CHAPTER 3

INTERSECTIONS

3.0 INTRODUCTION

By definition, an intersection is the general area where two or more highways join or cross including the roadway and roadside facilities for traffic movements within the area. The efficiency, safety, speed, cost of operation and capacity of an intersection depends upon its design. Since each intersection involves innumerable vehicle movements, these movements may be facilitated by various geometric design and traffic control depending on the type of intersection. The three general types of highway crossings are: (1) at-grade intersections, (2) grade separations without ramps and (3) interchanges.

The most important design considerations for intersections fall into two major categories: (1) the geometric design including a capacity analysis and (2) the location and type of traffic control devices. For the most part, these considerations are applicable to both new and existing intersections, although on existing intersections in built-up areas, heavy development may make extensive design changes impractical.

The design elements, capacity analysis and traffic control concepts presented in this Chapter apply to intersections and their appurtenant features. Additional sources of information and criteria to supplement the concepts presented in this Chapter are contained in the 2004 AASHTO Green Book, Chapter 9 and the *MUTCD*.

3.1 OBJECTIVES AND FACTORS FOR DESIGN CONSIDERATIONS

The main objective of intersection design is to facilitate the convenience, ease and comfort of people traversing the intersection while enhancing the efficient movement of motor vehicles, buses, trucks, bicycles, and pedestrians.

Refer to the section "General Design Considerations and Objectives" in the 2004 AASHTO Green Book, Chapter 9, for details about the five basic elements that should be considered in intersection design: human factors, traffic considerations, physical elements, economic factors, and functional intersection area. These should be identified and evaluated prior to selecting the type of design used.

For exhibits describing the functional intersection area, refer to the 2004 AASHTO Green Book, Chapter 9, Exhibits 9-1 and 9-2.

3.2 TYPES OF INTERSECTIONS

The basic types of intersections are determined primarily by the number of intersecting legs, the topography, the character of the intersecting highways, the traffic volumes, patterns and speeds, and the desired type of operation. The basic types of intersections include: (1) the three-leg or T, (2) the four-leg and (3) the multileg (with five or more intersection legs).

Limited sight distance may make it necessary to control traffic by yield signs, stop signs or traffic signals where the traffic densities are less than those ordinarily considered necessary for such control. The alignment and grade of the intersecting roadways and the angle of intersection may make it advisable to channelize or use auxiliary pavement areas, regardless of the traffic densities. In general, traffic service, highway design designation, physical conditions and cost of right-of-way are considered jointly in choosing the type of intersection.

It is not practical to indicate all possible variations; however, the basic types are presented in the 2004 AASHTO Green Book, Chapter 9, Exhibits 9-3 through 9-17 to illustrate the general application of intersection design. A basic intersection type can vary greatly in scope, shape and degree of channelization. Although many factors enter into the selection of the type of intersection and the extent of design, the principal control factors for the type of intersection design required are the design-hour traffic volume, the character or composition of traffic and the design speed. In selecting the type of intersection, the most significant factor is the traffic volume (actual and relative) involved in various turning and through movements. Once the type of intersection is established, the design controls and criteria and the elements of intersection design shall be applied to arrive at a suitable geometric plan. The modern roundabout may also be considered a type of intersection design and is discussed in more detail in Section 3.5. For additional information on variations of the basic types of intersections, their treatments and applications, refer to the section "Types and Examples of Intersections" in Chapter 9 of the 2004 AASHTO Green Book.

3.3 GEOMETRIC DESIGN ELEMENTS

At intersections, various geometric design elements should be considered to accommodate the type and amount of traffic and the turning movements that are expected.

A. Alignment and Profile. Since intersections represent points of conflict between vehicles, pedestrians and bicycles, the alignment and profile of the intersecting roads should permit users to maneuver safely with minimum interference by other users. The alignment should be as straight and the gradients as flat as practical. 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 messages of traffic control devices, and in controlling their operations.

For an alignment, design considerations should:

- Have intersecting roads generally meet at or nearly at right angles.
- Avoid short-radius horizontal curves on side road approaches to achieve right-angle intersections.
- Consider making an offset intersection 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.

For a profile, design considerations should:

- Avoid combinations of grade lines that make vehicle control difficult.
- Avoid substantial grade changes.
- 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.
- 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.

For a more detailed discussion of considerations for alignments and profiles, refer to the section "Alignment and Profile" in the 2004 AASHTO Green Book, Chapter 9.

B. Types of 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 almost all cases, turning roadways are designed for use by right-turning traffic. The widths for right-turning roadways may also be applied to other roadways within an intersection, such as between channelizing islands.

There are three typical types of right-turning roadways at intersections: (1) a minimum edge-of-traveled-way design; (2) a design with a corner triangular island; and (3) a free-flow design using a simple radius or compound radii. The turning radii and the pavement cross slopes for free-flow right turns are functions of design speed and type of vehicles.

As a control for the geometric design of turning roadways, the largest design vehicle likely to use that facility with considerable frequency, or a design vehicle with special characteristics that must be taken into account in dimensioning the facility, is used to determine the design of such critical features as radii at intersections and radii of turning roadways.

There are four general classes of design vehicles, namely (1) passenger cars, (2) buses, (3) trucks, and (4) recreational vehicles. Dimensions for 19 typical design vehicles, representing vehicles within these general classes, are presented in the 2004 AASHTO Green Book, Chapter 2, Exhibit 2-1. The minimum radii of the outside and inside wheel paths and the centerline radii for specific design vehicles are presented in the 2004 AASHTO Green Book, Chapter 2, Exhibit 2-2. The minimum turning paths for 19 typical design vehicles are illustrated in the 2004 AASHTO Green Book, Chapter 2, Exhibits 2-3 through 2-23. These exhibits should be used as a guide to determine the turning radii at intersections and the width of turning roadways.

The values for the minimum radii for intersection curves for operation at design speed, and the derived pavement widths for turning roadways for different design vehicles, shall conform to the values derived in the 2004 AASHTO Green Book, Chapter 3, Exhibits 3-25 through 3-27 and 3-50, respectively.

Where it is appropriate to provide for turning vehicles within minimum space and with minimum attainable speeds less than 15 km/h (10 mph), as at unchannelized intersections, the corner radii should be based on minimum turning paths of the design vehicles. 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, i.e., 0.6 m (2 ft) from the edge of traveled way on the tangents approaching and leaving the intersection curve. The minimum curve designs for edge of traveled way conforming to this assumption are shown in the 2004 AASHTO Green Book, Chapter 9, Exhibits 9-21 through 9-28.

For most simple intersections with an angle of turn equal to 90° or less, a single circular arc joining the tangent edges of pavement provides an adequate design. However, where provisions must be made for large design vehicles or when the angle of turn exceeds 90°, a three-centered curve to fit the traffic conditions may be selected. An alternate design that closely approximates the three-centered curve layout consists of a simple offset curve with connecting tapers. The suggested minimum designs in which simple curves and three-centered compound curves are used for each design vehicle when making the sharpest turn are indicated in the 2004 AASHTO Green Book, Chapter 9, Exhibits 9-19 and 9-20, respectively.

For additional information on intersection curves relative to widths and turning paths applicable to the various design vehicles, refer to the section "Types of Turning Roadways" in the 2004 AASHTO Green Book, Chapter 9.

C. Sight Distance. As a general consideration, the sight distance should be equal to or greater than the minimum values for specific intersection conditions.

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. 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.

For more information about sight triangles at intersections, refer to the section "Sight Triangles" in the 2004 AASHTO Green Book, Chapter 9.

For additional sight distance considerations at intersections, refer to Chapter 2, Section 2.17 and the section "Intersection Sight Distance" in Chapter 9 of the 2004 AASHTO Green Book.

D. Superelevation. The general factors that control the maximum rates of superelevation, as discussed in Chapter 2, Section 2.13, also apply to turning roadways at intersections. When entering or leaving a superelevated curve, the problem of how fast to introduce or remove the superelevation rate arises. The control of the rate of cross slope change for curves at intersections is that of riding comfort and appearance and shall be determined in accordance with the 2004 AASHTO Green Book, Chapter 9, Exhibit 9-44.

For additional information concerning superelevation for curves at intersections, refer to the section "Superelevation for Turning Roadways at Intersections" in the 2004 AASHTO Green Book, Chapter 9.

E. Traffic Islands. A traffic 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. They serve three primary functions:

1. Channelization (to control and direct traffic movement, usually turning).
2. Division (to divide opposing or same-direction traffic streams, usually through movements).
3. Refuge (to provide refuge for pedestrians).

For additional information concerning traffic island sizes and designations, delineation, approach-end treatments and island designs based on turning roadways, refer to the section "Islands" in the 2004 AASHTO Green Book, Chapter 9.

F. Median Openings. Intersections include median openings to accommodate crossing and turning traffic movements. Where appropriate, median openings may also be provided for U-turns. Factors to consider are the median width, the location and length of the opening and the design of the median ends, and the character and volume of through and turning traffic. Median openings should reflect street or block spacing and the access classification of the roadway. In addition, full median openings should be consistent with traffic signal spacing criteria.

An important factor in designing median openings is the path of each design vehicle making a minimum turn at 15 to 25 km/h (10 to 15 mph). The section "Control Radii for Minimum Turning Paths", found in the 2004 AASHTO Green Book, Chapter 9, 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 minimum designs for the shape of median ends are shown in the 2004 AASHTO Green Book, Chapter 9, Exhibits 9-77 through 9-87.

For any three-leg or four-leg intersections on a divided highway, 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. Where the crossroad is a divided highway, the length of opening should be at least equal to the width of the crossroad traveled ways plus the width of the median. In general, median openings longer than 25 m (80 ft) should be avoided, regardless of skew.

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.

For further discussion of median openings, including general design considerations, control radii for minimum turning paths, end shapes and dimensional requirements, refer to the section "Median Openings" in the 2004 AASHTO Green Book, Chapter 9.

G. Acceleration and Deceleration (Speed-Change) Lanes. When undue deceleration or acceleration by entering or leaving traffic takes place directly on the highway traveled way, it disrupts the flow of through traffic. To preclude or minimize these undesirable operations, the use of speed-change lanes has been developed as standard practice. A speed-change lane represents an auxiliary lane that contains tapered areas primarily for the acceleration or deceleration of vehicles entering or leaving the through-traffic lanes.

Although warrants for the use of speed-change lanes cannot be stated definitely, the general conclusions and considerations for their use are contained in Chapter 1, Section 1.6. For additional information and design guidance relative to speed-change lanes, including taper rates for lane drops, refer to the section "Speed Change Lanes at Intersections" in the 2004 AASHTO Green Book, Chapter 9.

H. Direct and Indirect Left Turns and U-Turns. The various design methods and arrangements to accommodate 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. The necessity to turn left or to make a U-turn in the urban or heavily developed residential or commercial sectors represents serious problems with respect to safety and efficient operations. The general design for direct and indirect left-turn and U-turns (including jughandles, turns using local streets, wide medians, and location) and for continuous and simultaneous left-turn lanes are contained in the sections "Indirect Left Turns and U-Turns", "Flush or Traversable Medians", "Offset Left Turn Lanes", "Median Left-Turn Lanes, and "Simultaneous Left Turns" in the 2004 AASHTO Green Book, Chapter 9.

I. Auxiliary Lanes. An auxiliary lane refers to that portion of the roadway adjoining the traveled lanes that may be provided for median openings and for intersections to supplement through-traffic movements. These lanes should be at least 3.0 m (10 ft) wide and desirably should equal that of the through lane and their length shall be 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. For additional information and design considerations for auxiliary lanes for intersections, refer to Publication 46, *Traffic Engineering Manual*, Chapter 11.

J. Curb Radii for Turning Movements in Urban Areas. 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.

The section "Corner Radii into Local Urban Streets", found in the 2004 AASHTO Green Book, Chapter 9, provides guidelines for right-turning and corner radii.

Exhibit 9-29 through Exhibit 9-32 in the 2004 AASHTO Green Book, Chapter 9 indicate how curb radii are influenced with and without the presence of parking lanes.

Corner radii at intersections should satisfy needs of the drivers using them, the amount of right-of-way available, the angle of turn between the intersection legs, numbers of pedestrians using the crosswalk, the width and number of lanes on the intersecting streets and the posted speeds on each street. The section "Effect of Curb Radii on Pedestrians", found in the 2004 AASHTO Green Book, Chapter 9, offers a guide with various dimensions of radii.

For additional guidelines on curb radii for turning movements in urban areas, refer to the section "Types of Turning Roadways" in the 2004 AASHTO Green Book, Chapter 9.

K. Free-Flow Turning Roadways at Intersections. Many intersections feature free-flow turning roadways alignment for right-turn movements. Ease and smoothness of operation can result when the free-flow turning roadway is designed with compound curves preceded by a right-turn deceleration lane. Refer to the section "Free-Flow Turning Roadways at Intersections" in the 2004 AASHTO Green Book, Chapter 9 for guidance on the shape and length of these curves.

The design speed of free-flow turning roadways may be equal to, or possibly within 20 to 30 km/h (10 to 20 mph) less, than the through roadway design speed. Turning roadways at intersections should use the "upper-range" design speeds whenever practical, although the "middle range" speeds may be used in constrained situations.

For additional information and design guidance relative to free-flow turning roadways at intersections, including the use of acceleration or deceleration lanes, refer to the section "Free-Flow Turning Roadways at Intersections" in the 2004 AASHTO Green Book, Chapter 9.

L. Channelization. Channelization is the separation of traffic flows into well-defined paths that minimize the area of conflict, typically through the use of islands and/or pavement markings. Channelization can increase intersection capacity, improve safety and operations, and is often used to separate left-turning traffic from through traffic.

The section "Channelization" in the 2004 AASHTO Green Book, Chapter 9 identifies the factors and principles that should be considered for channelization of intersections.

Significant controls involved in the design of a channelized intersection should encompass the type of design vehicle, cross sections on the crossroads, projected traffic volumes, pedestrian traffic, vehicle speed, bus stop locations and the type and location of traffic control devices. Certain physical controls such as right-of-way and topography may also affect the extent and amount of channelization that is economically practical.

M. Additional Design Considerations. In addition to the design concepts presented above, additional considerations relevant to intersection design include the items listed below. For information and design guidance for these items, refer to the reference indicated:

1. Frontage road design elements. (2004 AASHTO Green Book, Chapter 9, "Intersection Design Elements with Frontage Roads")

2. Control on wrong-way entry. (2004 AASHTO Green Book, Chapter 9, "Design to Discourage Wrong-Way Entry")

3. Curb cut ramps for the physically disabled. (2004 AASHTO Green Book, Chapter 9, "Wheelchair Ramps at Intersections" and Chapter 6)

4. Lighting. (2004 AASHTO Green Book, Chapter 9, "Lighting at Intersections" and Chapter 5)

5. Driveway terminals. (2004 AASHTO Green Book, Chapter 9, "Driveways"; provisions of 67 PA Code § 441; and Chapter 7)

6. Railroad-highway grade crossings. (2004 AASHTO Green Book, Chapter 9, "Railroad-Highway Grade Crossings"; Chapter 2, Section 2.18.D; and Publication 371, *Grade Crossing Manual*)

7. Modern roundabouts. (2004 AASHTO Green Book, Chapter 9, "Modern Roundabouts"; NCHRP Report 672, *Roundabouts: An Informational Guide, Second Edition*)

8. Flush or traversable medians. (2004 AASHTO Green Book, Chapter 9, "Flush or Traversable Medians")

9. Traffic calming. (Publication 383, *Pennsylvania's Traffic Calming Handbook*)

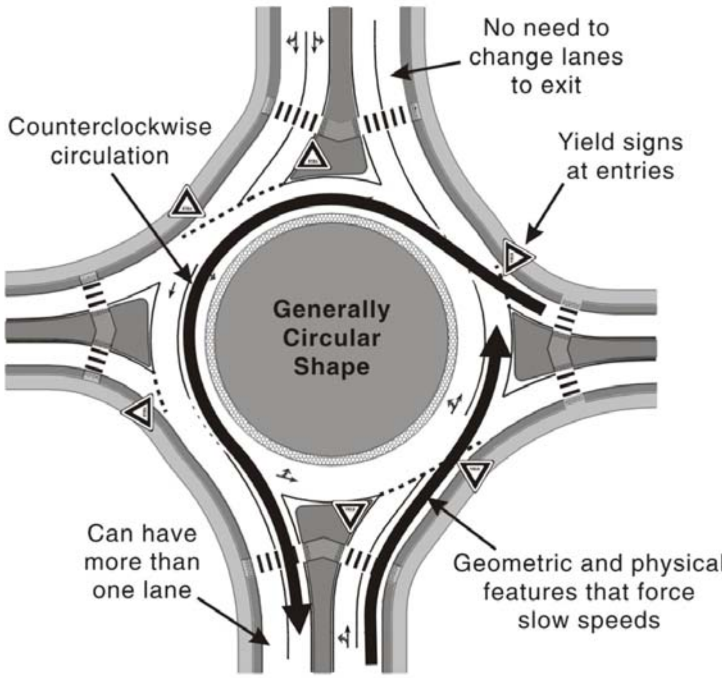
3.4 HIGHWAY CAPACITY ANALYSIS AND TRAFFIC CONTROL

The criteria, procedures and guidance for highway capacity analysis used on all Department projects shall comply with capacity concepts presented in the *HCM*. Where traffic signal controls may be required for intersections, the warrants for their installation shall be governed by the sources of reference listed in Chapter 2, Section 2.18.A.

3.5 ROUNDABOUTS

A. Introduction. 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 are distinctly different from other forms of circular intersections (rotaries, signalized traffic circles, etc.). Figure 3.1 illustrates the key characteristics of a modern roundabout.

Figure 3.1: Key Roundabout Characteristics



Modern roundabouts have demonstrated safety and operational benefits and should be considered as an alternative for intersection improvement projects. They can 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 or aesthetic features.

This section is not intended to be an exhaustive review of roundabouts, but rather is meant to emphasize the key principles related to roundabouts. For detailed guidance, the user should refer to National Cooperative Highway Research Program (NCHRP) Report 672, *Roundabouts: An Informational Guide, Second Edition*. A principle-based approach to design is recommended, noting that each roundabout will have its own unique design based on the context and goals of a particular project. There will never be a "cookie-cutter" design for a roundabout.

When planning intersection improvements, a variety of improvement alternatives should be evaluated, including roundabouts, to determine the most appropriate alternative.

B. Planning. At the planning stage, there are a variety of possible reasons or goals for considering a roundabout at a particular intersection, including but not limited to safety, operations, access management, and aesthetics. Questions to consider once a roundabout is identified as feasible include:

- Is a roundabout appropriate for this location?
- How big should it be or how many lanes are required?
- What sort of impacts are expected?
- What public education and outreach is appropriate?
- How can the construction phasing accommodate the existing traffic?

NCHRP Report 672, Chapter 1 presents a range of roundabout categories and suggested typical daily service volume thresholds below which four-leg roundabouts are expected to operate, without requiring a detailed capacity analysis. Chapter 2 introduces roundabout performance characteristics, including comparisons with other forms of intersection control. By confirming that there is a reason to believe that a roundabout is feasible and the best alternative, these planning activities avoid expending unnecessary effort required in more detailed steps.

The initial steps in planning for a roundabout are to clarify the objectives and understand the context in which the roundabout is being considered. The next step is to specify a preliminary configuration. This identifies the minimum number of lanes required on each approach and thus which type of roundabout is the most appropriate to use a basis for design: mini, single-lane, or multilane. Note that mini-roundabouts are not recommended for use on State roadways.

Figure 3.2 summarizes and compares some fundamental design and operational elements for each of the three roundabout categories.

Figure 3.2: Roundabout Category Comparison

Design Element	**Mini-Roundabout**	**Single-Lane Roundabout**	**Multilane Roundabout**
Desirable maximum entry design speed	15 to 20 mph (25 to 30 km/h)	20 to 25 mph (30 to 40 km/h)	25 to 30 mph (40 to 50 km/h)
Maximum number of entering lanes per approach	1	1	2-3
Typical inscribed circle diameter	45 to 90 ft (13 to 27 m)	90 to 180 ft (27 to 55 m)	150 to 300 ft (46 to 91 m)
Central island treatment	Fully traversable	Raised (may have traversable apron)	Raised (may have traversable apron)
Typical daily service volumes on 4-leg roundabout below which may be expected to operate without requiring a detailed capacity analysis (veh/day)*	Up to approximately 15,000	Up to approximately 25,000	Up to approximately 45,000 for two-lane roundabout

*Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.

Figure 3.3 outlines many of the considerations that may need to be investigated prior to deciding whether to implement a roundabout at an intersection. Note that this is not meant to be all-encompassing, nor is it intended to reflect minimum requirements. Rather, it is intended to provide a general framework for the steps typically necessary to determine feasibility.

Figure 3.3: Planning Framework

Consider the Context

- Is this the first roundabout in a community or are roundabouts already well established?
- Are there regional policy constraints that must be addressed?
- Are there site-specific and/or community impact reasons why a roundabout of any size would not be a good choice?
- What are the site constraints?
- What is the potential for future growth within the vicinity?
- What is the current or desired environment for non-motorized modes?

Clarify the Objectives

- Clarifying the objective for considering a roundabout at the beginning of the process may help to better guide the selection of an appropriate treatment and the need for additional information.
- Is the improvement needed from an operational or safety perspective? Both?
- Is the improvement desired to control vehicle speeds?
- Is the improvement intended purely for aesthetic reasons?

Determine preliminary lane numbers based on capacity requirements

Section 3.5 of NCHRP Report 672 provides a useful methodology for obtaining a basic understanding of the required number of lanes. Chapter 4 provides additional detail on operational analysis.

Determine the space requirements

How big does it need to be and is there enough right-of-way to build it? This is a potential rejection point in some locations due to potential cost or the additional administrative complications caused by right-of-way acquisition. Section 3.5 provides additional information for evaluating the space requirements based upon the required number of lanes.

Compare to other alternatives

Make appropriate comparisons with alternative intersection treatments

Assess Other Impacts

Are there other impacts that may occur from the roundabout, such as:

- Utilities;
- Existing buildings/structures;
- Business access; and
- Sensitive environmental areas.

Assess Other Opportunities

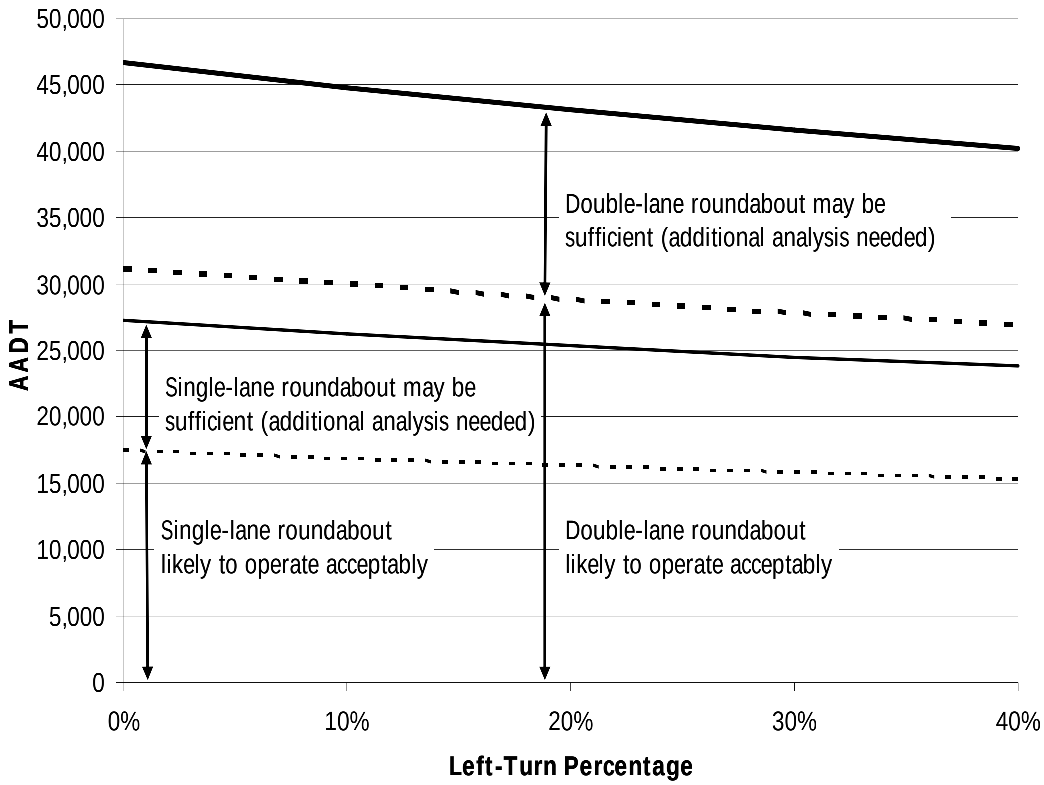
Does the roundabout offer any opportunities to improve existing conditions, such as:

- Improve access management;
- Stimulate redevelopment;
- Improve safety; and
- Improve oddly shaped intersection or other poor geometric condition.

Is a roundabout feasible and/or the preferred alternative worthy of advancing for additional analysis and design?

High-level planning often requires an initial screening of alternatives where turning-movement data may not be available but Annual Average Daily Traffic (AADT) volumes are known. Figure 3.4 presents ranges of AADT volumes to identify scenarios under which single-lane and two-lane roundabouts may perform adequately.

Figure 3.4: Planning-Level Daily Intersection Volumes



If the volumes fall within the ranges identified in Figure 3.4 where "additional analysis is needed," a single-lane or two-lane roundabout may still function quite well, but a closer look at the actual turning-movement volumes during the design hour is required. The procedure for such analysis is presented in the *HCM*, Chapter 21.

To help analyze the feasibility of using a roundabout at a particular location, PennDOT has developed a Roundabout Key Considerations Checklist, which can be found in Chapter 3, Appendix A.

1. Economic Evaluation. An economic evaluation should be performed when considering various types of intersection control. At a minimum, cost estimates should include construction costs, engineering and design fees, land acquisition, and maintenance costs over the anticipated life of the control form. Benefits may include reduced crash rates and severity, as well as reduced delay, stops, fuel consumption, and emissions. NCHRP Report 672, Section 3.8 provides a cost-benefit methodology for comparing intersection alternatives.

2. Public Involvement. Public acceptance of roundabouts has often been found to be one of the biggest challenges facing agencies planning the first roundabout in an area. Without the benefit of explanation or first-hand experience and observation, the public is likely to incorrectly associate roundabouts with older style traffic circles or rotaries. Also, the public will often have a natural hesitation or resistance to changes in their driving behavior and driving environment. Refer to Publication 295, *Project Level Public Involvement Handbook*.

PennDOT has produced brochures aimed at providing information to a variety of audiences. These educational brochures are available as separate publications (Publication 578, *Single-Lane Roundabout - General Information and Driving Tips for Motorists*; Publication 579, *Single-Lane Roundabout - General Information* *for Bicyclists and Pedestrians*; and Publication 580, *Multi-Lane Roundabout - General Information and Driving Tips for Motorists*). Two of the brochures provide information on how to navigate a roundabout, one for a single-lane and the other for a multilane roundabout. The third brochure deals with similar topics, but as they relate to single-lane roundabouts from the perspective of pedestrians and bicyclists. For additional information regarding public education and outreach, please refer to NCHRP Report 672, Section 3.8.

C. Operations. The *HCM* incorporates the roundabout operational analysis model developed in NCHRP Report 572, *Roundabouts in the United States* and allows for the evaluation of existing or planned single-lane and multilane roundabouts (with up to two circulating lanes). In cases where the existing or planned roundabout has more than two circulating lanes, FHWA approved deterministic software (such as SIDRA Intersection, Arcady or RODEL) or simulation (such as VISSIM or PARAMICS) is needed to evaluate the roundabout operations. Whenever deterministic software is utilized to evaluate a roundabout, the user shall ensure that it is calibrated to local driver behavior and effective geometry, and adjustments should be made to account for lane configurations or system effects.

Figure 3.5 displays situations in which the various roundabout analysis tools are appropriate.

Figure 3.5: Selection of Analysis Tool

Application	Typical Outcome Desired	Input Data Available	Potential Analysis Tool
Planning-level sizing	Number of lanes	Traffic volumes	NCHRP Report 672, Chapter 3, *HCM*, deterministic software
Preliminary design of roundabouts with up to two lanes	Detailed lane configuration	Traffic volumes, geometry	*HCM*, deterministic software
Preliminary design of roundabouts with three lanes and/or with short lanes/flared designs	Detailed lane configuration	Traffic volumes, geometry	Deterministic software
Analysis of pedestrian treatments	Vehicular delay, vehicular queuing, pedestrian delay	Vehicular traffic and pedestrian volumes, crosswalk design	*HCM*, deterministic software, simulation
System analysis	Travel time, delays and queues between intersections	Traffic volumes, geometry	*HCM*, simulation
Public involvement	Animation of no-build conditions and proposed alternatives	Traffic volumes, geometry	Simulation

For planning purposes, a volume-to-capacity (v/c) ratio of 0.85 or less is targeted for each approach leg. However, higher v/c ratios may be acceptable for future conditions depending upon the corresponding delay and queue prediction. When the *HCM* methodology predicts a v/c ratio greater than 0.85, but less than 0.95, other deterministic software methodologies or simulation should be utilized to verify the roundabout will operate acceptably. If the projected result produces a v/c ratio greater than 0.95, other alternatives, such as revised lane configurations or different intersection control types should be evaluated.

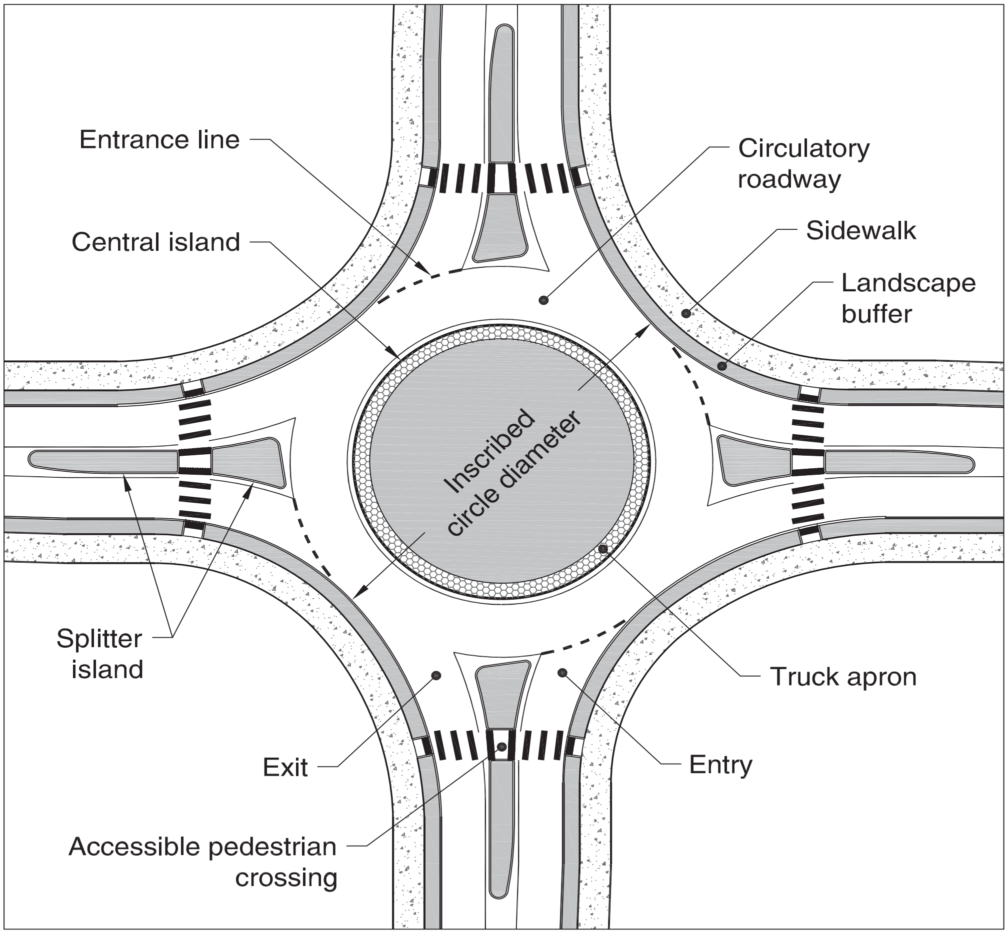
Consistent with the *HCM*, level of service (LOS) thresholds for roundabouts have been established using control delay, and are the same as defined for stop-controlled intersections.

D. Safety. Roundabouts are a proven safety measure due to their minimal conflict points and speed control. In particular, roundabouts can provide the most safety benefits when used at intersections with historically high crash rates, roads with historical problem of excessive speeds, and at intersections with more than four legs or with difficult skew angles. In order to achieve the full safety benefits of a roundabout, a principle-based design process including the proper application of performance checks should be utilized. The subsequent section discusses the principles of roundabout design.

Further information pertaining to roundabout safety is found in NCHRP Report 672, Chapter 5.

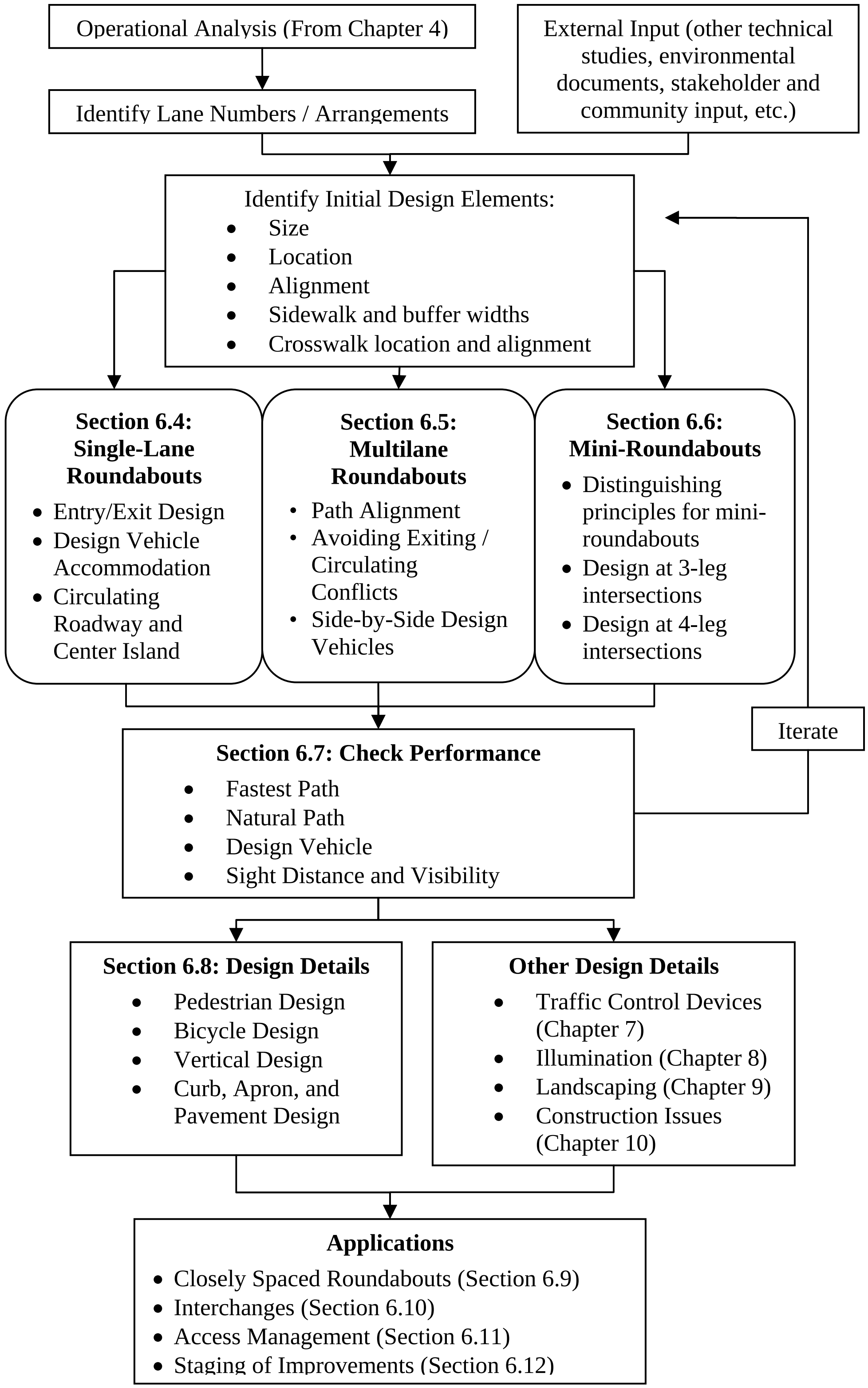
E. Design. Roundabout design follows a principles based design process. This process is focused on achieving and balancing several key objectives. Figure 3.6 displays the basic geometric elements of a roundabout.

Figure 3.6: Basic Geometric Elements of a Roundabout



The principles and objectives of the geometric design of roundabouts are achieved using the general design process shown in Figure 3.7. In particular, performance checks are an important element of the design process and guidance found in the NCHRP Report 672, Section 6.7 should be followed to ensure the performance checks are completed appropriately, including sight distances.

Figure 3.7: General Roundabout Design Process *



* Chapter and Section references are from NCHRP Report 672.

Roundabout projects should be classified as Moderately Complex or Major Projects. Therefore, Design Field View submissions are required for review and approval by the Bureau of Project Delivery. The need for a Final Design Office Meeting will be made on a project by project basis by the Bureau of Project Delivery or the FHWA as applicable.

Since modern roundabouts are somewhat new to Pennsylvania and much of its design community, the use of a Peer Review is highly recommended, especially for roundabouts being designed in-house or by design consultants with limited roundabout design experience.

1. Design Vehicle. The recommended design vehicle is an AASHTO WB-67 for roundabouts on state routes and interchange ramp terminals. 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. The use of other design vehicles will be made on site specific considerations, usually related to truck restrictions.

2. Splitter Islands. Splitter islands should be incorporated into all roundabouts, and generally at least 50 ft in length, although specific situations or design constraints may necessitate shorter splitter islands. Splitter islands should be a minimum of 6 ft wide at crosswalk locations to adequately provide 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. A more detailed discussion of splitter island geometry for high-speed approaches can be found in NCHRP Report 672, Section 6.8.5.3. See NCHRP Report 672, Sections 6.4.1 and 6.5.5 for more information regarding general design details for splitter islands.

3. Pedestrian Design Considerations. Pedestrians should generally be considered and accommodated at all roundabout intersections. Pedestrian accommodations typically include cut-throughs on splitter islands, two-stage perpendicular crossings, curb ramps and accessibility features such as detectable warning surfaces. In some situations (such as rural intersections), pedestrian accommodations may not be necessary; however, it is recommended that such splitter islands be designed to be wide enough to accommodate potential future crossings. Current Draft Public Right-of-Way Accessibility Guidelines (PROWAG) require pedestrian-activated signals at all multilane roundabout entries and exits as well as detectable edging where pedestrian crossings are not intended. Further information for the design of pedestrian accommodations for roundabouts is provided in NCHRP Report 672, Section 6.8.1. Also, refer to Chapter 6 for ADA compliance.

4. Bicycle Design Considerations. Where bicycle lanes are used on approach roadways, they should be terminated in advance of roundabouts using tapers to merge cyclists into traffic for circulation with other vehicles. For bike routes where cyclists remain within the traffic lane, it can be assumed that cyclists will continue through the roundabout in the travel lane. At multilane roundabouts consider providing bicycle ramps to allow bicyclists to exit the roadway onto the sidewalk and travel as pedestrians. Ramps should not normally be used at urban, single-lane roundabouts except where the complexity of the roundabout would make circulating like other vehicles more challenging for bicyclists. Further information for the design of bicycle accommodations for roundabouts is provided in NCHRP Report 672, Section 6.8.2.

5. High Speed Approaches. The primary safety concern in rural locations where approach speeds are high is to make drivers aware of the roundabout with sufficient advance 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. Further information on treatments for high speed approaches is provided in NCHRP Report 672, Section 6.8.5 and 7.4.4.

6. Drainage. Drainage structures should normally be placed on the outer curb line of the roundabout and upstream of crosswalks, but should not be placed in the entry and exit radii of the approaches. Drainage structures located on the outer curb line of the circulatory roadway shall be designed to withstand vehicle loading. Maximum gutter spreads should match the requirements for the approach roadways. Refer to NCHRP Report 672, Section 6.8.7 and Chapter 13 for a discussion of vertical alignment considerations which includes drainage.

7. Curbing. Concrete curb, as specified in Publication 72M, *Roadway Construction Standards*, should be used along the outside edge of all roundabouts which includes the entry radius, the circulatory roadway, and the exit radius, and for the splitter islands. For rural roadways it is desirable to extend outside curbing along approaches to the length of the required deceleration distance to the roundabout. A truck apron curb should be used between the truck apron and the circulatory roadway. Further information on the principles of using curbs on roundabouts is provided in NCHRP Report 672, Sections 6.8.7.4 and 6.8.8.1.

8. Pavement. Asphalt or dark colored concrete is the recommended material for the circulatory roadway to differentiate it from the concrete truck apron. At locations where a single-lane roundabout is constructed with the intention of later conversion to a multilane roundabout, asphalt pavement should be considered due to the need to redo the concrete jointing during conversion. Sidewalks should be constructed with a different texture and/or color than the truck apron to differentiate the pedestrian path and to deter pedestrians from using the truck apron. Further information on the design of pavements for roundabouts is provided in NCHRP Report 672, Section 6.8.8.

9. Staging of Improvements. 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 where a single-lane roundabout is expected to be sufficient for ten years or more from the date the roundabout would open to traffic.

To allow for this future expansion, the right-of-way and geometric needs of both the single-lane and multilane roundabout should be acquired. For further information refer to NCHRP Report 672, Section 6.12.

10. Traffic Control Devices. Traffic control devices for roundabouts shall be in accordance with the *MUTCD* and Publication 236, *Handbook of Approved Signs*. NCHRP Report 672, Chapter 7 provides a helpful presentation of the application of traffic control devices to roundabouts.

11. Illumination. Lighting of roundabouts serves two main purposes:

a. It provides visibility from a distance for users approaching the roundabout; and

b. It provides visibility of the key conflict areas to improve users' perception of the layout and visibility of other users within the roundabout.

For additional guidance and details regarding lighting layouts, illuminance levels, and other considerations, please refer to NCHRP Report 672, Chapter 8.

F. Other Considerations.

1. Landscaping. A realistic maintenance program should be considered in the design of landscape features, including identification of the responsible party for future maintenance, water supply, drainage, and expected growth of plantings. Maintenance Agreements with the Municipality should be setup as early as possibly during project development.

Landscaping must not reduce sight distances below minimum criteria. For a more detailed discussion of landscaping design consideration and best practices, please refer to NCHRP Report 672, Chapter 9.

2. Construction and Maintenance. Roundabouts can be constructed under three types of traffic conditions:

- With all traffic diverted away from the work area,
- With some traffic diverted, or
- Under full traffic.

The guiding principle is to minimize staging and provide large sections of the project to construct during each construction stage. This will increase quality of construction, reduce driver confusion, and reduce construction duration and cost. Generally, diverting or detouring as much traffic from the intersection as possible is the most desirable option. For a more detailed discussion of construction staging under all three types of conditions, please refer to NCHRP Report 672, Section 10.3.

3. Snow Removal. For a discussion of snow removal considerations and best practices, please refer to NCHRP Report 672, Section 10.7.2.

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