility and lighting provides for user safety. At all times, the driver must be able to see that a passenger is waiting for the bus and the passenger should be able to see the approaching bus from inside the shelter.
- **Accessibility.** Shelters should provide for convenient access and user safety and must meet ADA standards.
- **Appearance.** Shelters should be visually pleasing in relation to the surrounding environment, with the logo of the local transit provider clearly visible on the shelter.
- **Materials.** Typical construction materials include steel, anodized aluminum, wood, concrete and tile block, reinforced concrete, fiberglass, plastics, and glass. Recycled materials and those with vandal-resistant surfaces should be a priority. Cost, durability, availability, and appearance should guide the selection of construction materials.
- **Modular Construction.** Modular construction facilitates capacity expansion and design uniformity and can reduce costs.
- **Amenities.** The minimum recommended amenities include shelters, benches, and bicycle racks. Other features can include transit route maps, transit schedules, telephones, and trash receptacles.

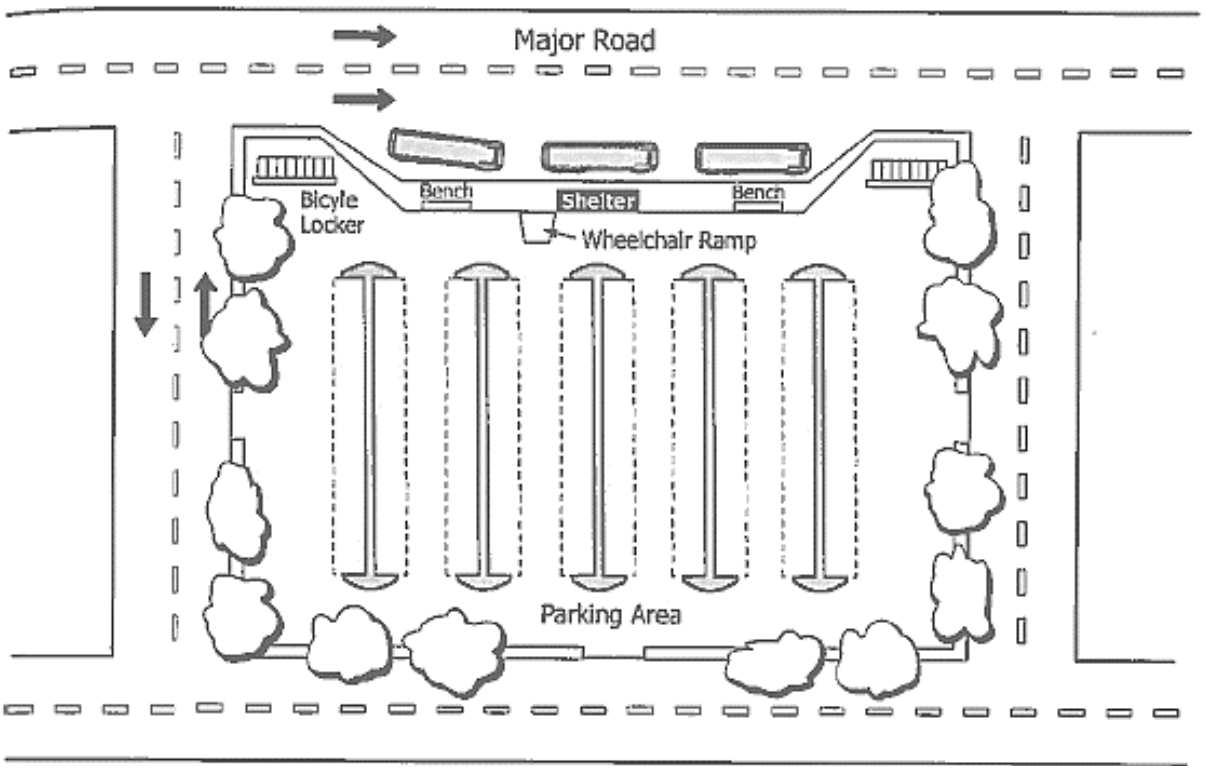
19.3.2.c.i – Bus Loading Areas

Bus loading areas are the specific locations at terminal facilities where passengers board and alight. Bus loading areas should be considered for Park-and-Ride facilities served by transit. Formal bus loading areas are recommended for inclusion during facility planning and design. Refer to the 2010 ADA Standards, Section 810.2, for additional information.

Retrofitting necessitates consideration of the pavement in the area where the stop is to be situated. Rigid pavement should be placed where vehicles stop for loading and unloading operations. Asphalt pavement is suitable for roadways, but should accommodate the wheel loadings of transit vehicles operating at slow speed.

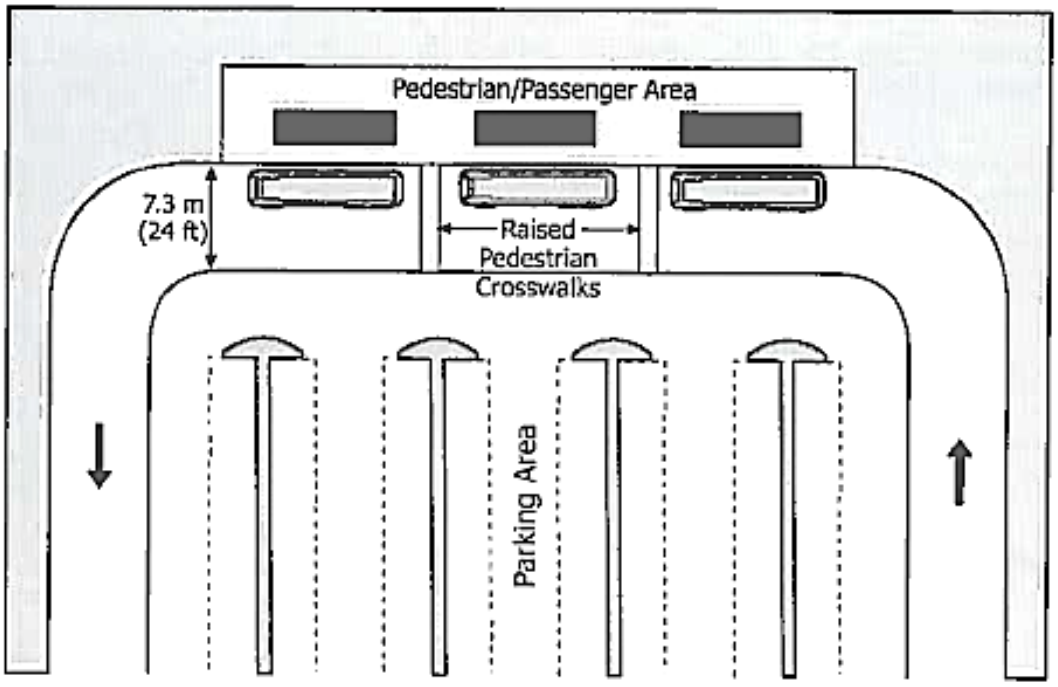
Shelters should be constructed in the bus stop area. AASHTO's *Guide for the Design of Park and Ride Facilities* offers guidance on bay dimensioning, and the Green Book provides turning radii requirements for buses. **Exhibits 19.3.3 and 19.3.4** illustrate examples of different bay arrangements and waiting areas for buses.

Exhibit 19.3.3 Example Bus Loading Area External to Parking Lot



(Source: AASHTO, *Guide for the Design of Park and Ride Facilities*)

Exhibit 19.3.4 Example Bus Loading Area Internal to Parking Lot



(Source: AASHTO, *Guide for the Design of Park and Ride Facilities*)

19.3.2 – Key Design Elements

19.3.2.a – External Features

The design of Park-and-Ride facilities should consider a number of factors related to the interface between the internal facility operation and the adjacent street network including:

1) Adequate and safe access and egress
2) Appropriately placed on-street bus stops and pullouts
3) Traffic control devices, including signalization (if warranted)
4) Wayfinding signage

Design Considerations:

- Safe and efficient movement of all modes using the facility, as well as on adjacent roadway facilities.
- Accommodation of transit, carpool, vanpool, taxis, pedestrians, motorized cycles, private vehicles, and bicycles both on, and adjacent to, the site as warranted.
- ITS 'Smart' transportation features that provide communications with Department and other transportation mode agencies mobility applications.
- Provision of an adequate number of parking spaces.
- Provision of customer amenities to ensure user comfort and attractiveness.
- Accommodation of users with disabilities (i.e., ADA standards).
- Secure parking area for patrons and vehicles.

19.3.2.a.i – Access and Egress Considerations

The designer should consider a number of access and egress factors related to the proper planning and conceptual design of facility access. A traffic engineering study should be performed to evaluate capacity conditions at potential lot access driveways and at critical locations on adjacent roadways. Each Park-and-Ride location is unique and has different needs.

19.3.2.a.i.1 – Efficient and Convenient Access

- The design should strive to minimize the time to change modes, including facility access time. The design should attempt to provide for direct approach and easy entrance to and exit from the facility.
- Whenever possible, the facility entrance should be located on the right side of the highest traffic volume direction to minimize the need for a left turn across traffic. If warranted, left turn signals and adequate storage bays should be designed.

- The most efficient access to a parking lot is via a collector intersecting the adjacent arterial at a signalized intersection. This eliminates the need for driveways and reduces conflicts on the arterial.
- Access points to the parking lot should be located to avoid queues from nearby intersections or freeway interchanges.
- The design should accommodate all modes anticipated to access the facility, including automobiles, buses, bicycles, and pedestrians. This impacts roadway widths, turning radii, and separation of non-vehicular and vehicular traffic.
- For lots in excess of 300 spaces, a minimum of two exits and two entrances is recommended. For lots in excess of 1,000 spaces, provision of entrances and exits on two adjacent streets is recommended to reduce traffic congestion, improve internal circulation, and provide for more efficient traffic distribution.
- Whenever possible, modes of travel should be separated to maximize safety and efficiency (e.g., buses should have their own travel lanes, entrances, and exits; passenger drop-off and pick-up area, also known as kiss-and-rides, should be separated from parking areas; and pedestrian and bicycle paths should be separated from automobile traffic paths as much as possible). Since safety is the primary goal, modal conflicts must be avoided as much as possible. At a minimum, signage and pavement markings must be provided to assist movement.

19.3.2.a.i.2 – Minimal Impact on Adjacent Road Operations

- Intersection and roadway link capacity analyses should be performed to minimize the traffic impacts on the adjacent highway network.
- The location and design of access driveways should strive to minimize the increase in congestion of adjacent roads served by the lot.
- The design of entrances and exits should not result in a major conflict point on access roads to the Park-and-Ride facility.
- Entrances and exits should not be placed near intersections or other potential conflict points unless it is a new leg to an existing intersection that can be appropriately accommodated.
- The design should provide for adequate storage for all entering and exiting movements.
- A new signal on an arterial should be considered only if warranted and not cause significant delays to existing traffic patterns.

19.3.2.a.i.3 – Safety

- The design should maximize safety by minimizing conflict points to minimize crashes.

- Entrances and exits should not be located near structures, and pedestrian / vehicular decision points.
- The design should provide for adequate sight distances for entrances, exits, and crossing maneuvers.
- Entrance and exit locations should provide for adequate weaving, merging, and lane-change distances.
- The location of facility exits relative to adjacent intersections should be such that signal control exits can be reasonably installed at a later time, should such control measures become warranted.
- The entrances and exits should discourage “cut-through” movements.
- The design should strive for separate access points for the different arrival modes anticipated for the facility (for larger facilities only).
- Two entrances and two exits should be considered for lots in excess of 300 spaces.

19.3.2.a.i.4 – Proper Design Practice

- Field observation of traffic operations and ADT in the vicinity of the site should be performed before deciding on access locations.
- Facility entrances should be located and designed to minimize impacts on traffic while providing safe entry and exit.

In developing a Park-and-Ride parking lot, the designer must consider factors that will optimize facility access. Therefore, a traffic engineering study should be performed to evaluate capacity conditions at potential lot access driveways and at critical locations on adjacent roadways. As part of the study, estimates of demand and corresponding volumes by direction should be developed. Additionally, if the facility will be maintained by PennDOT, it is important to involve the District Maintenance Office in the review of the preliminary design plans to minimize or alleviate costly maintenance concerns.

Chapter 441 of The Pennsylvania Code provides driveway design standards for driveway slopes at intersections, state highways, sight-distance requirements, and additional design inputs.

Chapter 8, *Road Diet*, provides additional design guidance related to driveways.

19.3.2.a.ii – Off-Site (External) Bus Access

The selection of where to locate and the design of bus stops, either off-site (external) or on-site (internal), should be made in coordination with the local transit providers and evaluation of the following:

1) Type and frequency of transit service.
2) Lot configuration and potential loss of parking spaces.
3) Ease of transfer, including consideration of the distance from parked vehicles to the bus stop and pedestrian connections provided within the site to the bus stop.
4) The additional time impact to the operating schedules of the bus routes potentially serving the Park-and-Ride facility. This aspect of the site design should be closely coordinated with the local transit provider.
5) The amount of on-site space that is needed for bus bays, storage areas, bus-only lanes, shelters, and benches, as well as passenger walking and waiting areas.
6) The type of off-site stop that could be developed (such as on-street loading and unloading versus separate bus bay/bus pullout). The type of stop will be based on the design policies of the constructing authority, operating policy of the local transit provider, volume of automobile traffic, location of the stop in relation to nearby intersections, and the frequency of service. Refer to Chapter 15, *Transit Facilities,* for more info on bus stops in streets.
7) The amount and cost of right-of-way needed and available for development of an on-street bus pullout.
8) The expected size of buses that will be accessing the facility (single or articulated).

19.3.2.a.ii.1 – On-Street Park-and-Ride Bus Stop Design Factors

A number of factors must be considered when designing bus stops at a Park-n-Ride lot where the bus stops on the roadway. These factors, presented as follows, relate to vehicle maneuverability, safety, and the ease with which buses re-enter the traffic stream. Refer to Chapter 15, *Transit Facilities*, for more information.

- Bus operations need to be considered, specifically whether the bus will need to have a longer layover, bus routing, and whether the bus will need to turn around.
- When deliberating on whether to have buses stop in the traveled way, the designer must carefully consider traffic volumes and the effect of stopping buses on traffic flows and roadway capacity.
- Local transit providers generally prefer to have stops located as close as possible to the rider's ultimate destination, so that the rider does not have to walk long distances.

- Far-side bus stops (stops located immediately after an intersection along the direction of travel) are typically preferred from traffic operations and safety standpoints, as they provide for greater pedestrian safety, reduced conflicts with right-turning vehicles, and better sight-distance conditions (particularly at unsignalized intersections).
- Near-side bus stops (stops located immediately before an intersection along the direction of travel) are sometimes considered because loading and unloading operations can coincide with the red-light phase and allows for buses to make right turns at the intersection. Refer to Chapter 15, *Transit Facilities*, for pros and cons of stop location before and after an intersection.
- Mid-block stops may require pedestrian crosswalks and special signals. See Chapter 13, *Pedestrian Facilities*.
- Bus pullouts should be considered for roads with high traffic volumes and lower speeds.
- Bus pullouts have the advantage of separating the bus from other traffic.
- Bus pullouts need a minimum and optimum right-of-way width of 12 feet and 14 feet, respectively. The entire pullout right-of-way is determined by the highway speed and size of the bus. Entrance and exit taper requirements are provided in Chapter 15, *Transit Facilities*.
- Bus stops and passenger amenities, such as benches and shelters, are to be installed consistent with PROWAG.
- Bus route signing should be included in the Park-and-Ride facility signing plan, with consideration of transit schedule information signs. The placing of these signs requires coordination with the local transit provider.
- On-street bus pullouts require special signing and marking. For more information, refer to Chapter 15, *Transit Facilities*.
- On-street bus pullouts should not be located in exclusive right-turn lanes. They should also be avoided in curb lanes that carry a heavy volume of right-turning traffic.
- Bus stops should not be located over drainage so passengers do not need to walk through these structures in order to access transit vehicles.

19.3.2.a.iii – Traffic Control Devices

Traffic control devices relevant to Park-and-Ride facilities include signals, roundabouts, regulatory signs, pavement markings, and channelization. The proper controls should be developed using traffic engineering analyses of proposed facility access drives, as well as review of nearby intersections that will be significantly affected by facility traffic. The design and application of traffic control devices should conform to Publication 212, *Official Traffic Control Devices*, and the MUTCD.

Considerations relevant to the design of traffic control devices external to Park-and-Ride facilities are presented below. Proper design is a function of the size of the lots and their location. More-elaborate traffic control devices should be considered for facilities with a larger number of spaces, higher expected utilization, and higher levels of transit service, as well as those on congested arterials. Refer to Publication 10X, Design Manual Part 1X, *Transportation Program Development and Project Delivery Process* (DM-1X), Appendix AI, for the *Intersection Control Evaluation Policy* to determine the appropriate traffic control at intersections impacted by the facility.

19.3.2.a.iii.1 – Facility Traffic Control Device Design Factors

One consideration particularly relevant to Park-and-Ride lots is the special traffic control requirements for transit operations. Most local transit providers will not allow a bus to make a left turn across a high-volume arterial into or out of a facility without a traffic signal. Close coordination with the local transit provider is recommended when accommodating transit services in a Park-and-Ride facility.

- Traffic signals, traffic signs, and pavement markings should be designed in accordance with Publication 212, *Official Traffic Control Devices*, and Publication 46, *Traffic Engineering Manual*.
- Planning and design of traffic control devices should be carried out in conjunction with the overall design of the street or highway. The devices and procedures utilized for traffic control should be predicated upon developing uniformity throughout the system and compatibility with adjacent jurisdictions. Refer to Publication 149, *Traffic Signal Design Handbook*, for guidance.
- Signals should be considered only after a thorough traffic study (refer to Publication 46, *Traffic Engineering Manual*) in the area and should be warranted or justified in a manner prescribed in the MUTCD.
- Timing and phasing adjustments to existing signals may be required to accommodate Park-and-Ride traffic. If the exit to a park and ride facility is signal-controlled, the signal operation should be designed to accommodate short duration spikes in volume after the arrival of a transit vehicle as the passengers depart in their vehicles.
- Minimum control requirements for a Park-and-Ride facility include stop signs, warning signs, guide signs, facility identification signs on roadways, stop lines, double-yellow centerlines, and turn-lane markings for exits onto public roadways.

19.3.2.a.iv – Guide Signs

Guide signs for Park-and-Ride parking lots guide users and promote the lot. It is recommended that signs be placed at all user decision points to lead them directly to the facility in the most efficient manner and placed on all routes providing nearby access to the facility. The signs

should be in conformance with PennDOT design criteria in Publication 111, *Traffic Control-Pavement Markings, and Signing Standards*, and Publication 236, *Handbook of Approved Signs*.

Considerations for developing wayfinding or guide signage plans for Park-and-Ride facilities include:

19.3.2.a.iv.1 – Guide Sign Design Factors

- All guide signs should conform to the MUTCD and Publication 111, *Traffic Control-Pavement Markings and Signing Standards*, which incorporate flexibility for signing special situations and services and for the inclusion of special logos. However, standard signs should always be used for driver expectancy and for reducing maintenance costs. The designer should review ADA standards to ensure consistent transit-sign formats and fonts.
- Signs should be located in the influence zones from which users are expected to be generated. The location should intercept users on their normal travel path and guide them directly to the facility.
- Sign placement should assume that motorists do not know where to access the lot. Guide signs should be placed at all decision points, far enough in advance to allow for an adequate distance to maneuver.
- Continuity of guide signing is critical. Guide signs should lead the motorist through decision points to the destination.
- Guide signs should be placed on all approaches to the facility, even on approaches usually deemed to service travel opposite to the predominate direction.
- Consideration should be given to the function of the lot. For example, rail stations with Park-and-Ride lots should have Park-and-Ride messages on the station guide signs.
- Consideration should be given to signage on nearby interstates or major arterial highways. Information about Park-and-Ride lots could be included on electronic message boards to direct users to the facilities.

Some areas may utilize variable message signs (VMS) to promote a lot and provide real-time information on the number of parking spaces, time until the next transit vehicle leaves, and other information. However, VMS use requires approval by the FHWA and/or PennDOT Highway Safety and Traffic Operations Division Chief.

19.3.2.a.v – Driveway Placement and Design

Irrespective of the functional classification of the roadway with access into and out of the facility, proper driveway design is critically important in the safe and efficient use of Park-and-Ride facilities. Chapter 441 of The Pennsylvania Code provides driveway design standards for

driveway slopes at intersections, state highways, sight-distance requirements, and additional design inputs.

Chapter 6, *Intersections and Driveways,* of this manual provides additional design guidance related to driveways.

If feasible, driveways should be located outside of auxiliary lanes and anticipated queue lengths at nearby intersections. The designer should also consider future expansion and modifications, such as signal installation, roundabouts, or other forms of traffic control, in identifying access points using DM-1X, Appendix AI, *Intersection Control Evaluation Policy*.

Driveway radii and widths should be designed for transit vehicles accessing them. The designer should confirm vehicle dimensions with the appropriate transit agencies and use turn-simulation software to confirm geometric sufficiency for the design vehicle.

19.3.2.b – On-Site (Internal) Lot Design

The design of the internal elements of a Park-and-Ride facility depends upon the modes expected to use the facility, as well as the size and configuration of the site. Certain components will have varying importance, depending on the function and use of the facility.

The internal components of the Park-and-Ride facility that should be considered include:

- Overall site layout and internal circulation
- Specific parking layout
- Transit terminal facilities
- Bus loading areas
- Carpool and vanpool staging areas
- Pavement and drainage
- Signing and marking
- Landscaping
- Security
- Boundary identification
- User amenities
- Art, architecture, and community integration
- Lighting
- Fencing
- Kiss-and-ride accommodation
- Taxi drop-off and pick-up

- Pedestrian considerations
- Bicycle storage and lanes

These components are addressed in the following subsections.

19.3.2.b.i – Internal Circulation

In providing access to a bus stop or a transit station, the design should minimize potential conflict points between motorized and non-motorized users. Pedestrian paths should be clearly marked and signed, with appropriate ADA-compliant slopes and warning surfaces at crossing and conflict points.

As mentioned in the section discussing access and egress, passenger waiting areas should be centrally located (to minimize walking distance) or at one end of the parking lot (to minimize bus and transit travel times), with adequate space on sidewalks or walkways clear of internal vehicle paths to ensure pedestrian safety. The design should also allow appropriate turning radius and emergency service vehicle access consistent with local ordinances and standards.

Intersections within the parking lot or secondary access points should be moved away from the primary external access points to minimize the risk of spillover queuing onto external roadways. Depending on the type and size of the lot, the designer should consider separating bus and other vehicular traffic. For lots in more suburban/rural areas, there may not be a benefit to separating bus and vehicular traffic while there may be a benefit in urban areas.

Design concepts that should be considered regarding site internal circulation include:

19.3.2.b.i.1 – Internal Circulation Design Concepts

- Transfer terminals (an area where passengers transfer from one bus to another) should be located either in a central location on the lot with parking areas surrounding it or on the outer perimeter, with the parking areas extending radially from the terminal.
- The facilities layout should strive to minimize access and egress times for transit and drop-off vehicles.
- The system of circulation produced by the arrangement of parking aisles and spaces should be designed to minimize travel distances, conflicting movements, and number of turns.
- Major circulation routes should be located at the periphery of the facility to minimize vehicle and pedestrian conflicts.
- Mixing of automobile and bus traffic should be avoided if possible.
- One-way, two-lane circulation roads permit passing of stopped transit vehicles and are desirable where buses and other vehicles cannot be separated.

- The layout of parking areas in regard to their proximity to a transfer terminal should be designed in the following order: 1) bicycle parking, 2) ADA accessible parking, 3) kiss-and-ride/passenger drop-off and pick up-areas, 4) short-term parking, and 5) long-term parking.
- The maximum reasonable walking distance is 1,000 feet. Longer walking distances may necessitate consideration of additional loading zones.
- Parking aisles should be oriented to the transfer terminal to provide for convenient pedestrian movement through the facility.
- Depending upon the size and type of parking lot, separate entrances and exits may be preferred. Otherwise, a traffic island or pavement markings separating exiting and entering vehicles should be provided.
- Generally, no more than 30 spaces should be provided without a cross aisle to move to exits, to other parking spaces, or to bypass disabled vehicles.
- Vehicle storage areas should be located near exit areas to avoid that conflict with circulation patterns and parking maneuvers.
- Site circulation roadways should not be located close to exit or entrances to prevent congestion.
- Drivers should not be confronted with multiple decisions at the same point in the circulation system.
- A 40-foot bus with a bicycle rack that accommodates at least two bicycles on the front should be used as the design vehicle for turning radii and circulating roadways unless an articulated bus is anticipated to navigate the facility. Other bus classifications could be considered for design purposes.
- Pedestrian paths should be interconnected with all modes of transit and waiting areas at an intermodal Park-and-Ride facility.
- A physical barrier, such as curbing, should separate bicycle parking from vehicular parking to minimize the risk of damage.
- Parking should be located outside of the direct pedestrian path to minimize tripping risk.
- When establishing bicycle parking, installation of additional amenities (such as lockers) should be coordinated with local cycling stakeholders and local transit agencies. The standard size of a bicycle parking stall is 2 feet by 6 feet. The standard size of a motorcycle stall is 3 feet by 6 feet.

19.3.2.b.ii – Automobile and Motorcycle Parking Layout

Parking layout is another critical feature of a successful facility design. Up to four of the following types of automobile parking areas must be considered in the site layout:

1) Accessible parking
2) Kiss-and-ride (passenger drop-off and pick-up areas)
3) Short-term parking
4) Standard or long-term Park-and-Ride parking

In addition, other parking areas that may be considered in designs include:

- Temporary carpool and vanpool parking
- Supervisor parking
- Police parking spaces
- Motorcycle parking
- Reserved parking spaces
- Employee parking spaces

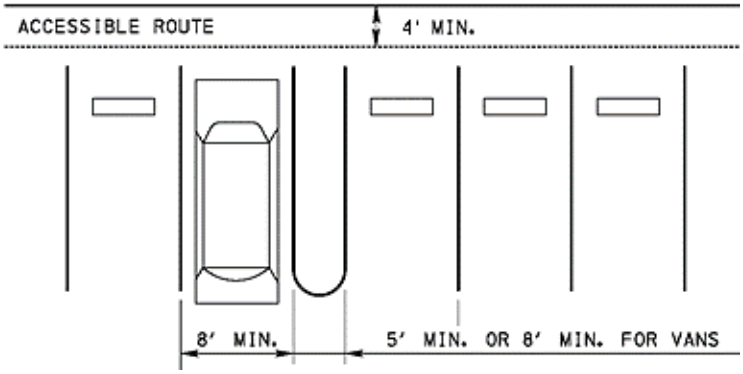
19.3.2.b.ii.1 – ADA Accessible Parking for Parking Lots

As with street parking, accessible parking shall be evaluated during new construction and alterations (resurfacing, etc.) to facility, i.e., parking space. Refer to Chapter 13, *Pedestrian Facilities*, for more information on alternations. Accessible parking spaces are provided for reasons of safety, convenience in accessing the vehicle, and easier access to transfer stations. ADA-accessible parking should be located as close as possible to the desired stop/station location to minimize the risk of exposure for patrons with disabilities.

The following considerations must be incorporated into the layout of accessible parking:

- Accessible routes must connect parking spaces to accessible entrances. In parking facilities where the accessible route must cross vehicular traffic lanes, marked crossings enhance pedestrian safety, particularly for people using wheelchairs and other mobility aids.
- It is preferred that individuals with disabilities not pass behind parked vehicles.
- Wheelchair ramps and curb ramps must be provided if platforms or curbs are present.

Exhibit 19.3.5 Sizing for Accessible Parking Spaces



Accessible parking space dimensions may be contained in local codes. Recommended accessible parking space sizes vary and typically range from 9 feet wide by 18 feet long to 10 feet wide by 20 feet long. 8 feet is the minimum width. Smaller spaces should incorporate pavement markings between spaces to facilitate vehicle access. ADA standards require a minimum parking space width of 8 feet plus a 5-foot (8-foot for vans) clear zone between vehicles to allow for vehicle access. There is also the option to provide an 11’ space adjacent to a 5’ aisle for both van and car accessibility.

Exhibit 19.3.5 illustrates sizing for accessible parking spaces. If the spaces are adjacent to a pedestrian path or sidewalk, appropriate measures, such as wheel stops, should be provided to prevent vehicle overhang into the pedestrian path. In cases where buses or trucks may block ADA accessible parking, separate pooling areas should be provided to allow for longer rest and idling periods.

Accessible spaces should be marked with the bottom of a sign at least 7’ high at the head of each parking space. The International Symbol of Accessibility pavement marking may be provided, as well as specific signage as specified in Publications 111, *Traffic Control-Pavement Markings and Signing Standards,* and Publication 236, *Handbook of Approved Signs*. The color of accessible pavement markings is usually light blue to delineate accessible spaces. Markings for accessible spaces shall be white. A blue background behind the accessible symbol may be used as an option.

As presented in **Exhibit 19.3.6**, the ADA standards contain guidelines for selecting the number of accessible parking spaces demarcated at public parking lots and transfer facilities. The designer shall conform to local, state, or federal site development codes, tailored to accommodate the Park-and-Ride facility patrons.

Exhibit 19.3.6 2010 ADA Standards for Accessible Design Parking Space Requirement

Total Parking Spaces	Minimum Number of Accessible Spaces
1 to 25	1
26 to 50	2
51 to 75	3
76 to 100	4
101 to 150	5
151 to 200	6
201 to 300	7
301 to 400	8
401 to 500	9
501 to 1,000	2%
Over 1,000	20 plus 1 for each 100 over 1,000

(Source: *ADA Accessibility Guidelines*)

Access Board standards require that accessible parking spots should be level with a cross slope not exceeding 2% in any direction and have a minimum width of 8 feet. For every 6 (or fraction of 6) accessible parking spaces, there shall be at least one van parking space. A minimum of 98" vertical clear should be provided for vans.

Exhibits 19.3.7, **19.3.8**, and **19.3.9** illustrate guidelines for the different categories of accessible parking stalls. Refer to the ADA Accessibility Standards for guidance on usage and the number of required spaces. Note that these exhibits refer to guidelines for parking lots and do not apply to angle street parking.

Exhibit 19.3.7 Parking Dimensions for Accessible Parking Stalls

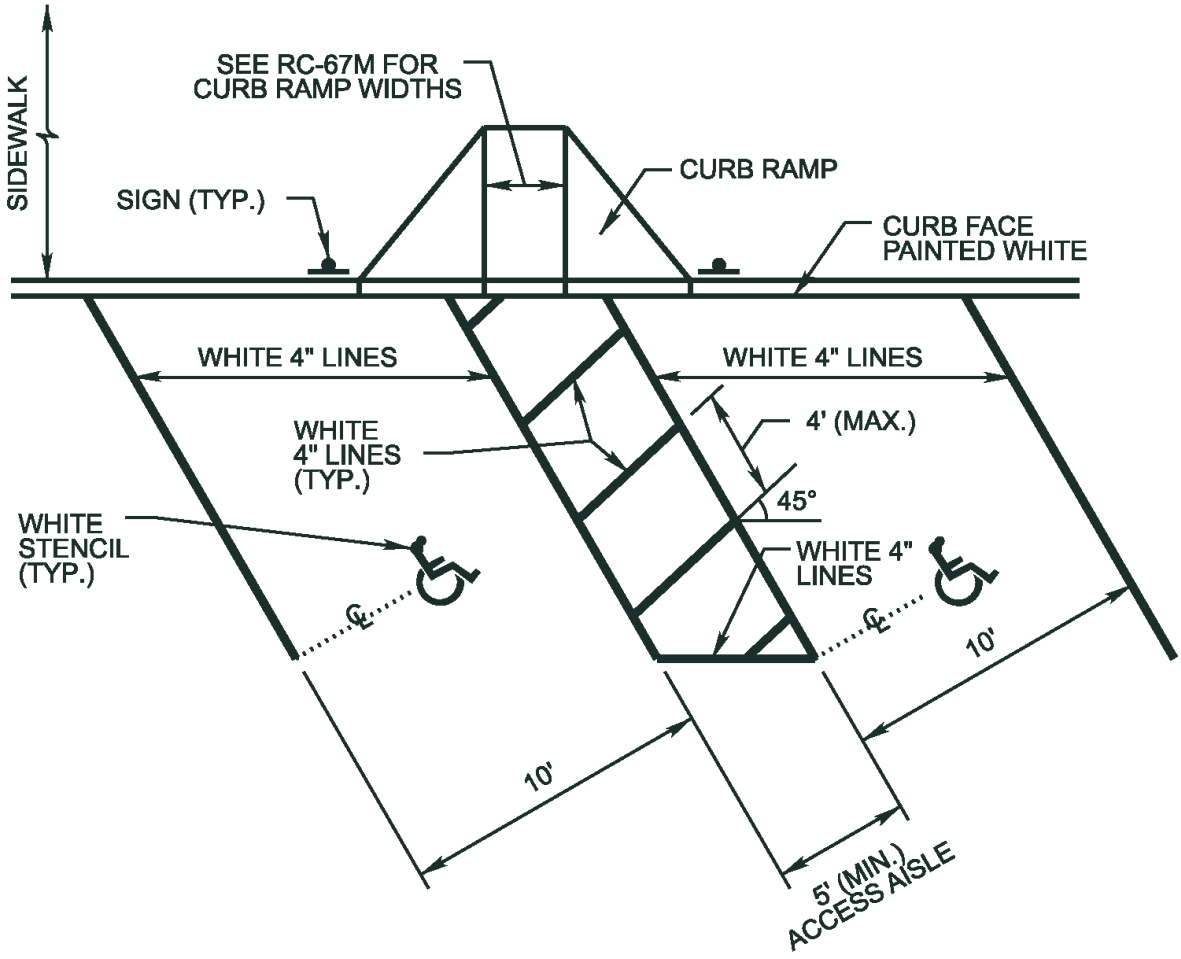


Exhibit 19.3.8 Parking Dimensions for Van Accessible Parking Stall

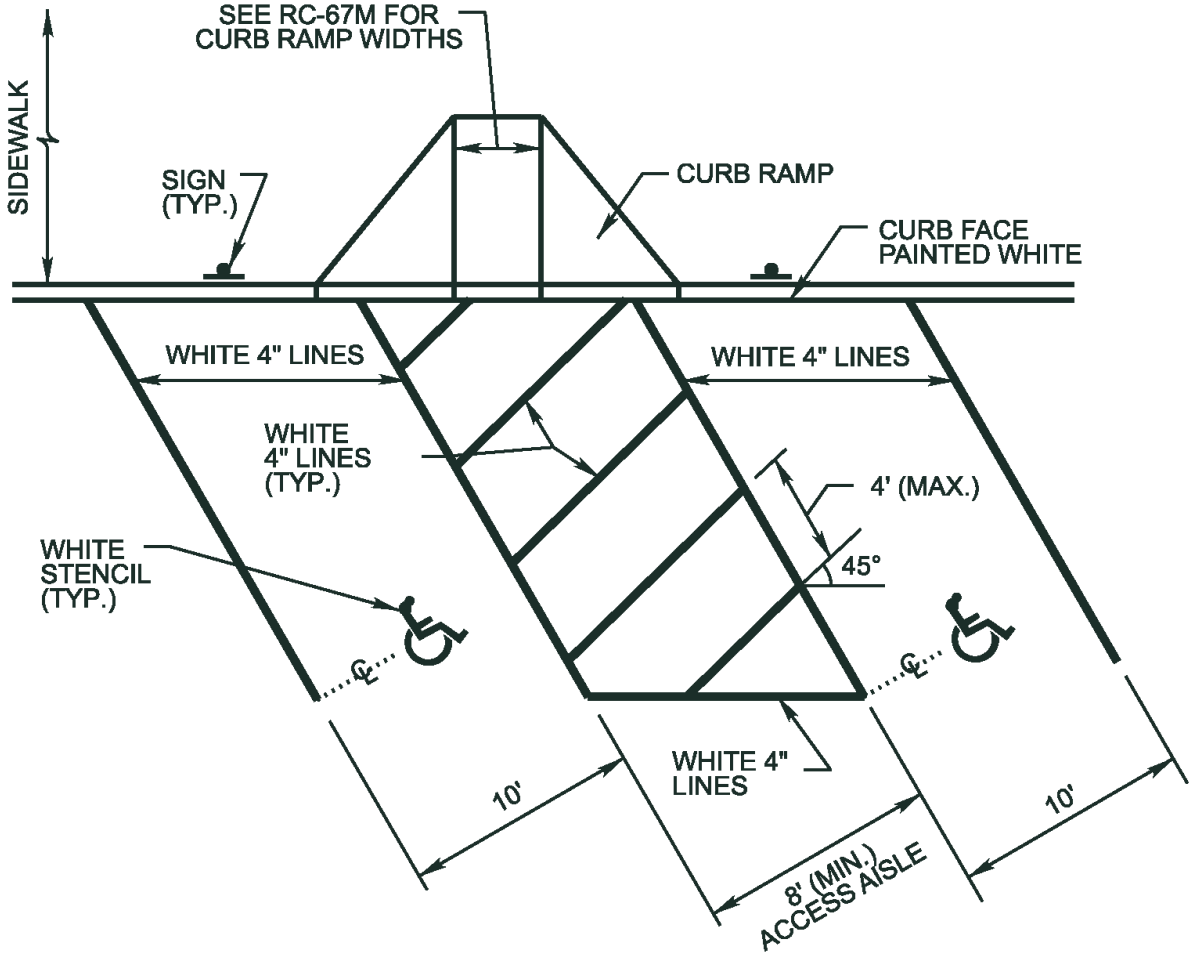
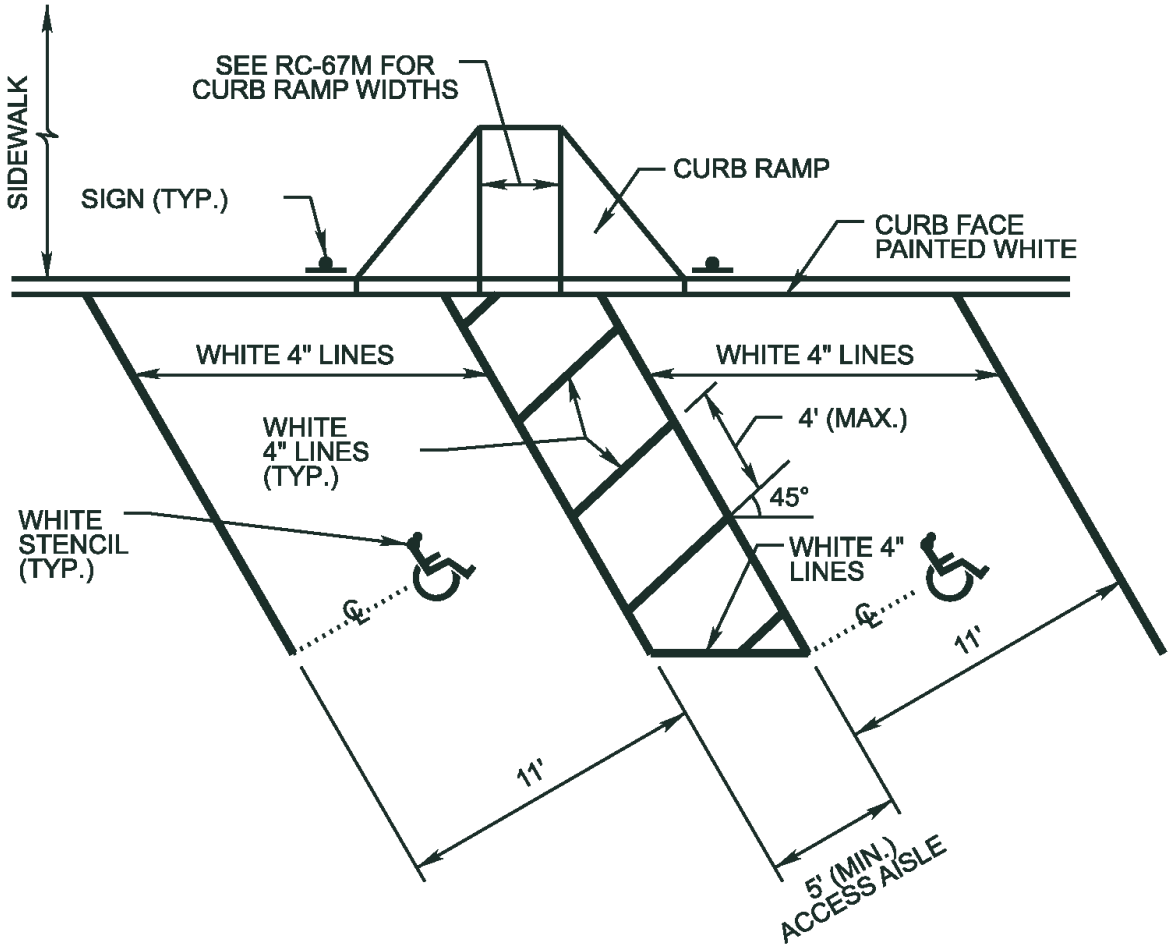


Exhibit 19.3.9 Parking Dimensions for Universal Accessible Parking Stalls



19.3.2.b.ii.2 – Kiss-and-Ride/ Passenger Drop-Off and Pick-Up Areas (Passenger Loading Zones)

Kiss-and-ride areas should provide for easy and safe access to the transit terminal or bus loading zone. Kiss-and-ride traffic should be separated from transit and normal Park-and-Ride traffic to the greatest degree reasonable to reduce congestion, conflicts and increase safety. Consideration should be given to one-way operation in the kiss-and-ride area, as well as for pull-through, brief parking areas for waiting vehicles, angled at 45 degrees and facing in the direction of the transit station. Designers should keep in mind ride-share drivers will queue at busy locations and wait to be called. This may cause back-ups in loading zones. More information is available in the *ADA Standards for Accessible Design*, Section 209.2.1.

19.3.2.b.ii.3 – Short-Term Parking

Providing short-term parking at a Park-and-Ride facility promotes the use of transit and provides joint use of the facility with surrounding land uses. Short-term parking is permitted to provide access to nearby establishments; however, the use of short-term parking is controlled by restrictions on the amount of time vehicles can be parked. Short-term parking areas should be located next to kiss-and-ride areas, but farther away from the transit terminal.

Since Park-and-Ride facilities are typically established to promote commuter usage, the establishment of short-term parking on its own is questionable. However, provision of such parking may prove beneficial to the acceptance of the facility by area businesses.

Specific short-term parking spaces may also be designated for specifically reserved spaces, such as taxi use, temporary carpool and vanpool parking, ride-sharing services, and police parking.

19.3.2.b.ii.4 – Standard Long-term Park-and-Ride Parking

Standard parking for Park-and-Ride facilities provides spaces where individuals can park their vehicles, then use public transport to commute to work and back. Specific spaces that may be included in this category and that provide preferential or closer parking to a transit loading or waiting area include parking for motorcycles, compact vehicles, vehicles whose occupants use baby strollers, transit employees, and other reserved uses.

The layout of long-term parking areas can be designed in much the same manner as other parking facilities, and should consider the maximization of parking spaces, circulation in the parking area, and parking dimensions. Alignment of parking rows should be in the direction of the longest dimension of the site, resulting in fewer aisle spaces and more parking spaces. Ninety-degree parking is generally the most efficient layout as measured by square feet per space. Aisles must be designed for two-way traffic for 90-degree parking and should be aligned to facilitate convenient pedestrian movement toward the transit loading zone. Aisle lengths should not exceed 400 feet, if possible.

Parking space sizes should be in accordance with AASHTO's *Guide for Park and Ride Facilities*, which recommends a standard parking stall size of 9 feet by 20 feet, with variations based on angle, designation for compact and subcompact vehicles, or other factors. The guide also states that a stall size of 8.5 feet by 18 feet may be acceptable. However, using the minimum dimensions should be avoided to reduce the risk of vehicles straddling parking stalls.

Mixing standard- and compact-vehicle parking-space sizes can provide for a greater number of spaces on a site. However, to realize this efficiency, compact parking must be given a preference and located in areas convenient to the user. Otherwise, compact cars will be parked in standard-size parking spaces, effectively reducing the number of useful spaces. The trend is to provide only standard-size spaces because of the difficulty of preventing parking of standard-sized vehicles in compact spaces.

Major circulation routes and drop-off points should be external to parking aisles. In providing for circulation routes, preference should be given to high-occupancy vehicles. This allows drop-off users to avoid conflicts with pedestrians circulating within the parking aisles. The minimum lane width is 12 feet for these circulation routes and bus loading areas. If accommodating vanpool service, the designer should consider a loading area that is separate from the bus-stop location to minimize confusion, unnecessary pedestrian circulation, and conflicts.



(Source: Washington DOT)

19.3.2.b.iii – Carpool and Vanpool Staging Areas

Vanpools and carpools sometimes utilize park and ride lots as meeting areas. Installing a vanpool and carpool staging area is most applicable to large facilities in providing a central meeting place. However, this may be a nonessential improvement, as experience has shown that users tend to meet in prearranged areas in the lot.

These staging areas consist of a shelter, benches, and adequate space for dropping off passengers. When considering vanpool and carpool staging areas, the potential for shared use of the transit stop area (including shelters and benches) and the size of the facility should be evaluated. Consideration for increasing the capacity of these areas may be necessary if it is expected that they will be heavily used by vanpool and carpool users.

19.3.2.b.iv – Signing and Pavement Markings

Signing and pavement markings within the Park-and-Ride facility require different types of signing than roadways.

These signs include:

- Guide signs to direct vehicles to kiss-and-ride temporary parking for waiting vehicles and drop-off and pick-up areas, accessible parking, bicycle paths, and other parking areas.
- Guide signs to direct traffic to facility exits (which is particularly applicable to large lots).
- Regulatory and warning signs to control traffic on roadways, particularly at locations where vehicular, pedestrian, and bicycle conflicts are anticipated.
- Regulatory signs should be in place to prohibit unauthorized use.
- Parking restriction signs including, but are not limited to, accessible parking, no-parking zones, bus stop, and tow-away zones.
- Information signs describing transit information, proper use of the facility, and declarations of liability responsibility.
- Information signs indicating the responsible administrating agency (which helps to reduce unauthorized use of the facility).
- Information signs identifying specific sections, by name or number, of a large lot to facilitate vehicle retrieval.
- Bicycle signs directing users to where bicycle storage or parking is located, as well as where bike lanes or routes are designated.
- Other parking considerations that may apply.

It is recommended that a sign be placed at the entrance to the Park-and-Ride facility that includes the name of the facility, address, services available, phone number and web address, and the cost of parking. All signage shall conform to Publications 111 and 236. Where information on particular signs applicable to Park-and-Ride facilities is not contained in these Publications, signs shall be designed in accordance with the MUTCD requirements. The Bureau of Operations must approve all signs not contained in Publications 111, *Traffic Control-Pavement Marking and Signing Standards*, and 236, *Handbook of Approved Signs*.

Pavement markings within the facility control traffic and provide for orderly vehicle parking. Except for those associated with parking, all markings should be reflectorized and conform to Publication 111, Publication 408, and the MUTCD.

Types of pavement markings applicable to a Park-and-Ride facility include:

- Centerlines, lane separation lines, and channelizing lines
- Stop bars

- Symbol arrows
- Pedestrian crosswalks
- Parking space demarcation lines
- International Symbol of Accessibility marking
- Bike lanes or sharrows

Pedestrian crosswalks require a higher degree of demarcation than typical urban intersections. For example, pedestrians may cross roadways at unexpected locations, or a motorist's attention may be diverted from the traveled way while attempting to locate suitable parking spaces or fellow car-poolers. In addition, more clearly demarcated crosswalks near transit transfer stations help to better define the station, making it a safer facility.

19.3.2.b.vi – Drainage and Landscaping

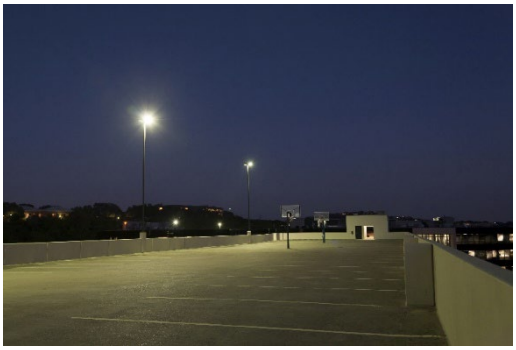
Adequate slopes and facilities that convey stormwater (e.g., curbs and inlets) to an outfall or detention facility should be provided to maintain proper drainage and avoid potential ponding and/or freezing within the lot. Park-and-Ride lots, in many cases, are subject to the same stormwater and permitting regulations as typical roadway or bridge projects. Coordination with review agencies and municipalities during design will ensure that appropriate best management practices (BMPs) are incorporated.

Chapter 10, *Drainage*, provides more information on drainage design.

Landscaping aids provide a more aesthetically pleasing environment and should be coordinated with any planting BMPs in the overall project design. Coordination of landscaping and maintenance is important in balancing the need for plantings and other treatments with providing available room for snow removal.

Chapter 24, *Rest Areas and Welcome Centers*, provides information on landscaping.

19.3.2.b.vii – Lighting



Lighting can be a critical element in any Park-and-Ride facility, providing a safer environment for users and a deterrent to criminal activity. Additionally, a secure facility promotes usage of a Park-and-Ride lot.

Installation of lighting at any Park-and-Ride facility needs to be considered in the context of surrounding land use and should be coordinated with local stakeholders and transit agencies. AASHTO's *Guide for Geometric Design of Transit Facilities on Highways and Streets* offers details on appropriate lighting standards and treatments.

Chapter 20, *Lighting*, of this manual provides additional information on lighting design.

19.4 – Rest Area Parking Design Guidelines

19.4.1 – Parking Area Sizing

In sizing the parking facility, the design-year peak hourly traffic volume should be used to determine expected usage and subsequent parking requirements. Chapter 24, *Rest Areas and Welcome Centers*, offers guidance for making projections based on the location of the facility, as well as additional information on the design elements for rest areas and welcome centers.

Approximately 10% to 15% of mainline traffic will typically use a rest area facility, with percentages varying by vehicle type. Some consideration should be given to the expected duration that visitors might stay. In more remote areas or areas prone to significant crash or weather events, vehicle turnover may be lower and visits of longer duration may be more common. This should be reflected in the required parking capacity for the site.



(Source: Washington DOT)



(Source: Washington DOT)

FHWA's *Commercial Driver Rest Area Requirements: Making Space for Safety* provides a model for determining the number of appropriate truck parking spaces, based on a variety of inputs.

Beyond parking stall and aisle requirements within the lot, space should be dedicated for snow and ice removal. As with heavy and longer vehicle classes, turn evaluations should be completed in design to confirm that adequate space is provided for snow removal equipment. The parking areas should avoid small, acute-angle curbed areas and excessive small protrusions or islands into the parking area, which can make snow removal operations difficult.

19.4.2 – Parking Stall Mix and Spacing

Another important factor in rest area parking design is determining appropriate accommodations for a mix of vehicles. It is recommended that approximately one-third of the parking spots should provide for heavy and long vehicles. However, parking mix within the lot should be a

function of the adjoining roadway (e.g., interstate, or scenic route), the vehicle mix, and the expected profile of stopping vehicles.

Geometrics for lot circulation should be confirmed using turn-evaluation software to ensure access to parking spots. On routes expecting a significant number of buses and transit vehicles, the transit parking spots should be located so that pedestrians can easily access paths leading to rest area amenities.

Calculating the mix of parking spaces uses the percentage of expected vehicle types traveling the adjoining roadway. The equations are as follows:

M = Total parking spaces

Car parking spaces = M × percentage of cars*

*Generally, about 0.80; a lower factor may be used if anticipated truck traffic is high.

Truck parking spaces = M - car parking spaces

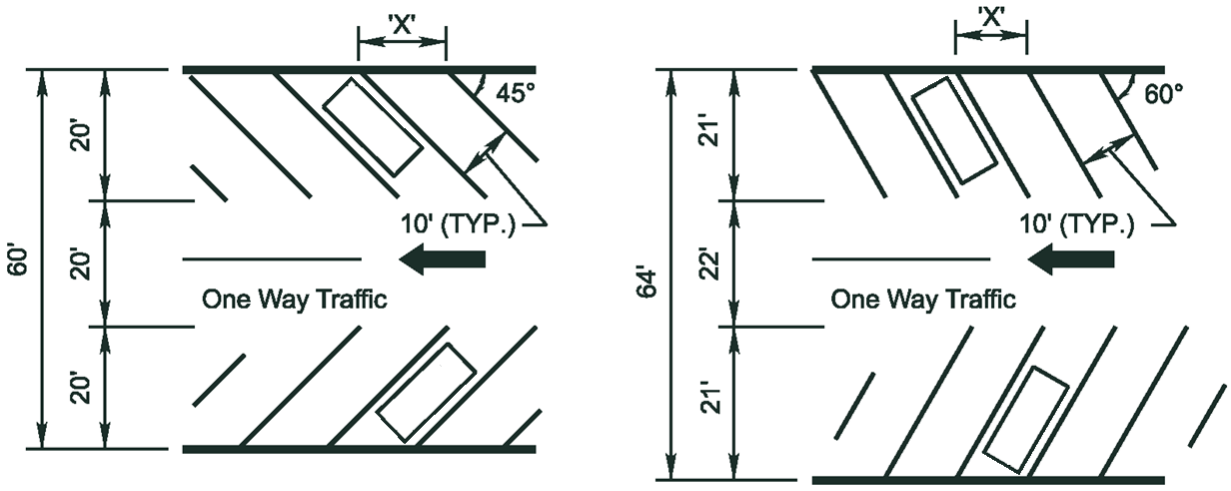
If parking stalls are too narrow, drivers will often ignore stripe demarcation lines and overlap into adjacent stalls. Often, drivers do not park precisely in the center of the designated stall and do not always pull into the full depth of the stall. Therefore, where space permits, it is always best to exceed minimum stall dimensions. Also, EV charging stations may need to be factored into future designs or retrofits of existing facilities.

Angular parking is preferred to parallel parking because it requires less time to enter and exit. Car parking stalls should be designed for head-in parking either at a 60-degree or 45-degree angle to the traffic lane.

- Stalls at a 60-degree angle are more commonly used and are generally considered the most satisfactory in relation to pull-in and back-out vehicle movements. Traffic aisle and parking lot widths are reasonable.
- Stalls at a 45-degree angle are preferred in some cases, as they require a smaller change of direction to enter the stall and allow a reduced lot width. However, fewer cars can be parked in a given space since the stall width dimension per vehicle measured along the curb is greater.

Accessible stalls should be placed as near as possible to the rest area amenities and building. **Exhibit 19.4.1** provides design values and a diagram for minimum dimensioning of one-way angled parking.

Exhibit 19.4.1 Typical Parking Dimensions for One-Way Angled Automobile Parking



PARKING ANGLE (DEGREES)	AISLE WIDTH (ft)	STALL DEPTH (ft)	STALL WIDTH (ft)	TOTAL WIDTH (ft)	CURB LENGTH 'x' (ft)
45	20	20	10	60	14.14
60	22	21	10	64	11.55

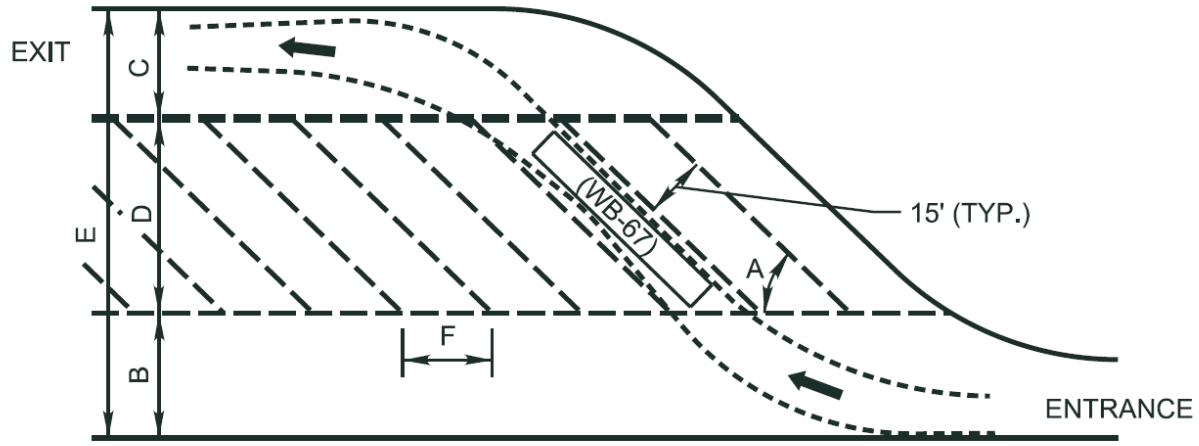
Separate or auxiliary parking facilities should be provided for vehicles larger than passenger cars. Placing truck-parking areas at the back of a rest area is recommended, unless blocking a viewshed. For new designs, large-vehicle parking should be located on the far side of the site, away from the highway for improved highway visibility and site security.

Truck-parking stalls should be designed for pull-through operation. A 30-degree angle is generally more satisfactory in relation to pull-through vehicle movements; 45-degree and 60-degree angles are also permissible, depending on space requirements and constraints. Perpendicular (i.e., 90 degree) parking is not preferred, since it permits two-way operation within the lot, which may lead to wrong-way entries. Angled parking serves to reinforce one-way circulation through the rest area lot. Parking stall dimensions should accommodate WB-67interstate semi-trailer units.

In certain situations, the design should consider parallel-park stalls for recreational vehicles or car-trailer type vehicles that allow a right-side curb discharge for occupants. This will increase the capacity of the parking area and safety of the vehicle occupants.

An accessible pedestrian route must be provided from the truck parking lot and other parking areas to the amenities. **Exhibit 19.4.2** offers dimensional guidance.

Exhibit 19.4.2 Recommended Parking Dimensions for One-Way Angled Truck and Bus Parking



Typical Parking Stall Dimensions for a WB-67 Design Vehicle					
ANGLE OF PARKING (DEGREES) "A"	ENTRANCE ROADWAY WIDTH (ft) "B"	EXIT ROADWAY WIDTH (ft) "C"	PARKING WIDTH (ft) "D"	TOTAL WIDTH PARKING AREA (ft) "E"	STALL ENTRANCE WIDTH (ft) "F"
30*	22	22	46	90	30
45	30	30	60	120	21.2
60	40	35	70	145	17.3

*Note: The "D" parking width dimension will allow a truck vehicle length of 78 feet if parked in the center of the stall.

19.4.3 – Rest Area Circulation

To access the lot, one-directional ingress and egress is preferred to minimize the risk of wrong-way highway re-entry. Within the parking aisles, signage, and pavement markings guide vehicles toward the rest area exit. For vehicles entering the rest area, the design should incorporate the most direct route to parking areas. Drivers are often fatigued when entering the rest area and a simple, clearly signed path will help to minimize crash risk.

Pedestrian paths should also be clearly signed and defined for the benefit of both pedestrians and drivers. These paths should provide straightforward directions to rest area amenities. Paths must be accessible for patrons with disabilities in accordance with the 2010 ADA Standards.

Guidelines for the different categories of accessible parking stalls are as follows:

- Parking area gradients should be relatively level, but they should still be sloped or crowned to permit surface drainage flows directed toward inlet structures.
- The maximum allowable grade for the accessible parking stalls is 1V:50H (2.00%). Parking spaces that are not level may deny use to individuals with disabilities since vehicle doors are more difficult to operate on slopes where wheelchairs tend to roll.
- Vehicular traffic should flow in a continuous, one-way direction. The design should avoid two-way traffic and the use of dead-end parking lot arrangements.

The designer should consider the following for accessibility design:

- Access aisles should be delineated with white cross-hatch pavement markings to clearly indicate that these areas should not be obstructed by parked vehicles.
- Four-inch-wide stripes spaced 48 inches center-to-center should be used to delineate the access aisle, with the entire area bordered with a 4-inch-wide stripe. Generally, the stripe should be positioned at a 45-degree angle to the vehicle stall curb line and stripes extended the full length and width of the aisle.
- An accessible route must be provided from the truck parking lot to rest area buildings.

Section 502 of the *ADA Standards for Accessible Design* provides additional information on accessibility design.

19.5 – Electric Vehicle (EV) Charging Stations

19.5.1 – General

EV charging stations may be provided on-street or in parking lots. However, there are some significant differences in use that warrant EV charging spaces be treated differently from parking spaces.

EV charging requires drivers with or without disabilities to exit their vehicle, traverse to the charger, and carry the connector back to their vehicle charging inlet (which may be on the opposite side of where they enter/exit their EV). Since EV's do not have a standard location for the vehicle charging inlet, more space is needed around the entire EV.

For new construction of EV charging spaces, the vehicle charging spaces must use the same dimensions as for parking spaces provided in this chapter, except for angle head-in or back-in spaces, for which the vehicle space width must be a minimum of 9 ft; consider providing additional width (e.g., 10 ft) as site conditions allow. This allows extra space for the user to move around the vehicle with the charging cords.

If an EV charger is added to an existing parking space, i.e., a parking space is converted to an EV charging space, consider updating the space dimensions as noted above.

All communication features and operable parts of the EV chargers must be accessible.

19.5.2 – Number of Accessible (ADA) Charging Spaces Required

Like any other service or program provided by a state or local government, access for people with disabilities must be provided. A reasonable number of EV chargers must comply with the Americans with Disabilities Act (ADA) accessibility requirements.

PennDOT requires the following number of EV charging stations, based on the total number of charging stations provided in a lot or a block perimeter, to meet ADA accessibility guidelines provided in Section 19.5.3:

- When there are two and up to 25 EV charging stations, at least two must meet ADA accessibility guidelines.
- When there are 25 or more EV charging stations, at least 8% must meet ADA accessibility guidelines.

Note that accessible EV charging spaces do not count towards the number of ADA compliant parking spaces discussed earlier in this chapter.

19.5.3 – Accessibility Guidelines (ADA)

Accessible (ADA) EV charging spaces must provide physical access for people who use mobility devices, such as wheelchairs, scooters, walkers, and canes. Accessible mobility features primarily concern the size of the vehicle charging space, providing access aisles, how and where the chargers are installed, and the physical operability of the charger. This involves a more complex array of design considerations than simply providing a larger space.

The U.S. Access Board, an independent federal agency that issues accessibility guidelines under the ADA and other laws, is providing a technical assistance document to assist in the design and construction of EV charging stations that are accessible to and usable by people with disabilities. The guidelines, EV Charging Stations Guidance (access-board.gov), developed by the U.S. Access Board are considered the best practices for providing accessible EV charging stations.

PennDOT requires that accessible EV charging stations shall comply with the guidelines provided by the U.S. Access Board to the maximum extent feasible within the scope and limits of the project.

The ADA covers entities including state and local governments (Title II) and places of public accommodation and commercial facilities (Title III). These entities are subject to the ADA and must provide EV charging stations that are accessible to and usable by people with disabilities. Some examples of EV charging stations that may be covered under the ADA include those installed at:

- State or local government offices

- Municipal building parking lots
- Park and Ride lots*
- In the public right-of-way, including on-street locations
- Public EV charging stations provided by a private entity
- Rest stops along the Interstate Highway System and Freeways*

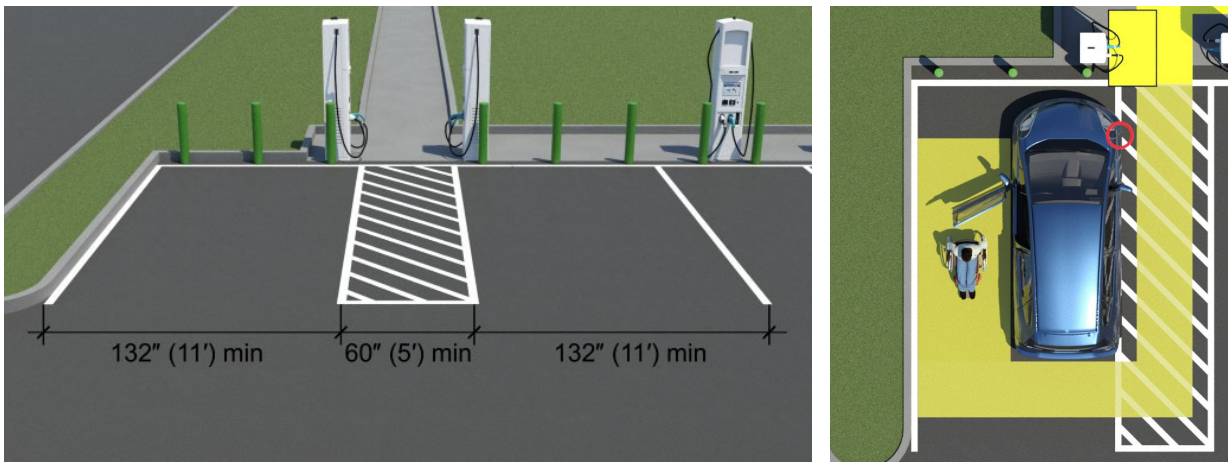
* PennDOT does not allow EV charging stations within Limited Access Right-of-Way (ROW) because Pennsylvania's LIMITED ACCESS HIGHWAY LAW Cl. 36 Act of May. 29, 1945 does not allow commercial sale within Limited Access ROW.

19.5.3.a – Accessible (ADA) EV Charging Space Features for Parking Lots and On-Street Locations

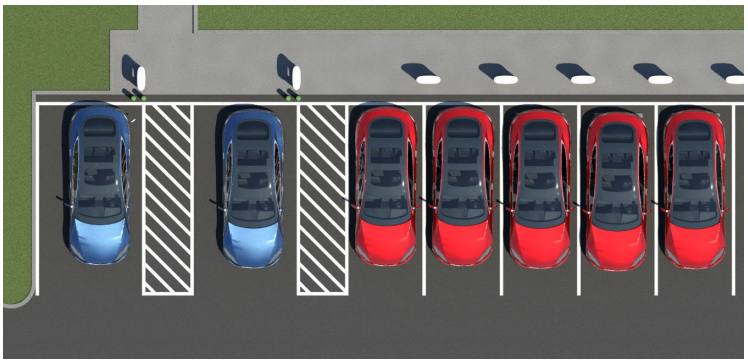
EV chargers designed to serve people who use mobility devices must be located on an accessible route and shall provide, to the maximum extent feasible:

- A vehicle charging space at least 11 feet wide and 20 feet long.
- An adjoining access aisle, the full length of the charging space, at least 5 feet wide.
- Clear floor or ground space at the same level as the vehicle charging space and positioned for an unobstructed side reach.
- Accessible operable parts, including on the charger and connector.
- Clear access aisles which are not blocked or obscured by features such as curbs, wheel stops, bollards, or charging cable slack.
- Floor or ground surfaces of vehicle charging spaces and access aisles shall comply with §302 of the ADA Standards and not have changes in level or slopes that exceed 1:48. For more information, consult the Access Board's guide on floor and ground surfaces and guide on parking spaces.

These mobility features allow sufficient space for a person who uses a mobility device to exit and maneuver around the vehicle, retrieve the EV connector, and plug the connector into the electric vehicle charging inlet.



One access aisle may be shared by two vehicle charging spaces, or a charging space and a parking space. The exception in §502.2 of the 2010 ADA Standards that allows two 8-foot wide accessible parking spaces to share an 8-foot access aisle cannot be used for vehicle charging spaces because there would be insufficient space to access the vehicle charging inlets on the opposite side of the access aisle.



19.5.4 – "Use Last" Approach to Accessible EV Charging Stations

Traditionally, accessible parking spaces are identified with the International Symbol of Accessibility (ISA) and reserved for use only by a person with a disability placard or license plate. However, the use of the ISA at EV charging spaces causes confusion about whether people without a disability placard can use accessible EV charging spaces. Since EV charging stations usually have only a few chargers, reserving a charging space only for use by a person with a disability placard may result in underutilized chargers.

To better utilize charging stations, the "use last" model must be used. The "use last" model does not require that the charging spaces be reserved exclusively for people with disability placards. People without disability placards can use accessible EV charging spaces when all other spaces are occupied, resulting in greater use of available chargers. This allows users to have more options to find a charging space, and alternative charging spaces to use if a charger is broken or obscured.

The following signs must be placed by accessible charging spaces. A “use last” sign indicates an EV charging space is accessible, but also directs people to use this space only when other charging spaces are occupied or accessibility features are needed. Sign details can be found in Publication 236. Note that the D9-11-1 sign is also applicable to other alternative fuel stations.



D9-11B (top)
D9-11-1 (bottom)

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 chapters 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

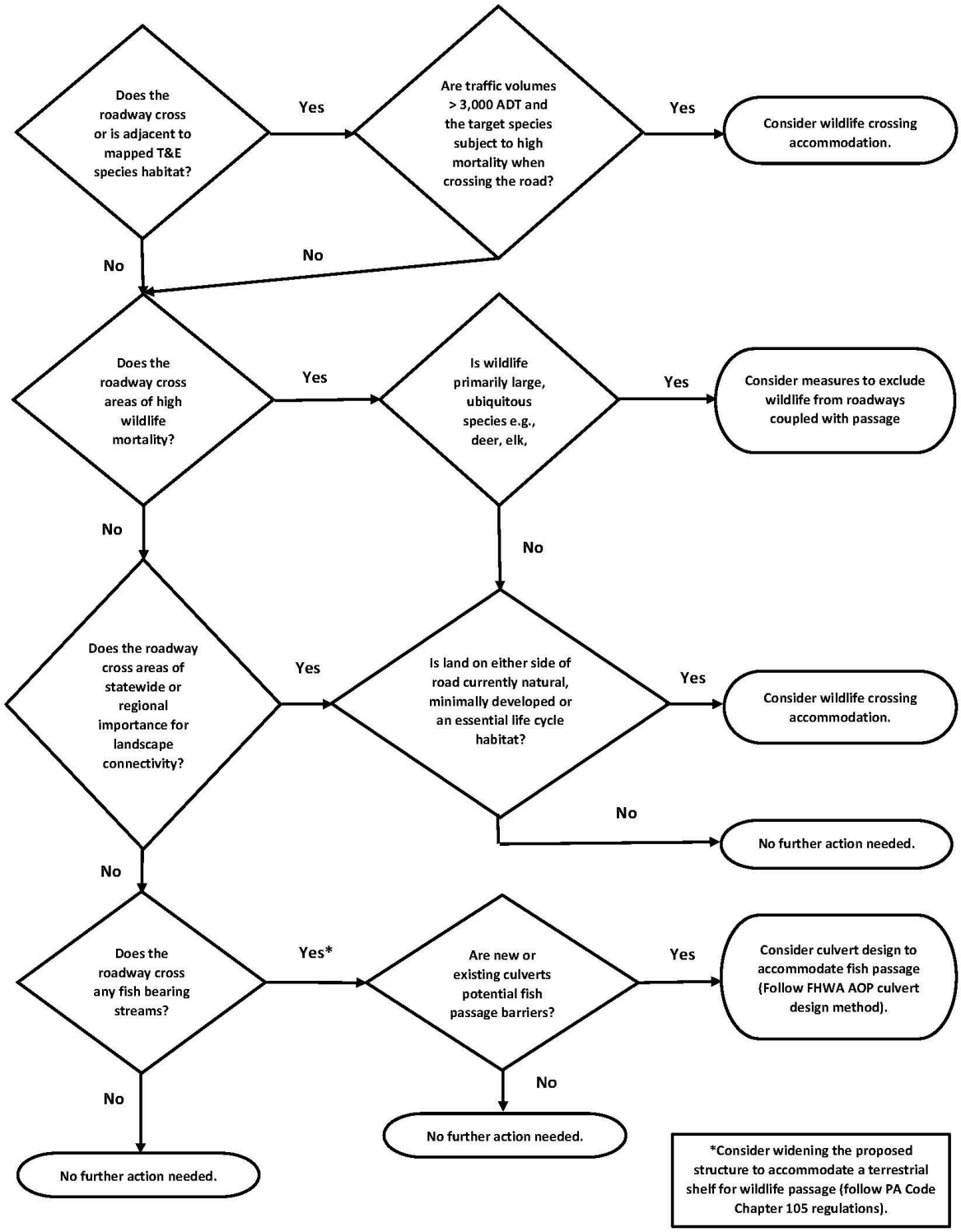
Criteria listed in this section, including **Exhibit 21.3.1**, should be used when determining whether to include a wildlife crossing within a transportation project in conjunction with existing data sources. Some useful data sources include: PennDOT Crash Information Tool, PA habitat

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 FHWA, *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 Amphibians (if adapted)	**W: 230 ft**	**W: >330 ft**
Wildlife Overpass	Wildlife only	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals Small mammals Reptiles Amphibians (if adapted)	**W: 130-165 ft**	**W: 165-230 ft**
Multi-use Underpass	Mixed use: Wildlife & Human activities	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals. Small mammals Amphibians (if adapted) 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 High-mobility medium-sized mammals Low mobility medium-sized mammals Semi-arboreal & semi-aquatic Mammals (adapted) Small mammals Amphibians (adapted) Reptiles	**W: 23 ft** **Ht: 13 ft**	**W: >32 ft** **Ht: >13 ft**
Multi-use Underpass	Mixed use: Wildlife & Human activities	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals Semi-arboreal & semi-aquatic Mammals (adapted) Small mammals Amphibians (adapted) Reptiles	**W: 16.5 ft** **Ht: 8.2 ft**	**W: >23 ft** **Ht: >11.5 ft**

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

● Recommended/Optimum solution; O 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 chapters 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.

  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

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

- 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.*

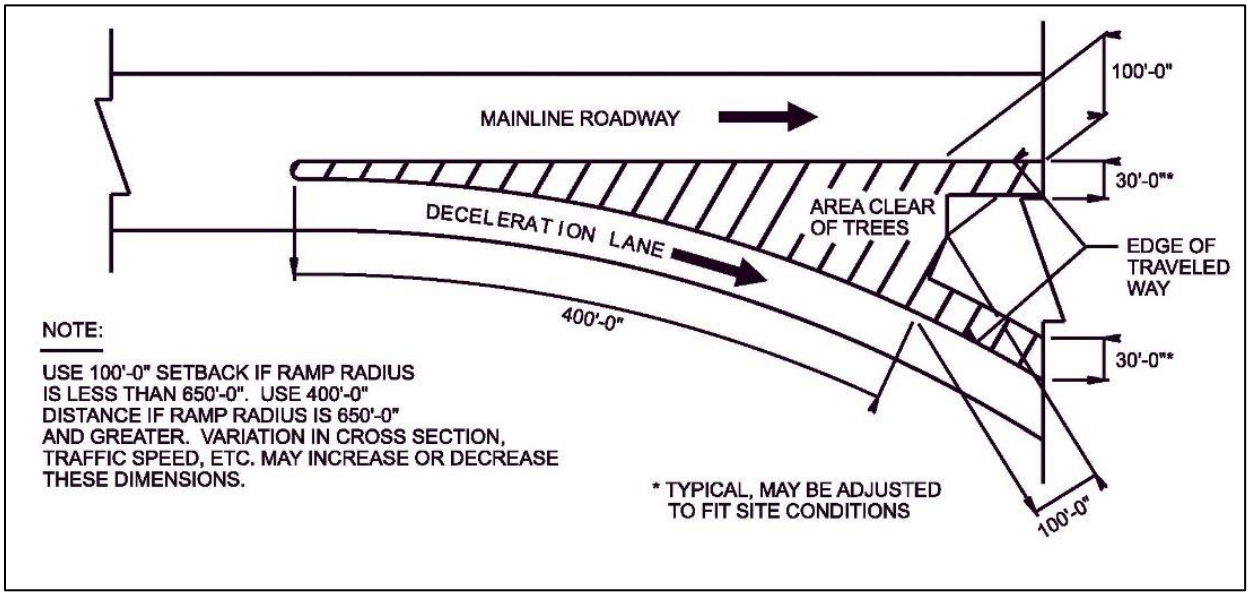
22.2.2 – Setback Distance

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.

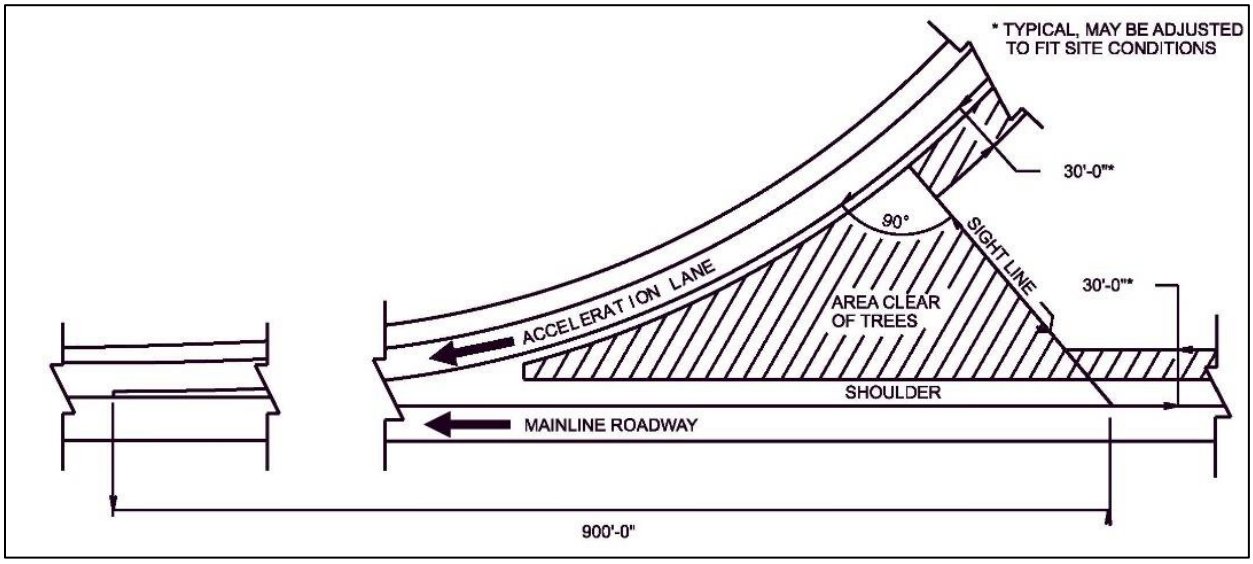
Exhibit 22.2.1 Safety Set-Back for Interchange Tree Planting



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

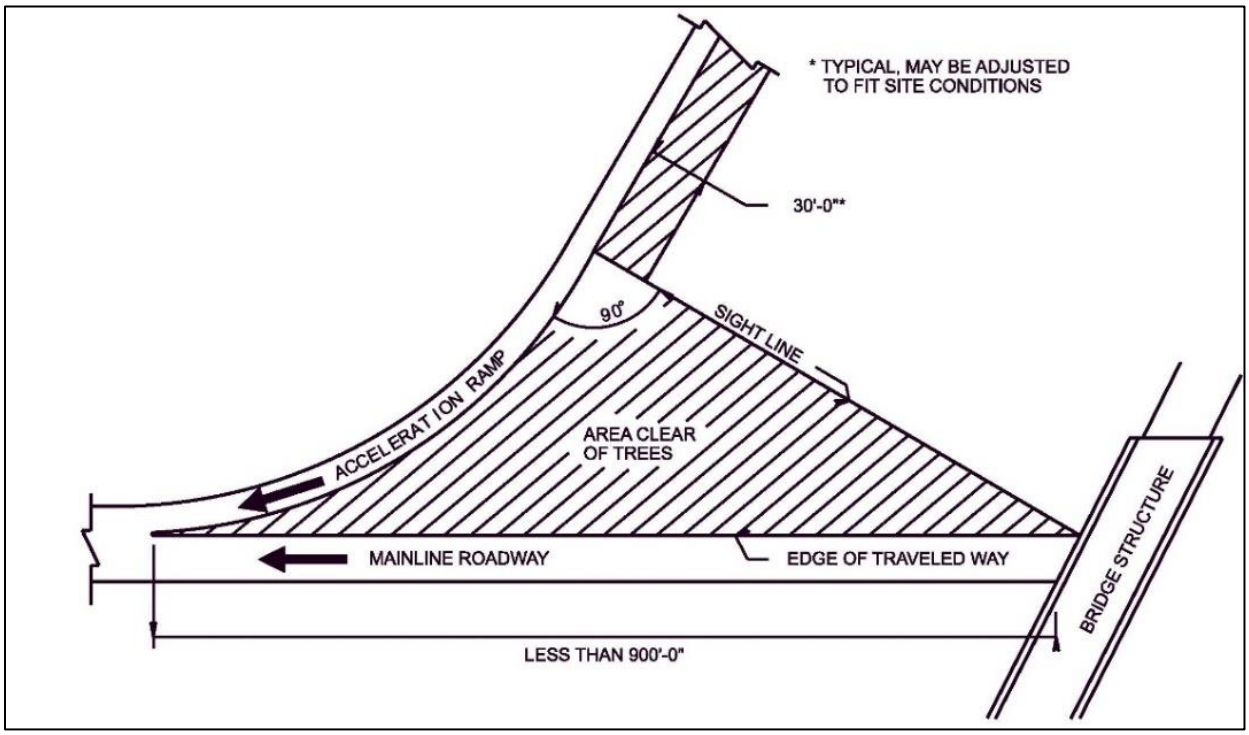
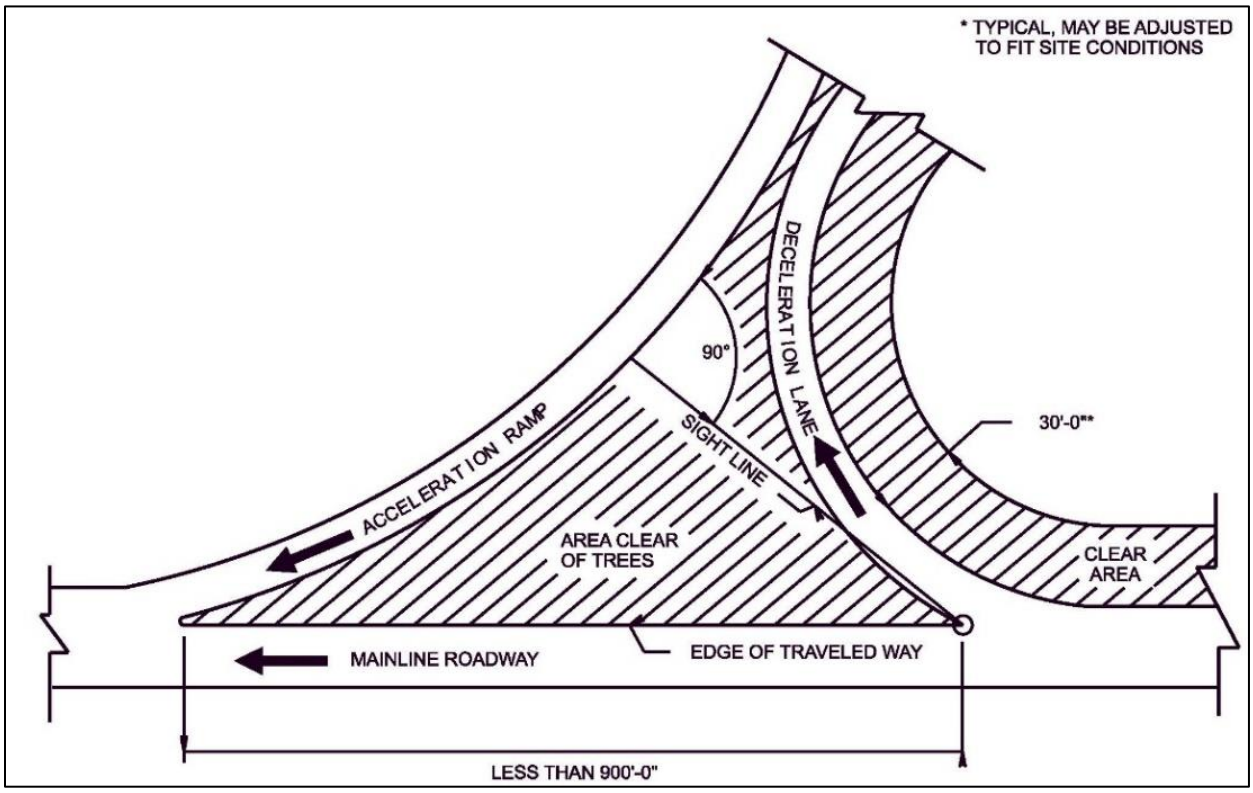


Exhibit 22.2.4 Clear Sight Distance for Interchange Tree and Shrub Planting



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 chapters 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:

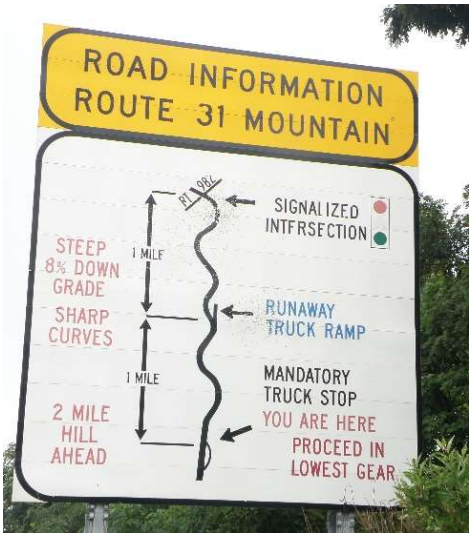
- Locating emergency escape ramps.
- Selecting the appropriate arrester bed type.
- Designing all elements of the ramp.



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.



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.

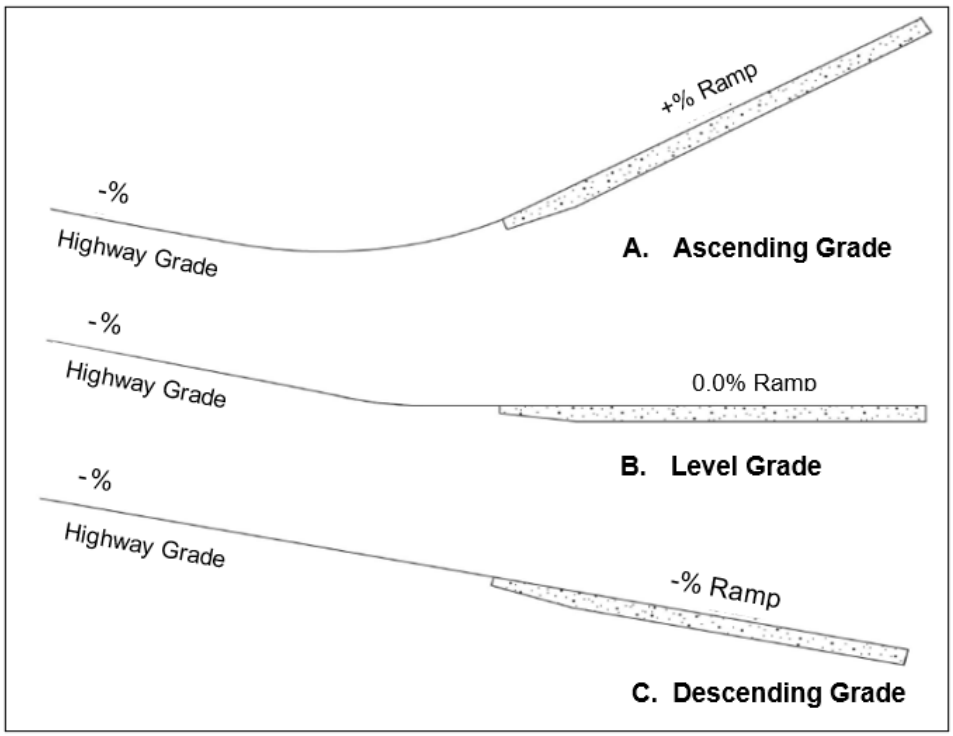
In Pennsylvania only aggregate arrester bed escape ramps are used. Sand pile escape ramps are not used because they are prone to freezing in Pennsylvania's climate. Gravity ramps are not used because of their inability to prevent a vehicle from rolling back down the ramp grade and jackknifing without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

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

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 23.4.2 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

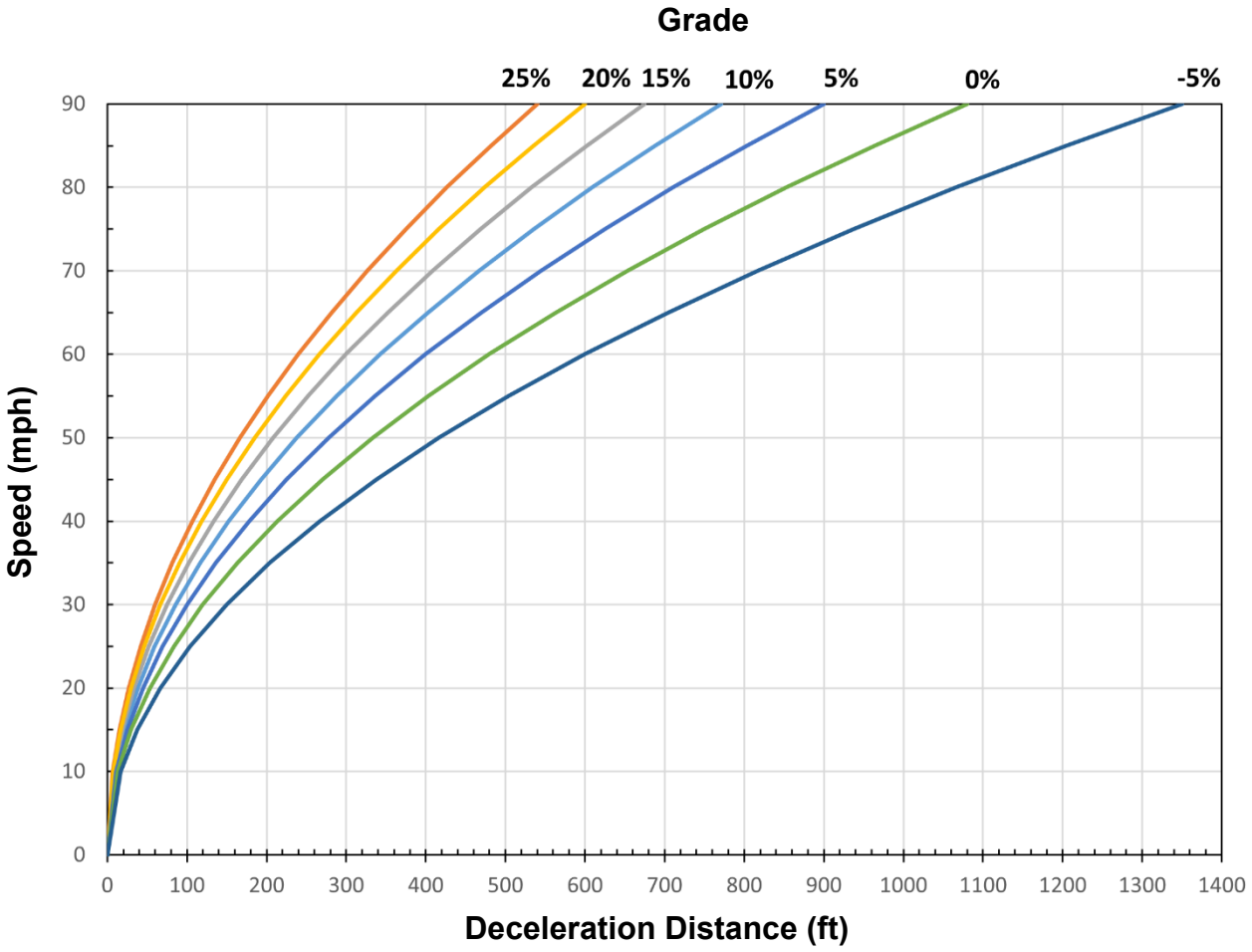
$$L = \frac{90^2 - 0}{30(0.25+0.10)} = 771.43$$

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.

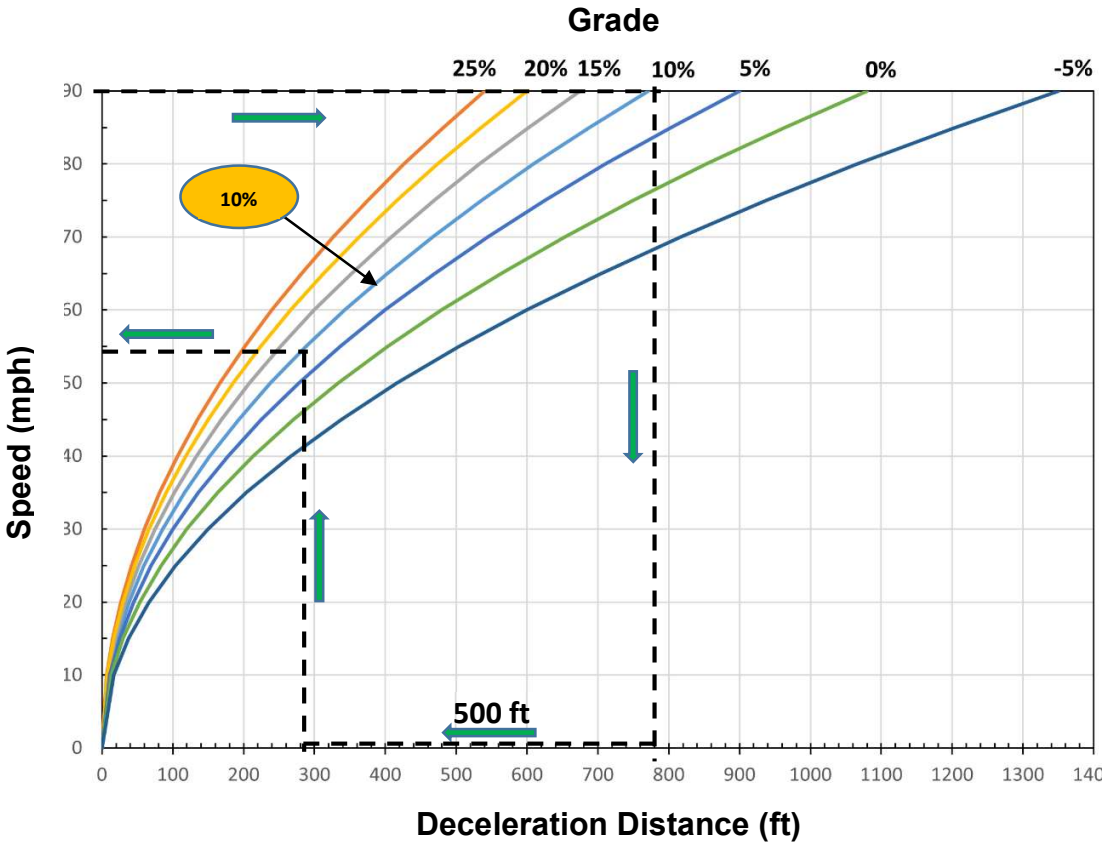
Exhibit 23.4.2 Effect of Grade on Vehicle Speed in an Arrester Bed of Pea Gravel



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.

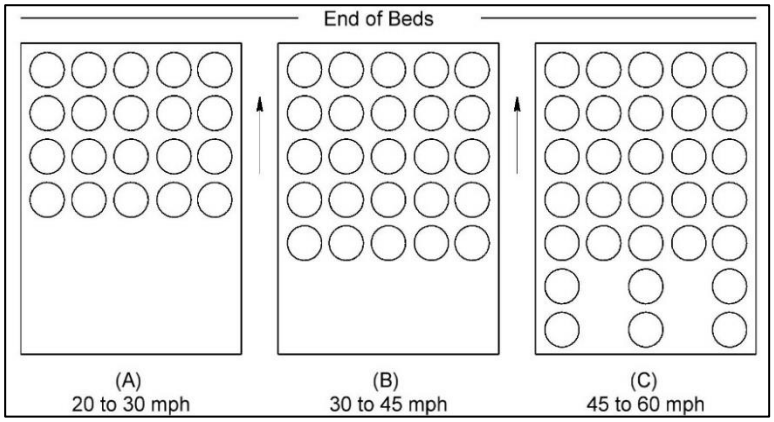
Deceleration is measured in “g’s” (32.2 ft/s^2), with the rate of deceleration expressed in units of standard earth gravity. A vehicle colliding with a row of three full barrels decelerates much faster than a vehicle colliding with a single half-full barrel—the more barrels impacted, the more resistance 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.

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.

Exhibit 23.4.3 – Barrel Impact Attenuator Configurations on a 20-Foot-Wide Bed at Different Entry Speeds



(Not to scale)

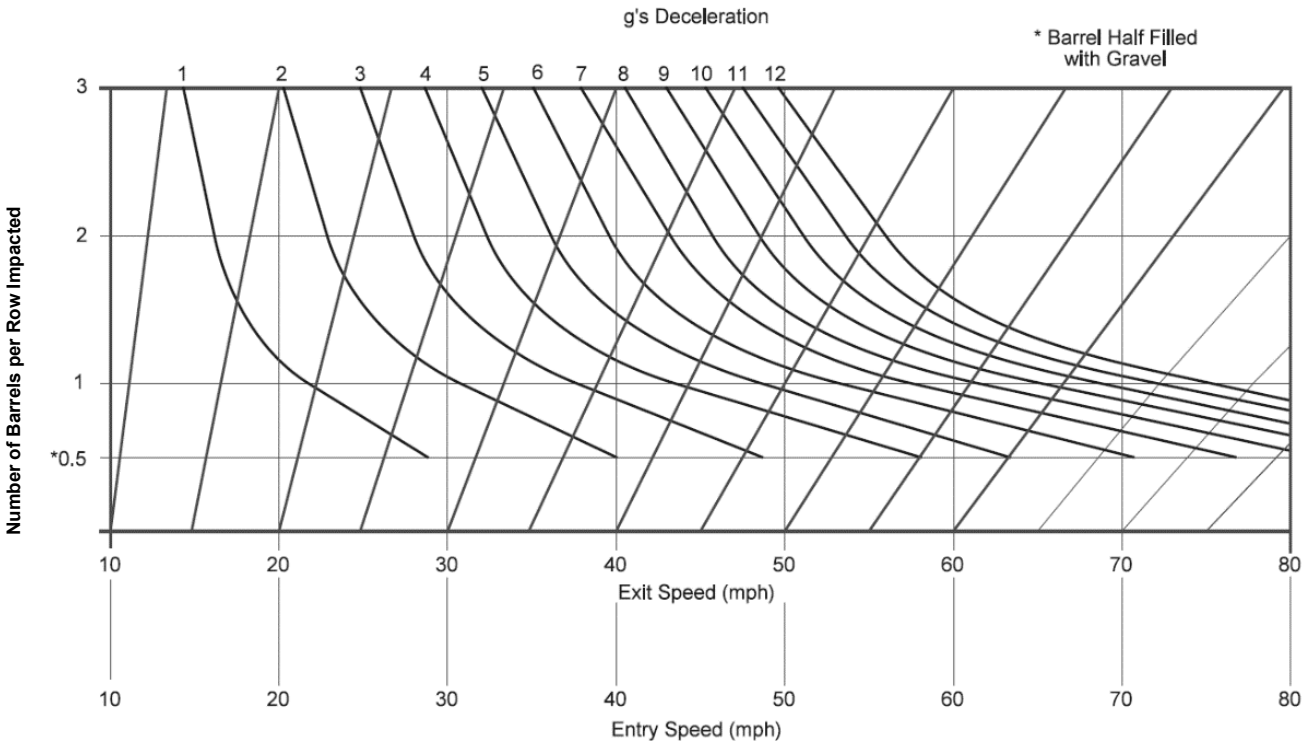
The range of entry (impact) speeds noted in Exhibit 23.4.3 are typical; the designer needs to perform the calculations to determine the design entry and exit speeds.

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 ft^3 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

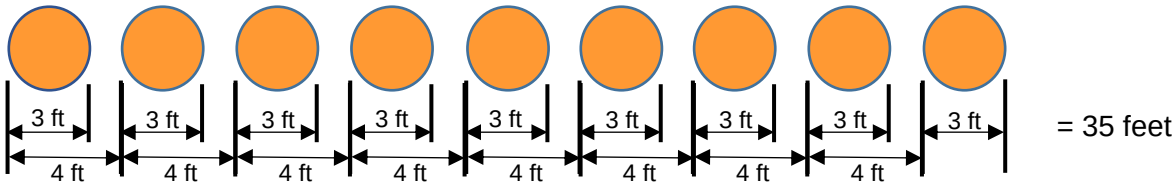
As a continuation of Example 2, the designer must determine a barrel configuration to absorb the energy resulting from the remaining 53 mph. The first step is to determine the general barrel layout needed to bring the vehicle to a stop.

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.

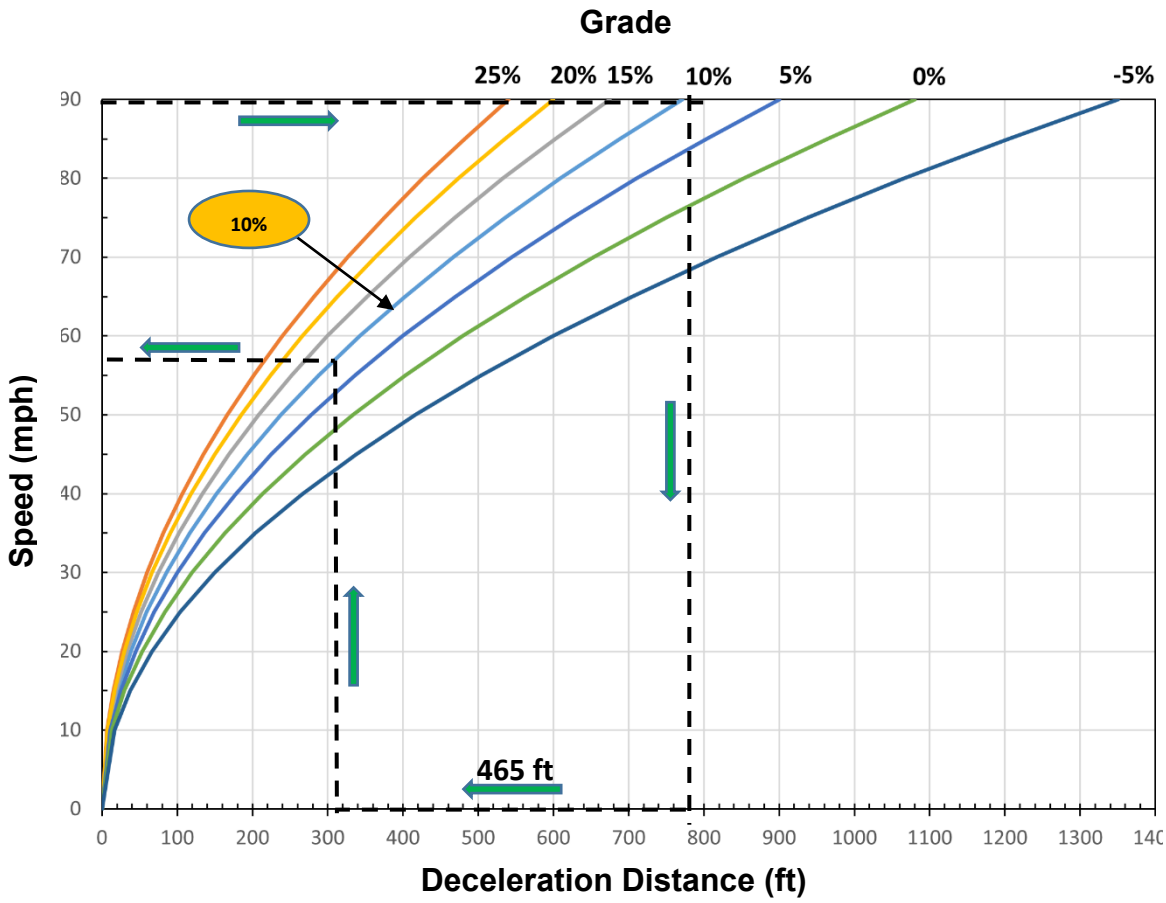
Guidance

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.

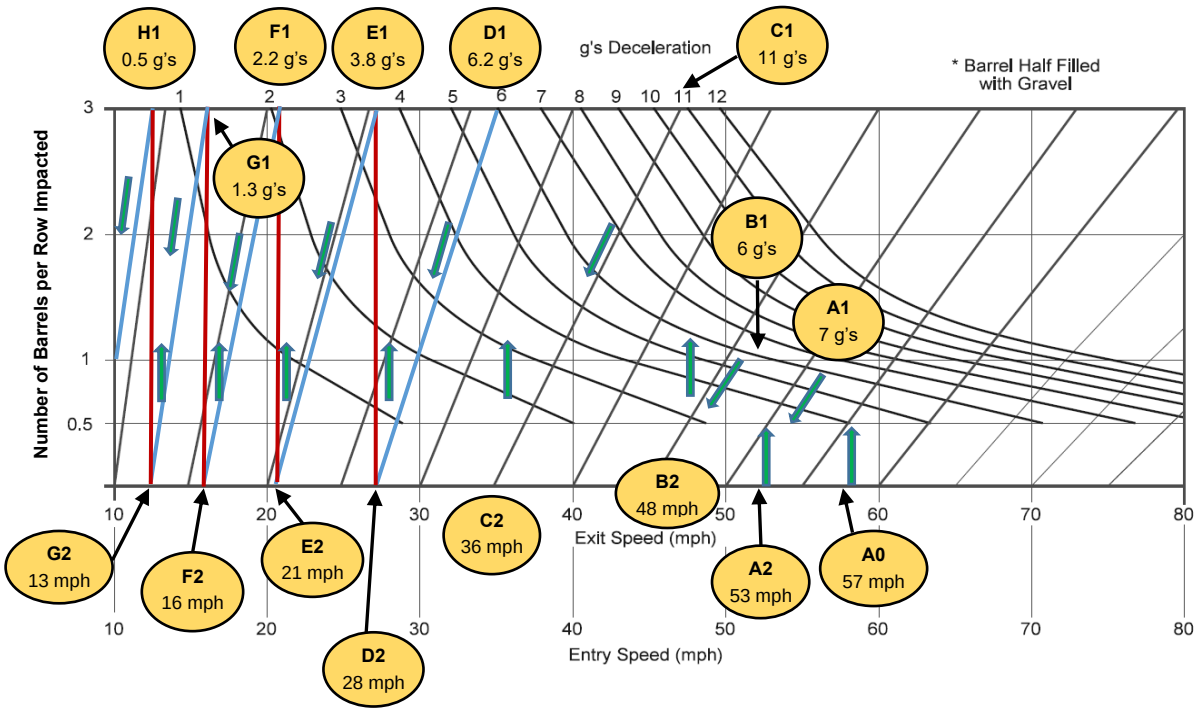


Using Exhibit 23.4.4, and completing the following steps, will enable the designer to determine the exit speed and deceleration of an 80,000-pound vehicle after it strikes each of the rows of barrels in a barrel array.

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.

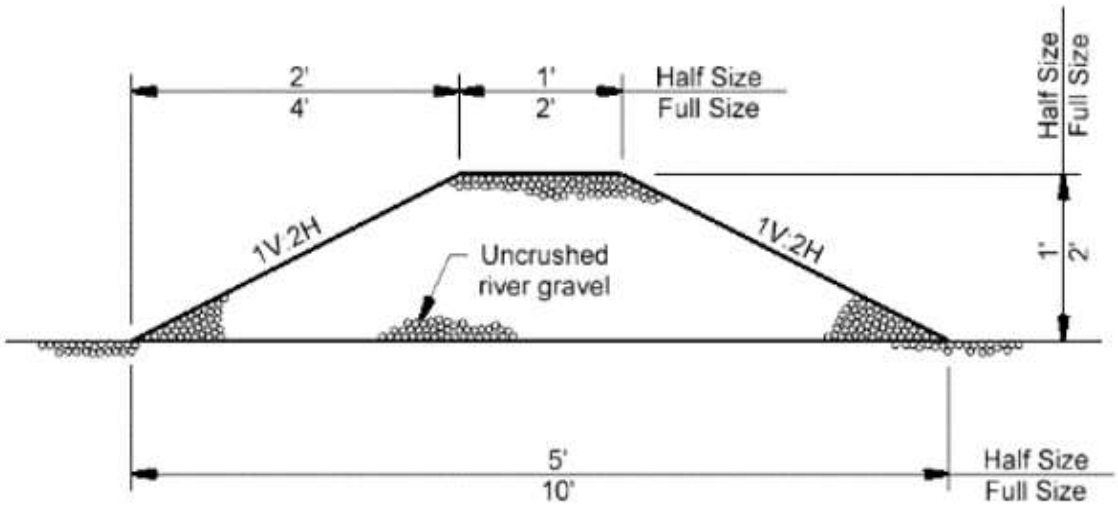
With the given parameters of a 500 ft arrester bed on a 10% grade with a design speed of 90 mph, the results from using Exhibit 23.4.4 show that the first two rows of barrels within the nine-row array will need to have one barrel per impacted row. The remaining rows after that will contain three barrels per impacted row and an 80,000-pound vehicle should come to a stop after the eighth row of barrels.

23.4.2.b – 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



NOT TO SCALE

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

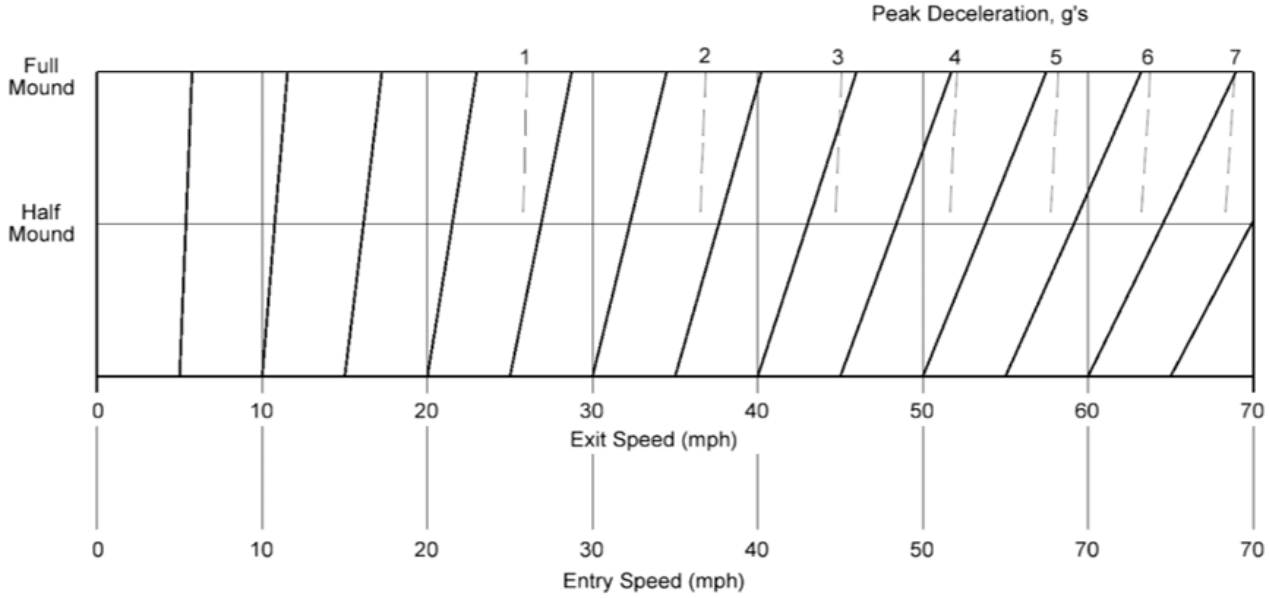


Exhibit 23.4.6 is similar to Exhibit 23.4.5 and contains the following elements:

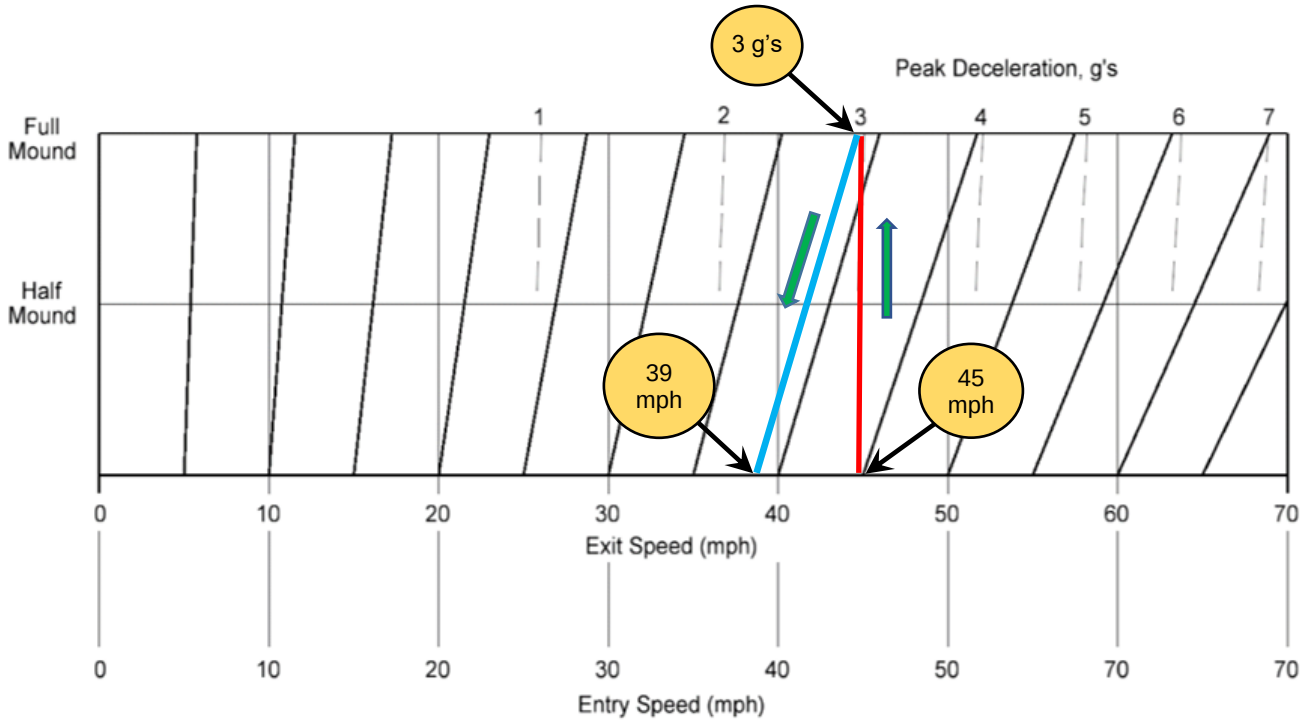
- **Speed Axis**. The horizontal line at the bottom of the graph is the speed axis. It indicates a range of speeds from 0 mph to 70 mph and is used for both the entry and exit speeds of a vehicle impacting a gravel mound. Note however that although the axis extends up to 70 mph, the use of mounds should 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.

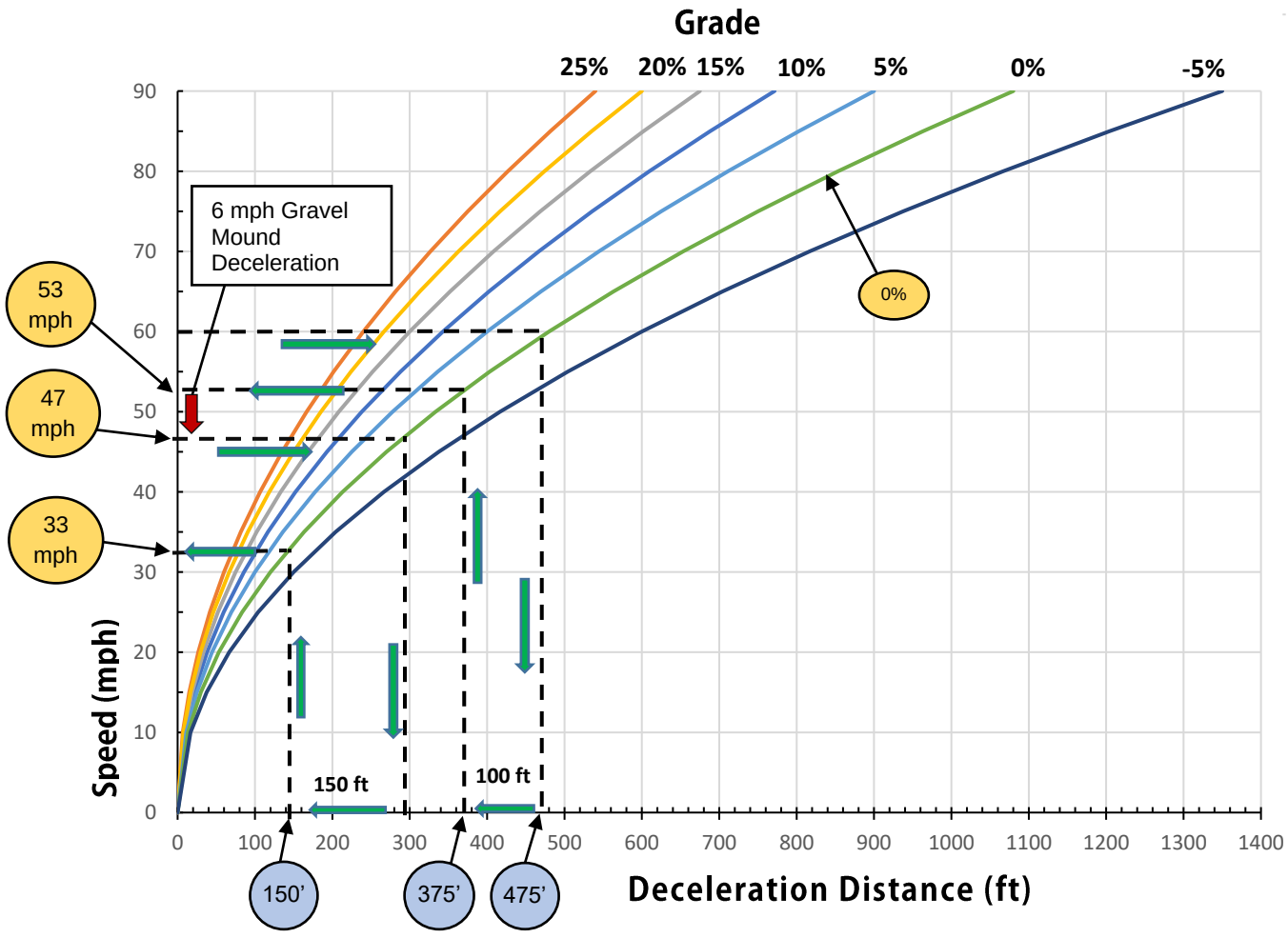
23.4.3 – Design with Combination Bed, Mounds, and Barrels

A bed design in combination with mounds, barrels, or both requires the use of the exhibits previously presented.

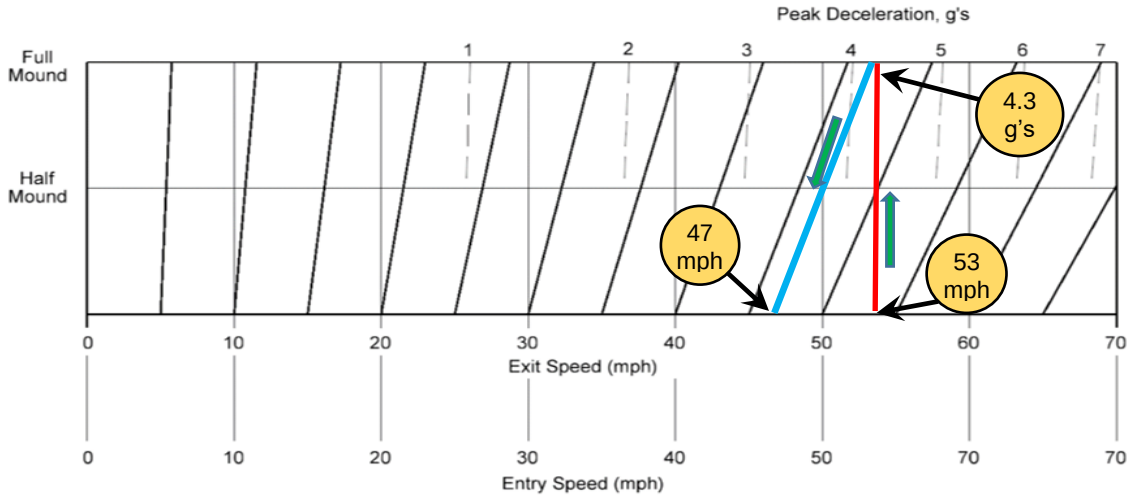
Example 5: Determining the Length Required to Stop a Vehicle

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.

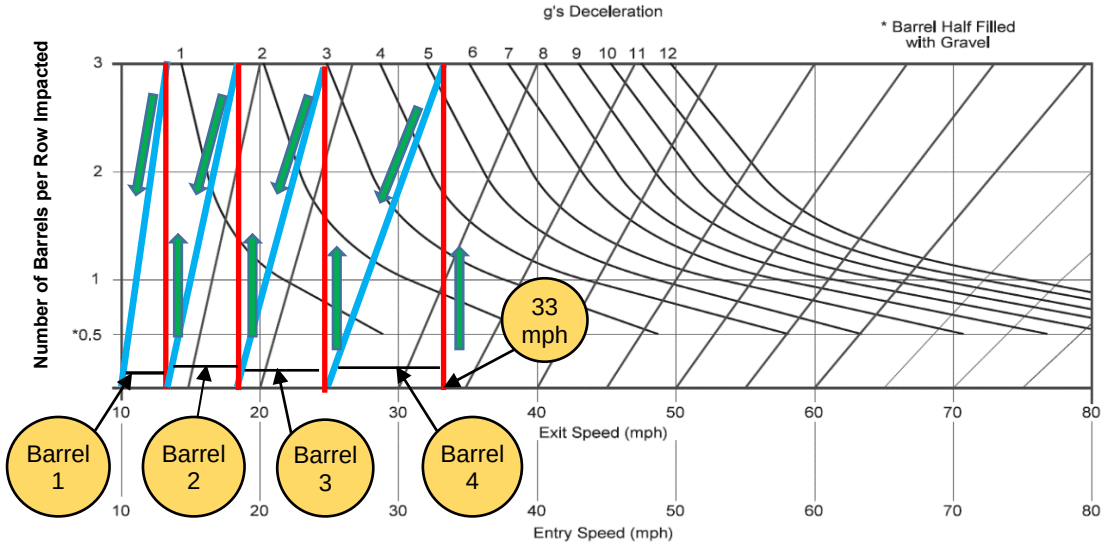


A gravel mound must be placed a minimum of 100 feet into the arrester bed. At this location, the vehicle impacts the mound at 53 mph. The exit speed after impacting a full mound is 47 mph (as shown in the graphic below, based on Exhibit 23.4.6), which occurs across the gravel mound width of 10 feet.

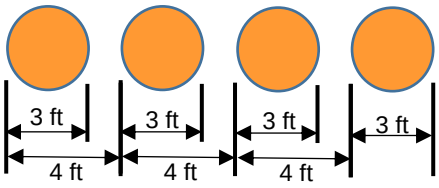


This leaves 190 ft of available length which does not provide enough length to dissipate the remaining speed. Therefore, it is assumed that a barrel array will be required at the end, for which 40 feet is a reasonable assumed length. This leaves an assumed length of 150 ft of arrester bed between the 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.



This barrel configuration uses 15 feet of arrester bed length.



= 15 feet

To dissipate the remaining 10-mph exit speed, additional length of arrester bed is required. This additional length is calculated using Equation 23.1.

$$L = \frac{V^2}{30(R \pm G)} = \frac{10^2}{30(0.25 + 0)} = 13.33'$$ (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.

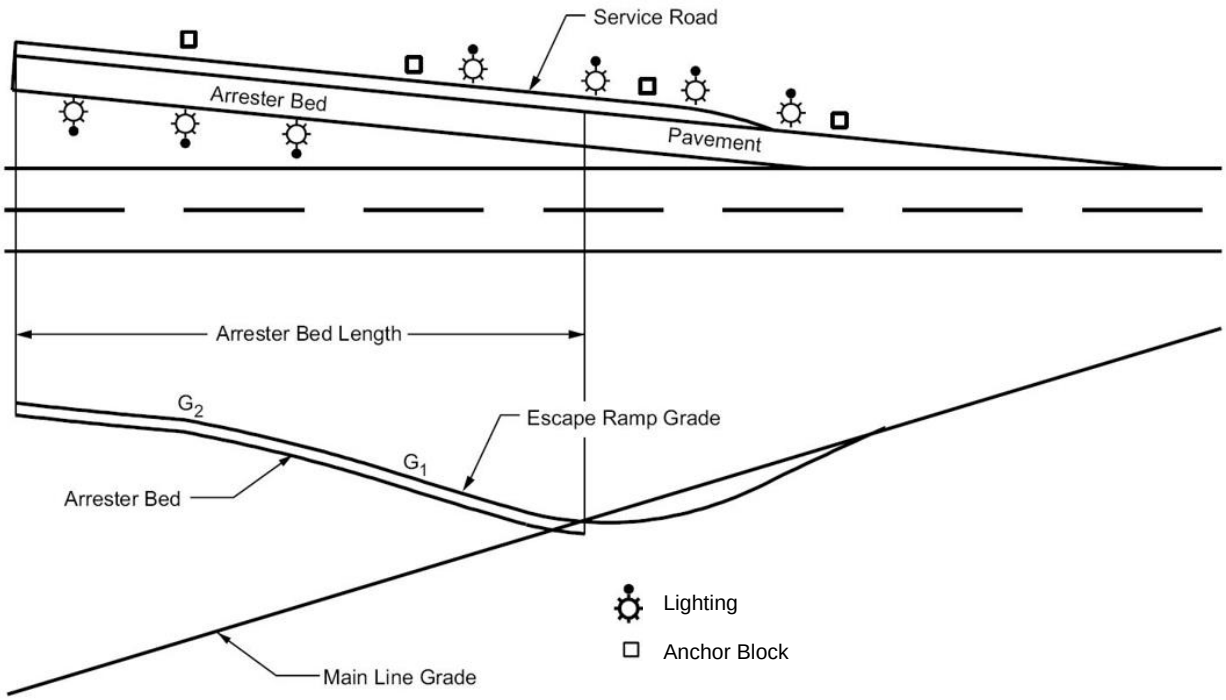
23.5.1 – Anchor Blocks

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:

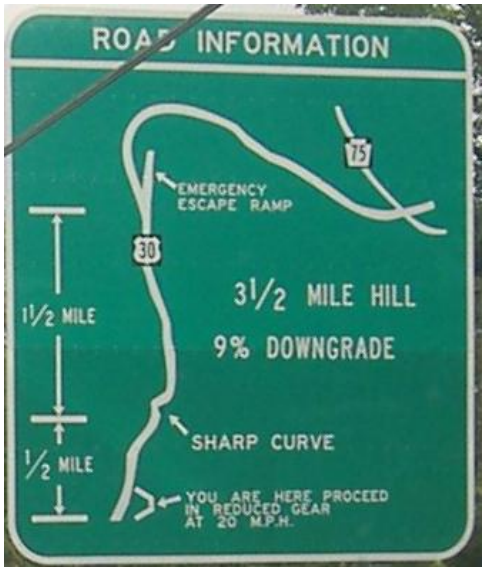
- Be offset to the side of the service road away from the gravel.
- Be evenly spaced at about 150-foot intervals (±25 feet).
- Be designated by a pavement marking on the adjacent service road for ease in locating.
- Be buried so the top of the anchor is flush with the ground.
- Include one anchor located 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 Publication 72M*, Roadway Construction Standards*, RC-101M, for concrete anchor block design details.

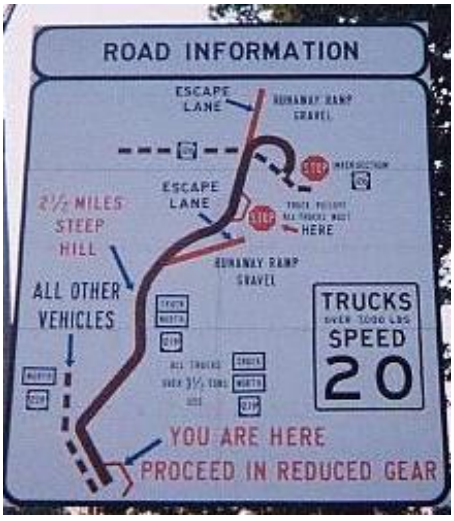
23.6 – Brake-Check Areas and Signing



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

In this chapter there are references to future chapters 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 24 – Rest Areas and Welcome Centers

24.0 – Introduction

Rest areas provide safety and convenience to the traveling public along interstate highways and major arterials. Benefits include reduced driver fatigue, refuge from adverse driving conditions, restroom provisions, reduced number of vehicles parked on roadway shoulders, and tourism promotion. A rest area typically provides restrooms, travel information, picnic tables, benches, sidewalks, drinking fountains, vending machines, and trash receptacles.

Rest areas should be considered in highway planning. Rest areas located near the highway entry point of a state border are welcome centers. To provide a multi-use opportunity, space may also be allotted for commercial motor vehicle (CMV) size, weight, and safety inspections.

Important context questions:

- Where should a rest area be located?
- What amenities should be included in the design of the rest area?
- How many parking stalls should be provided for each vehicle type?

Key design components:

- Space rest areas at the approximate distance that can be traveled in one hour.
- Provide separate parking and circulation areas for standard passenger vehicles (e.g., cars, pickup trucks, vans, etc.), and larger vehicles (i.e., all other trucks, buses, and recreational vehicles).

24.0.1 – Resources and References

- AASHTO, *Guide for Development of Rest Areas on Major Arterials and Freeways*, 2001.
- AASHTO, *Roadway Lighting Design Guide,* 2018.
- Code of Federal Regulations, *Landscape and Roadside Development,* Title 23, Ch. 1, Subch. H, Part 752, 1978.
- Code of Federal Regulations, *Right-of-Ways and Environment,* Title 23, Ch. 1, Subch. H, Part 710, 1977.
- Department of General Services (DGS), *Project Procedure Manual*, 2017.
- Environmental Protection Agency, National Pollutant Discharge Elimination System (NPDES) regulations.
- FHWA, *Manual for Safety Rest Area Water Supply Systems FHWA-RD-77-113*, 1977.

- FHWA, *Truck Parking Development Handbook,* 2022.
- FHWA, *Wastewater Treatment Systems for Rest Areas FHWA-RD-77-107,* 1977.
- PA Code, *Roadside Rest Areas,* Ch. 443, 1961.
- PA State Transportation Advisory Committee*, Truck Parking in Pennsylvania,* 2007.
- VA Department of Transportation, *Virginia Truck Parking Study,* 2015.

24.1 – Definitions

Rest Area – A roadside facility safely removed from the roadway, containing parking and other facilities deemed necessary for the rest, relaxation, comfort, and convenience of the motorist.

Exhibit 24.1.1 Rest Area, I-81 Southbound, Grantville, PA



Source: Google Earth Imagery

Welcome Center – A rest area that also provides travel and tourism information specific to the area. Welcome centers are generally located at major highway entry points to the state.

Welcome centers often are locations for inspection and enforcement areas for vehicles entering the commonwealth.

Exhibit 24.1.2 Pennsylvania Welcome Center



I-95 Northbound, Boothwyn, PA

Exhibit 24.1.3 Interior of Pennsylvania Welcome Center



I-95 Northbound, Boothwyn, PA

Inspection and Enforcement Area – A section of a rest area specifically designed and used for conducting size, weight, and safety inspections of motor vehicles. These are commonly included at welcome centers as well as other rest areas and are either a permanent or a temporary operation.

24.2 – Site Selection

24.2.1 – Assessment of Need

Adding rest areas may be deemed necessary if the spacing between existing services along a corridor, (i.e., the distance between rest areas, commercial establishments, etc.) is too far. The need for additional rest areas may also be noted in a comprehensive corridor plan or determined based on traffic volumes.

Existing rest areas may need to be rehabilitated or reconstructed due to security issues, deterioration, obsolescence, or facilities being excessively out of compliance with current standards.

An existing rest area that is no longer necessary may be permanently closed. Refer to Section 24.12 for more information on closures.

24.2.2 – Location

Rest areas are typically located on an interstate, divided highway, or other major arterial. Along

a divided highway, two rest areas are usually paired together (i.e., one adjacent to each direction of travel). A single rest area, located on one side of the roadway, may serve both directions of travel by utilizing an appropriately designed roadway crossover, such as a grade-separated crossover for interstates or intersections for other roadways. Rest areas in the median are not recommended because they require less-than-desirable left-hand exiting and entering.

The general spacing interval guideline for rest areas is the approximate distance that can be traveled in one hour. Other factors include:

- Distance between interchanges.
- The proximity to emergency services.
- The proximity to alternate rest opportunities (such as commercial establishments), which offer similar traveler services and amenities.
- The proximity to a state border (for welcome centers).
- The proximity to other interference, such as an interchange.

Once the general vicinity along the corridor has been determined, the specific site location is selected based primarily on topography. Topographic considerations include:

- Grades and slopes to accommodate parking, sewage treatment, drainage, buildings, and inspection and enforcement areas.
- High water level, particularly if the site is in a floodplain.
- Soil conditions and soil types, which affect structural designs and on-site sewage treatment systems.
- Vegetation and natural features.
- Impacts to existing wetlands, environmental features, stormwater drainage, etc.
- Prevailing wind direction and typical wind velocities that can affect visitor experience.
- Attractiveness of the location.
- Availability of utilities (water supply, electricity, etc.).

24.3 – Site Design

Rest area design components include acceleration and deceleration ramps, turning radii, vehicle parking areas, signing, pavement markings, pedestrian accommodations, picnic areas, buildings, landscaping, lighting, surface water drainage, wastewater disposal, and inspection and enforcement areas Therefore, rest area projects require the efforts of a design team with expertise in a variety of disciplines, including highway engineering, architecture, building systems and landscaping, and others.

Rest Area site development should provide visually pleasing, safe, and convenient facilities that

are accessible to persons with disabilities. The design of rest areas must be in accordance with current PennDOT and the American Association of State Highway and Transportation Officials (AASHTO) design standards.

24.3.1 – Site Sizing

A typical rest area requires approximately 25 acres of land within the highway right-of-way. The site should be large enough to accommodate all the facilities mentioned in Section 24.3, and also account for additional landscaping while retaining existing landscaping features as much as possible.

24.3.2 – General Site Layout

Site layout considerations include:

- For interstate rest areas, vehicular access will only be from the interstate.
- The use of reverse curves is not preferable.
- Provide a buffer area between the mainline pavement and parking areas (Preferable: 175 ft; Minimum: 35 ft). The parking area and all buildings, picnic areas, and walkways must be located outside the clear zone of the mainline roadway.
- Refer to Chapter 3, *New Construction and Reconstruction Change In Road Type,* for lane and shoulder width requirements between the mainline and ramp gore point. General guidance calls for a 4 ft left shoulder and 12 ft right shoulder between the gore point and the rest area.
- The left and right shoulders shall be constructed to full depth pavement structure to provide long-term shoulder integrity due to occasional shoulder use by traffic during emergency conditions.
- Design ramps to slow traffic from the faster highway speeds to slower speeds suitable for a pedestrian environment entering the parking area. Per PA Code Chapter 443, motor vehicle speeds within a rest area shall not exceed 25 miles per hour, except on the entrance and exit ramps. Refer to Chapter 18, *Traffic Calming*.
- Design paved areas to attain minimum slopes of 0.5% for drainage, with maximum slopes of 5.0% for safety and comfort. Typically, for inspection and enforcement areas, provide a profile grade along the vehicle path of 0% with a cross-slope near 0% with a 3.0% maximum; however, coordinate with the Pennsylvania State Police (PSP) Commercial Vehicle Safety Division for the current design requirements.
- Preserve significant site features such as topography, views and vistas, wooded areas, cultural and historic features, water elements, geological features, wetlands, and other inherent qualities.

- Minimize the impact of grading on sensitive portions of the site. The grading should reflect the site topography, accentuate landforms, and provide smooth transitions between existing and proposed topographic features.
- Consider providing a buffer area or acquiring a scenic easement on adjacent lands to protect scenic views and existing vegetation.
- Incorporate any cultural, historical, or scenic points of interest into the site design to enhance visitor experience and area education.
- Include buildings, restrooms, picnic shelters, custodial housing, storage structures, etc., in the site design.
- Locate buildings and public use areas between the car and truck parking areas so that they are within short walking distance for all motorists.
- Locate the inspection and enforcement area near to its potential office space and separated from the general public areas.
- Consider including locking gates when the inspection and enforcement area is separate from truck parking areas.
- Consider snow removal and provide snow stockpile areas.
- Provide perimeter site fencing to ensure exclusive highway motorist use (i.e., to prevent residents from using it as a local park or community facility).
- Provide dumpsters (non-public access) that are animal resistant, screened from public areas, fenced within an enclosed corral, and accessible to trash trucks.
- Include flagpoles that will accommodate one or more flags.
- Refer to Section 24.11 for the design of inspection and enforcement areas.

24.3.3 – Landscaping and Aesthetics

General guidelines and suggestions are as follows:

Exhibit 24.3.1 Rest Area Greenery



- A successful, sustainable rest area site will balance preservation of scenic, environmental, and cultural features with mobility, safety, maintainability, energy conservation and economy. Designs should ensure that all portions of the rest area are accessible and usable by all people of all ages and abilities.
- The rest area site and facilities should contribute to the visual environment by drawing inspiration from the cultural and historic background of the region. The buildings and site structures should have a common architectural design theme reflecting the site setting.
- The use of artwork and interpretive exhibits is beneficial in developing an interesting, inviting place.
- Provide trails, nature walks, paths, and sidewalks that fit naturally into the existing surroundings.
- Preserve existing trees and provide new trees that will shade table pad areas throughout the afternoon.
- Consider incorporating pollinator habitat and native species into the landscape design.
- Consider the visual effect of the paving.

Refer to Chapter 22, *Landscape Planting Design,* for additional information.

24.4 – Parking

The design should be based on the 20-year projected traffic volume and be expandable to accommodate the 30-year projected traffic volume.

Note that the vehicle code pertaining to roadside rest areas (Pa Code 67, Chapter 443) states parking of a vehicle for more than 2 hours in a single 24-hour period or in excess of the posted time is prohibited. If parking is to be allowed over 2 hours, signing stating the time limit should be posted.

24.4.1 – Parking Capacity Guidelines

The following should be considered when determining the required parking capacity:

- Provided parking spaces should comply with AASHTO's Guide for Development of Rest Areas on Major Arterials and Freeways.
- The design should include accommodation for the circulation and parking of larger vehicles, i.e., trucks, buses, and recreational vehicles (RVs). Generally, space limitations of the site and the physical limitations of the restrooms and wastewater disposal system limit the practical number of bus parking spaces to three or less, regardless of the number of buses that may travel the corridor.
- Rest areas on highways that pass through recreational or historic areas tend to have fewer trucks and a higher percentage of passenger cars and RVs with trailers.
- Consideration should be given to the expected duration of visitor stays. A range of 20 to 30 minutes is typical.
- For rest areas with higher truck usage (e.g., - located close to major delivery or distribution centers), consider increasing the number of truck parking spaces.
- An expected 10% to 15% of mainline traffic will use a rest area facility, with percentages varying by vehicle type.
- Rest area usage is generally the highest during a summer weekend. During the day, passenger cars tend to make up a higher percentage of the rest area usage. At night, trucks and RVs tend to make up the higher percentage of rest area usage.
- The demand for rest area usage and parking, particularly by CMVs, may spike considerably during winter storm events at rest areas located just within Commonwealth borders, at junctures of interstates with other major truck routes, or within areas of known severe weather conditions.

See Chapter 19, *Parking Facilities,* for parking stall and circulation design guidelines.

24.4.2 – Parking Capacity Calculations

24.4.2.a – Car Parking Demand

The required parking capacities are determined from traffic volume data for the design year (typically a 20-year projection), and are calculated as outlined below:

Equation 1: Car Parking Spaces Calculation

Peak Hour Directional (PHD) Traffic = ADT × K × D

- ADT = Average Daily Traffic (Two-Way)
- K = Ratio of Design Hourly Volume to ADT (Interstate: 12% (Rural); 10% (Urban))
- D = Directional Distribution (generally about 0.60)

M = Total Car Parking Spaces = PHD × N × L x % Cars

- N = Location Factor (The percentage of vehicles stopping at rest areas during peak hours)

  The percentage varies from 5% to 13% (percentages may be interpolated to reflect the proximity to other rest areas) using the following guidelines:

  - Near commercial or recreational facilities = 5%
  - Rural Area = 9%
  - Isolated area with no nearby commercial or recreational facilities = 13%
- L = length of stay in rest area (hours), generally 20 min. (0.33 hr.) to 30 min. (0.5 hr.)
- % Cars = Percent of Cars in the Daily Traffic

Example 1: Determine the desirable range of car parking spaces (M) for a rest area in a rural area.

Assume:

- ADT = 31,714 (20-year design projection)
- K = 0.12 (rural area)
- D = 0.60
- % Cars = 80%
- N = 9% (rural area)
- $L_{(min)}$ = Minimum Length of stay of 20 min = 0.33 hr.
- $L_{(max)}$ = Maximum Length of stay of 30 min = 0.50 hr.

Therefore:

- PHD = 31,714 × 0.12 × 0.60 = **2,283**
- $M_{(min.)}$ = 2,283 × 0.09 × 0.33 x 0.80 = **54.3 Spaces** (at a minimum)
- $M_{(max.)}$ = 2,283 × 0.09 × 0.50 x 0.80 = **82.2 Spaces** (at a maximum)

Result:

- Desirable range of car parking spaces = **54 to 82 spaces**

24.4.2.b – Truck Parking Demand

The truck parking needed at a rest area is the combination of the parking demands for the short-haul and long-haul trips (since both occur simultaneously). The equations and the constants derived from the assumptions below are from PA State Transportation Advisory Committee, *Truck Parking Study in Pennsylvania*. Refer to the report to determine whether these assumptions apply to the particular rest area being designed.

Equation 2: Short-Haul Truck Parking Demand

$D_{short\text{-}haul}$ = Parking Demand for Short-Haul Trucks

$D_{short\text{-}haul} = P_t \times AADT \times L/S \times 0.004772$

- P_t = Percent of Vehicles that Consist of Commercial Trucks
- AADT = Annual Average Daily Traffic (Vehicles Per Day)
- L = Length of Highway Segment (mi)
- S = Speed Limit of Highway (mph)

Equation 3: Long-Haul Truck Parking

$D_{long\text{-}haul}$ = Parking Demand for Long-Haul Trucks

$D_{long\text{-}haul} = P_t \times AADT \times L/S \times 0.03777$

- P_t = Percent of Trucks
- AADT = Annual Average Daily Traffic (Vehicles Per Day)
- L = Length of Highway Segment (mi)
- S = Speed Limit of Highway (mph)

To determine the total number of truck parking spots needed for the rest area, add the short-haul and long-haul demands:

Equation 4: Total Truck Parking Demand

D_{Total} = Demand for All Trucks

$D_{Total} = D_{short\text{-}haul} + D_{long\text{-}haul}$

$D_{Total} = P_t \times AADT \times L/S \times 0.04254$

- P_t = Percent of Trucks
- AADT = Annual Average Daily Traffic (Vehicles Per Day)
- L = Length of Highway Segment (mi)
- S = Speed Limit of Highway (mph)

24.5 – Pedestrian Accommodations

Pedestrian circulation through the rest area should be usable, safe, and effective for all ages and abilities. Pedestrian circulation routes should be easily visible through appropriate pavement markings and signage and designed to reduce potential vehicle/pedestrian conflicts. Barrier-free walkways shall be provided for access to buildings, picnic areas, pet walks, and other areas of interest. Walkways should be designed for long-term durability and ease of maintenance. Skid-resistant pavement markings should be provided in areas with potential for high pedestrian use.

Design rest area grounds and facilities to accommodate individuals with disabilities. All public-use components must comply with the Americans with Disabilities Act Accessibility Guidelines (ADAAG) and Chapter 13, *Pedestrian Facilities.* An accessible route must be provided between the truck and RV parking areas to the rest area facilities. Provide ADA ramps, automatic door openers, and ADA signage. At least one walkway leading to the restroom building, one picnic table, and any significant feature (e.g., scenic overlook) must be ADA-accessible.

24.6 – Amenities

Typical Amenities include a public use building with restrooms, picnic tables and shelters, benches, pet accommodations, play structures, drinking fountains, vending machines, and waste receptacles.

Exhibit 24.6.1 Vending Machines



24.6.1 – Public Use Buildings

Rest areas typically provide a building with rest rooms, and some degree of public information services. Office space may be provided for CMV enforcement officers or other staff. There is no standard rest area building design; the building and appropriate amenities vary for each site location. The building design and construction is procured through the Commonwealth of Pennsylvania, Department of General Services.

Generally, the design of the building, facilities, grounds, materials, and fixtures should maximize energy efficiency and minimize the operational and maintenance effort.

- Adhere to the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) standards where practicable.
- Comply with current versions of all applicable state and local code requirements (e.g., the International Building Code, International Plumbing Code, National Electric Code, Americans with Disabilities Act Accessibility Guidelines).
- For welcome centers, the rest area building will house additional travel information center activities (e.g., staffed counter space, brochure exhibit space, offices, storage space, and workspace).
- Consider vandal-resistant materials for building components such as fixtures, fasteners, and surface coatings.

24.6.2 – Pet Accommodations

Walk areas for pets on leashes should be provided, preferably separate from high use areas. Designers should consider pet exercise areas and pet tethering posts. These areas should be located away from areas designated solely for human use, such as pedestrian circulation routes, picnic areas, and parking areas to avoid safety and sanitary issues. Signing should be provided to indicate areas restricted for pets.

24.6.3 – Picnic Facilities

Picnic tables and shelters should be located so that vehicular traffic does not pose an undue hazard. Provide the required number of ADA-accessible picnic tables. Picnic tables should be durable, vandal-resistant, and relatively maintenance free. Picnic tables are often anchored to a concrete or asphalt pad.

Exhibit 24.6.2 Picnic Tables



24.6.4 – Travel and Tourism Information

Consistent with FHWA policy, 23 CFR 752.7, rest areas may include travel information centers, which provide directions, maps, and brochures. The information facility can be as small as a kiosk or bulletin board, or as large as an entire building separate from the rest area complex. More sophisticated welcome centers are commonly located near the highway entry point of the state border or at geographical or cultural attractions. These facilities distribute information regarding regional attractions and accommodations, as well as natural, cultural, historic, recreational, and scenic resources.

Exhibit 24.6.3 Brochure Display



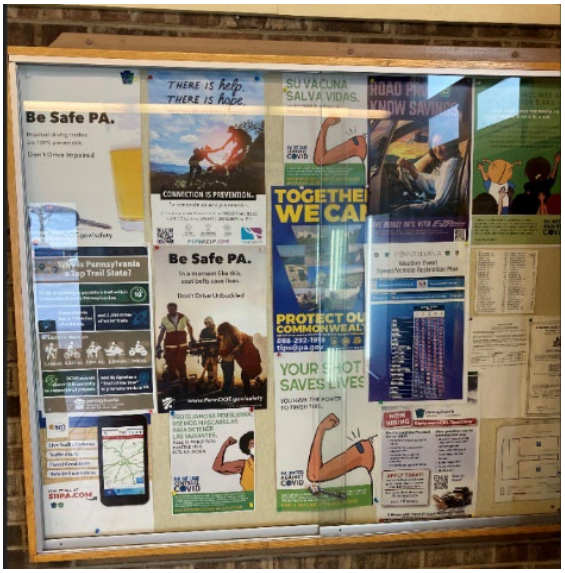
Other potential informational amenities include:

- Travel information kiosks.
- TV monitors to provide real-time information and advisories regarding road conditions, traffic flow, weather, crashes, snow emergencies, flooding, and “Amber Alerts”.
- Cultural, historical, or natural resource educational kiosks and displays.

Exhibit 24.6.4 Welcome Sign



Exhibit 24.6.5 Information Display



24.6.5 – Intelligent Transportation Systems (ITS) and Emerging Technologies

The designer should be aware of new and emerging technologies and look for opportunities to incorporate them into their projects. Consider ITS devices that incorporate emerging technologies such as real-time parking identification/notification systems where advantageous or applicable.

24.6.6 – Other

Other potential amenities include:

- Telephones - Public telephone service may be unnecessary due to the wide availability of cellular phones. The likelihood of vandalism is also a negative. If telephones are provided, they must meet ADAAG requirements.
- Benches.
- Playground equipment.
- Drinking fountains.
- Vending machines.
- Trash cans.

Coordinate with the Department of General Services (DGS) regarding the inclusion of these amenities.

24.7 – Exterior Lighting

Exhibit 24.7.1 Overhead Lighting



Illuminate all ramps, roadways, walkways, truck safety inspection and weighing areas, and parking lots. Solar and other energy conserving lighting types should be considered. All parking lots shall be illuminated for nighttime use and security.

Refer to Chapter 20, *Lighting,* for additional guidance.

24.8 – Security

Avoid building designs and site layouts that create potential hiding places. Provide perimeter fencing, and adequate interior, exterior, and perimeter lighting.

24.9 – Snow Removal

The location and drainage of snow removal storage areas must also be considered. Providing large, obstacle-free areas will maximize snow removal efficiency.

24.10 – Signage

24.10.1 – Advance Signing

Rest areas with truck size, weight, and safety inspection activities should have permanently installed mainline signs (lit when open for inspections) that are remote-controlled by inspection staff. Radio controlled solar-powered flashing signs can provide a cost-effective alternate to signs that require buried electrical services.

Refer to Pub 236 for standard signage for truck inspections.

24.10.2 – On-Site Signing

Rest area signage should provide clear and adequate direction to the various amenities. To inform motorists of their location in the event of an emergency, the name of the rest area shall be prominently displayed on the exterior and interior of the building.

24.11 – Motor Carrier Inspection and Enforcement Areas

Determine whether an inspection and enforcement area will be modified or provided. If so, coordinate with the organizations listed below regarding their current requirements, policies, technologies, equipment, pavement marking and operational needs:

- PSP's Commercial Vehicle Safety Division (which oversees the Motor Carrier Safety Assistance Program and the Weight Enforcement Program).
- PennDOT's Bureau of Operations.
- PennDOT's Bureau of Planning and Research (which manages weigh-in-motion (WIM) sites).

Design requirements may pertain to:

- Horizontal alignment (tangent length requirements).
- Vertical alignment (maximum roadway gradient).
- Transverse slope and superelevation.
- Surface uniformity.

- Electrical supply.
- ITS facilities.
- Technology requirements.

Additionally:

- Consider the location of these facilities with respect to the truck parking stalls and access roadways.
- Provide adequate storage so that WIM and inspection queue lengths do not disrupt normal circulation or back up onto ramps and shoulders. This queuing distance will be based on:
    - Number of trucks on the mainline.
    - Length of trucks.
    - Expected hours of operation.
    - Time required for actual weighing.
- Provide a holding area for trucks that have failed inspection.
- Locking gates may be installed around the facility.
- Coordinate with PennDOT's Bureau of Planning and Research regarding any proposed or current WIM project, including removal. Current policy is to relocate (when possible) WIM detectors onto the mainline - approximately 1 mile upstream from the rest area/welcome center - instead of on rest area ramps.

24.12 – Closures

Federal Highway Administration (FHWA) approval is required for an interstate rest area permanent closure (or transfer to another federal, state, or local agency). If the rest area contains a WIM scale system, contact PennDOT's Bureau of Planning and Research, which is responsible for managing these systems.

Notification of Closures

If a rest area or welcome center is going to be partially, temporarily or permanently closed:

- Notify the PSP so they can plan for alternative inspection and enforcement operations.
- Notify the PA Motor Truck Association so they can alert truckers of the closure and loss of parking.