Intersection Geometric Design

Course No: C04-033
Credit: 4 PDH

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INTRODUCTION

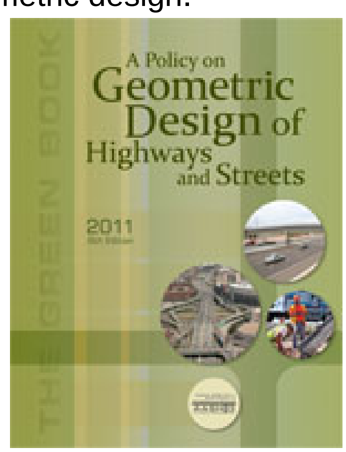
This course summarizes and highlights the geometric design process for modern roadway intersections. The contents of this document are intended to serve as guidance and not as an absolute standard or rule.

When you complete this course, you should be familiar with the general guidelines for at-grade intersection design. The course objective is to give engineers and designers an in-depth look at the principles to be considered when selecting and designing intersections.

Subjects include:

1. *General design considerations – function, objectives, capacity*
2. *Alignment and profile*
3. *Sight distance – sight triangles, skew*
4. *Turning roadways – channelization, islands, superelevation*
5. *Auxiliary lanes*
6. *Median openings – control radii, lengths, skew*
7. *Left turns and U-turns*
8. *Roundabouts*
9. *Miscellaneous considerations – pedestrians, traffic control, frontage roads*
10. *Railroad crossings – alignments, sight distance*

For this course, Chapter 9 of **A Policy on Geometric Design of Highways and Streets** (also known as the "Green Book") published by the American Association of State Highway and Transportation Officials (AASHTO) will be used primarily for fundamental geometric design principles. This text is considered to be the primary guidance for U.S. roadway geometric design.



This document is intended to explain some principles of good roadway design and show the potential trade-offs that the designer may have to face in a variety of situations, including cost of construction, maintenance requirements, compatibility with adjacent land uses, operational and safety impacts, environmental sensitivity, and compatibility with infrastructure needs.

Geometric design is the assembly of the fundamental three-dimensional features of the highway that are related to its operational quality and safety. Its basic objective is to provide a smooth-flowing, crash-free facility. Geometric roadway design consists of three main parts: **cross section** (lanes and shoulders, curbs, medians, roadside slopes and ditches, sidewalks); **horizontal alignment** (tangents and curves); and **vertical alignment** (grades and vertical curves). Combined, these elements provide a three-dimensional layout for a roadway.

Effective geometric design transmits knowledge from research and operational experience to the user. It reflects both human and vehicular characteristics and capabilities.

The practice of geometric design will always be a dynamic process with a multitude of considerations: driver age and abilities; vehicle fleet variety and types; construction costs; maintenance requirements; environmental sensitivity; land use; aesthetics; and most importantly, societal values.

Despite this dynamic character, the primary objective of good design will remain as it has always been – **to provide a safe, efficient and cost-effective roadway that addresses conflicting needs or concerns.**

INTERSECTIONS

Intersections are unique roadway elements where conflicting vehicle streams (and sometimes non-motorized users) share the same space. This area encompasses all modes of travel including:

- pedestrian
- bicycle
- passenger vehicle
- truck
- transit

Intersections also encompass auxiliary lanes, medians, islands, sidewalks and pedestrian ramps. These may further heighten the accident potential and constrain the operational efficiency and network capacity of the urban street system. However, *the main objective of intersection design is to facilitate the roadway user and enhance efficient vehicle movement.* The need to provide extra time for drivers to perceive, decide, and navigate through the intersection is central to intersection design controls and practices.

Designing to accommodate the appropriate traffic control are critical to good intersection design. Warrants and guidelines for selection of appropriate intersection control (including stop, yield, all-stop, or signal control) may be found in the MUTCD.

Basic Elements of Intersection Design:

Human Factors: Driver habits, decision ability, driver expectancy, decision/reaction time, paths of movement, pedestrian characteristics, bicyclists

Traffic Considerations: Roadway classifications, capacities, turning movements, vehicle characteristics, traffic movements, vehicle speeds, transit, crash history, bicycles, pedestrians

Physical Elements: Abutting properties, vertical alignments, sight distance, intersection angle, conflict area, speed-change lanes, geometric design, traffic control, lighting, roadside design, environmental factors, crosswalks, driveways, access management

Economic Factors: Improvement costs, energy consumption, right-of-way impacts

A range of design elements are available to achieve the functional objectives, including horizontal and vertical geometry, left- and right-turn lanes, channelization, etc.

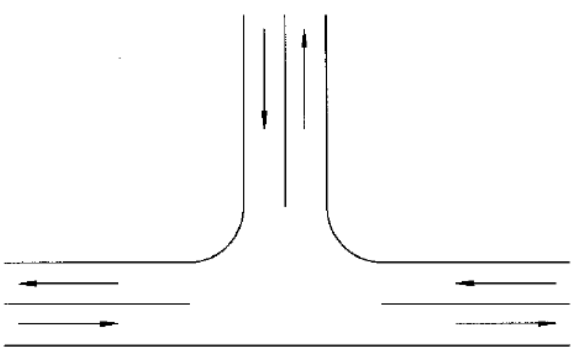
Level of service analysis and roadway capacity are critical considerations in intersection design. Capacity is determined by constraints at intersections. Vehicle turns at intersections interrupt traffic flow and reduce levels of service.

AASHTO defines intersection capacity as “the maximum hourly rate at which vehicles can reasonably be expected to pass through the intersection under prevailing traffic, roadway, and signalization conditions”. The Highway Capacity Manual (HCM) provides various analysis techniques for comparing different conditions at intersections.

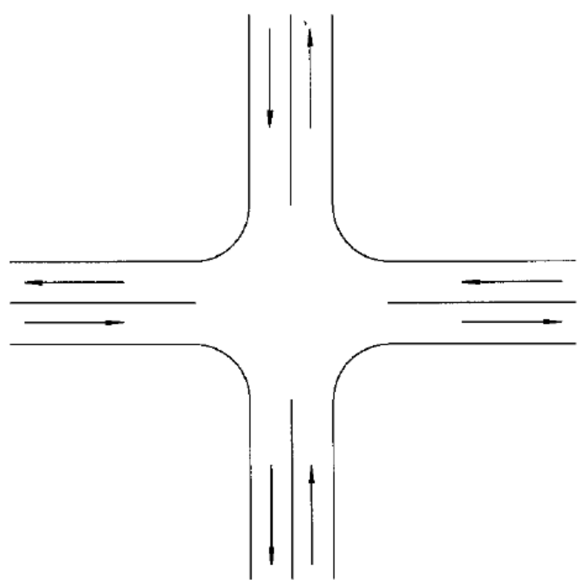
A well-designed intersection is clear to the driver with design dimensions supporting operational requirements, traffic control devices functioning as intended, and nonmotorized vehicle users operating safely through the intersection.

Basic Types of Intersections:

- Three-leg (T)
- Four-leg
- Multi-leg
- Roundabout



THREE-LEG INTERSECTION



FOUR-LEG INTERSECTION

These types may vary based on scope, shape, flaring (for auxiliary lanes), and channelization (separation/regulation of conflicting traffic).

Variables for determining the type of intersection to be used at a location include:

- Topography
- Traffic characteristics
- Number of legs
- Type of operation
- Roadway character

Three-leg

The typical three-leg intersection configuration contains normal paving widths with paved corner radii for accommodating design vehicles. The angle of intersection typically ranges from 60 to 120 degrees.

Auxiliary lanes (left or right-turn lanes) may be used to increase roadway capacity and provide better operational conditions.

Channelization may be achieved by increasing corner radii to separate a turning roadway from the normal traveled ways by an island.

Four-leg

Many of the three-leg intersection design considerations (islands, auxiliary lanes, channelization, etc.) may also be applied to four-leg intersections.

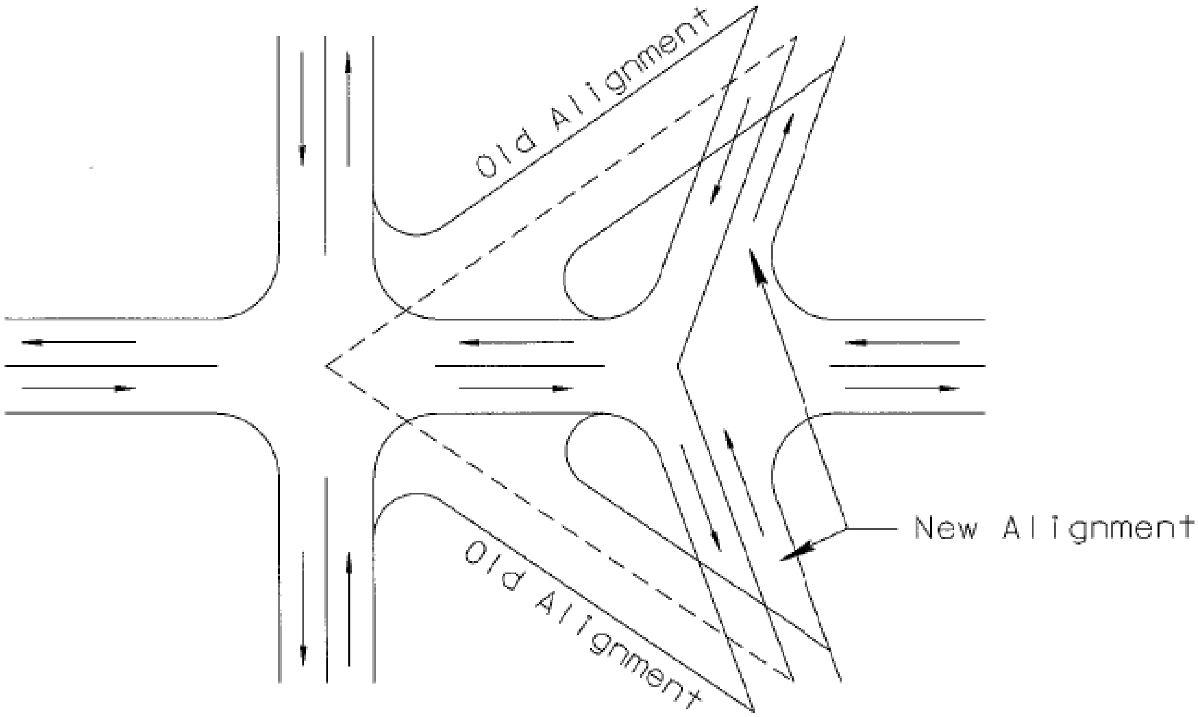
Multi-leg

Intersection designs with multiple legs (5 or more) should not be used unless there is no other viable alternative. If multi-legs must be used, a common paved area where all legs intersect may be desirable for light traffic volumes and stop control.

Operational efficiency can also be increased by removing major conflicting movements.

Multi-leg Reconfiguration Options:

- Realigning one or more legs
- Combining traffic movements at subsidiary intersections
- Redesigning as a roundabout
- Converting legs to one-way operation



MULTILEG INTERSECTION REALIGNMENT

Alignment and Profile
Roadway geometry influences its safety performance. This has been confirmed by research showing that roadway factors are the second most contributing factor to roadway crashes. In the U.S., the average crash rate for horizontal curves is about three times that of other highway segments.

Conflicts tend to occur more frequently on roadways with sudden changes in their character (i.e. sharp curves at the end of long tangent roadway sections). The concept of design consistency compares adjacent road segments and identifies sites with changes that might appear sudden or unexpected. Design consistency analysis can be used to show the decrease in operating speed at a curve.

The **horizontal** and **vertical geometries** are the most critical design elements of any roadway. While most designers normally design the horizontal and then the vertical alignment, these should be coordinated to enhance vehicle operation, uniform speed, and facility appearance without additional costs (checking for additional sight distance prior to major changes in the horizontal alignment; revising design elements to eliminate potential drainage problems; etc.). Computer-aided design (CAD) is the most popular method used to facilitate the iterative three-dimensional design and coordinate the horizontal and vertical alignments.

The location of a roadway may be determined by traffic, topography, geotechnical concerns, culture, future development, and project limits. Design speed limits many design values (curves, sight distance) and influences others (width, clearance, maximum gradient).

Intersecting roads should be aligned at approximate right angles in order to reduce costs and potential crashes. Intersections with acute angles need larger turning areas, limit visibility, and increase vehicle exposure time. Although minor road intersections with major roads are desired to be as close to 90 degrees as practical, some deviation is allowable – angles of 60 degrees provide most of the benefits of right angle intersections (reduced right-of-way and construction costs).

Vertical grades that impact vehicle control should be avoided at intersections. Stopping and accelerating distances calculated for passenger vehicles on 3 percent maximum grades differ little from those on the level. Grades steeper than 3 percent may require modifications to different design elements to match similar operations on level roadways. Therefore, **avoid grades for intersecting roads in excess of 3 percent within intersection areas** unless cost prohibitive, then a maximum limit of 6 percent may be permissible.

AASHTO provides the following general design guidelines regarding horizontal and vertical alignment combinations:

- Vertical and horizontal elements should be balanced. A design which optimizes safety, capacity, operation, and aesthetics within the location's topography is desirable.

- Horizontal and vertical alignment elements should coincide to provide a pleasing facility for roadway traffic.

- Avoid sharp horizontal curves near the top of a crest vertical curve or near the low point of a sag vertical curve. This condition may violate driver expectations. Using higher design values (well above the minimum) for design speed can produce suitable designs.

- Horizontal and vertical curves should be as flat as possible for intersections with sight distance concerns.

- For divided roadways, it may be suitable to vary the median width or use independent horizontal/vertical alignments for individual one-way roads.

- Roadway alignments should be designed to minimize nuisance in residential areas. Measures may include: depressed facilities (decreases facility visibility and noise), or horizontal adjustments (increases buffer zones between traffic and neighborhoods).

- Horizontal and vertical elements should be used to enhance environmental features (parks, rivers, terrain, etc.). The roadway should lead into outstanding views or features instead of avoiding them where possible.

Exception
Long tangent sections for sufficient passing sight distance may be appropriate for two-lane roads in need of passing sections at frequent intervals.

INTERSECTION SIGHT DISTANCE

Intersection sight distance is the length of roadway along the intersecting road for the driver on the approach to perceive and react to the presence of potentially conflicting vehicles. Drivers approaching intersections should have a clear view of the intersection with adequate roadway to perceive and avoid potential hazards. Sight distance should also be provided to allow stopped vehicles a sufficient view of the intersecting roadway in order to enter or cross it. Intersection sight distances that exceed stopping sight distances are preferable along major roads to enhance traffic operations. Methods for determining intersection sight distances are based on many of the same principles as stopping sight distance.

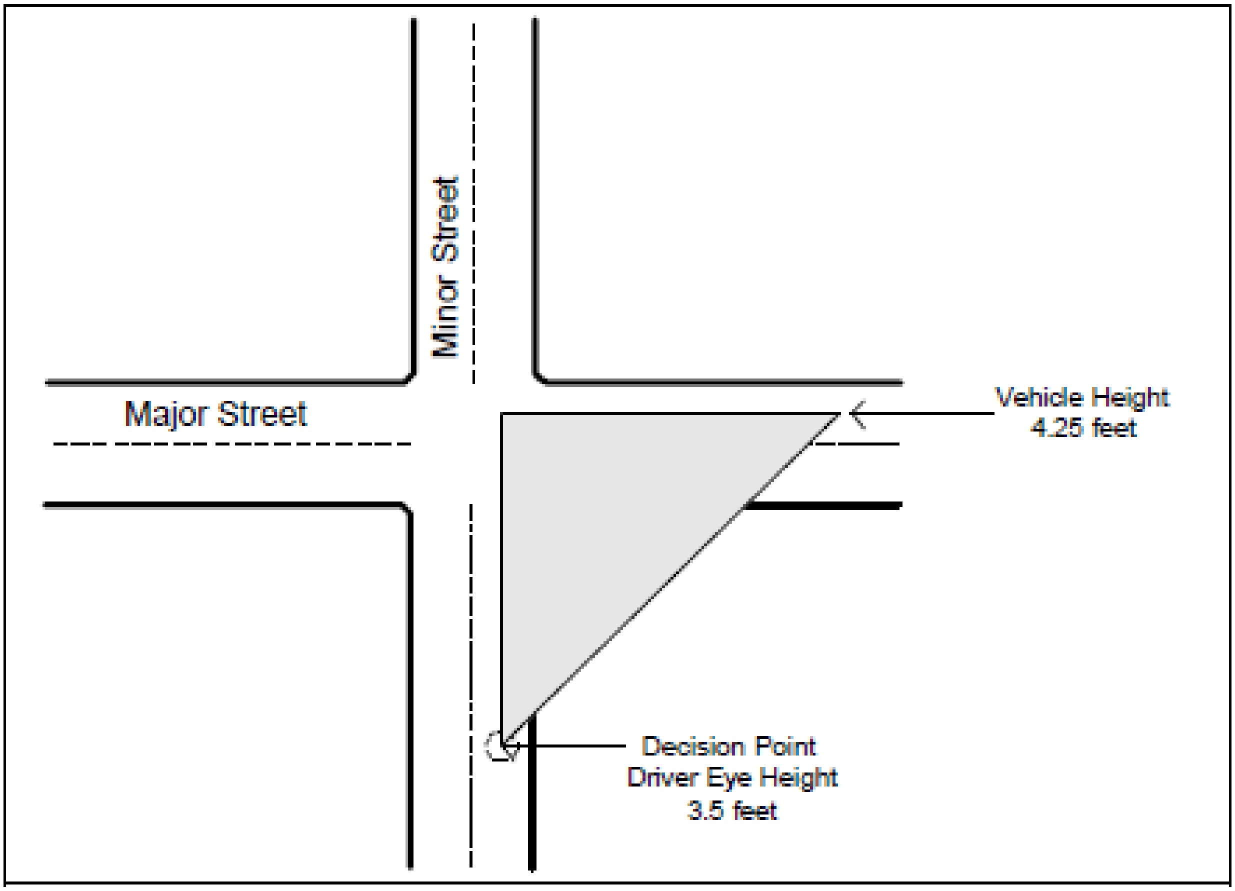


Figure 4.3. Heights Pertaining to Sight Triangles

(Source: CTRE – Iowa State University)

Sight triangles are areas along intersection approach legs that should be clear of obstructions that could block a driver's view. The dimensions are based on driver behavior, roadway design speeds, and type of traffic control. Object height (3.50 feet above the intersecting roadway surface) is based on vehicle height of **4.35 feet** (representing the 15th percentile of current passenger car vehicle heights). The height of the driver's eye is typically assumed to be 3.50 feet above the roadway surface.

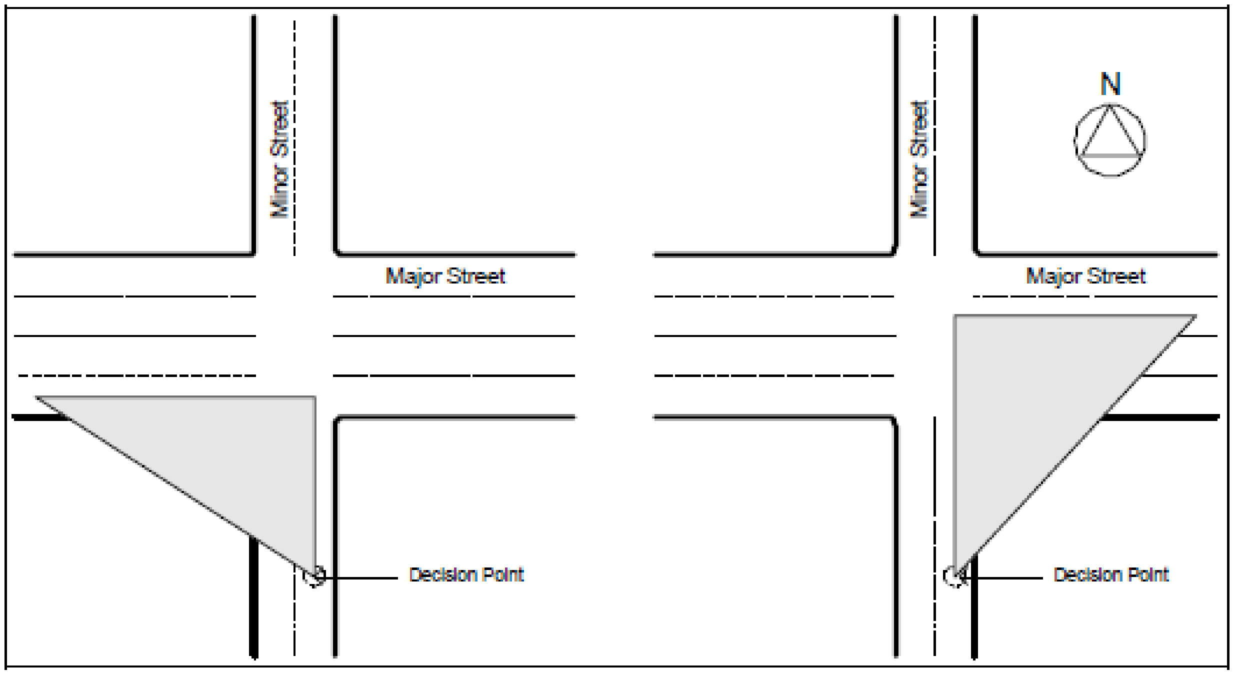


Figure 4.1. Approach Sight Triangles

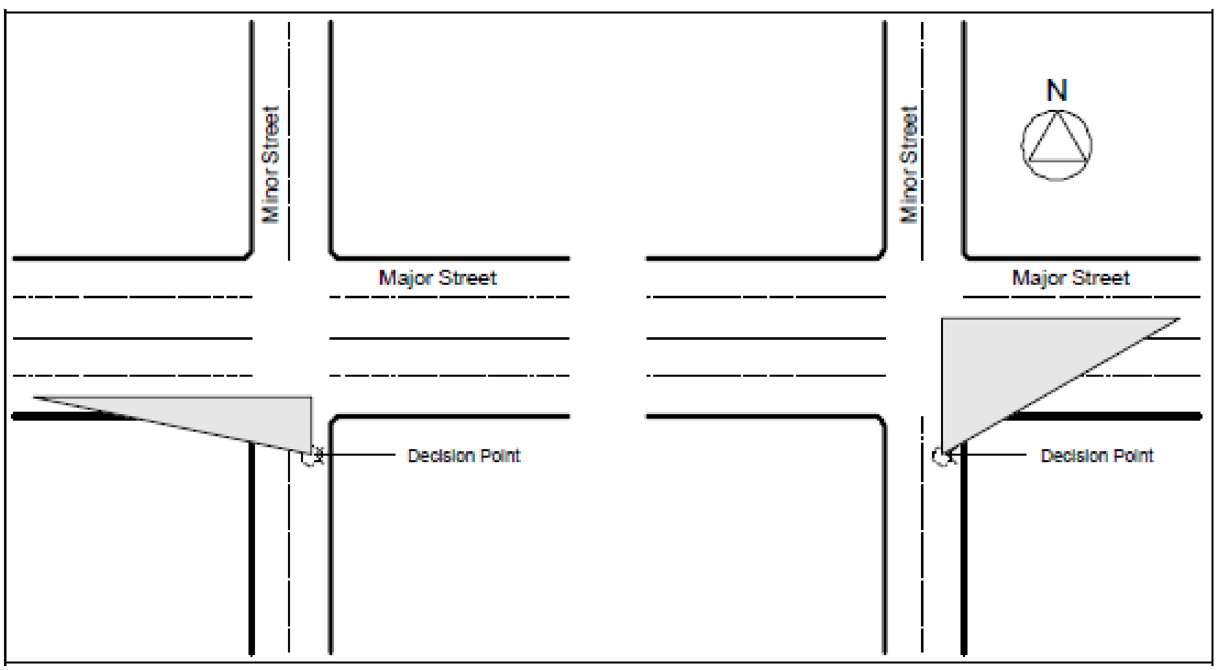


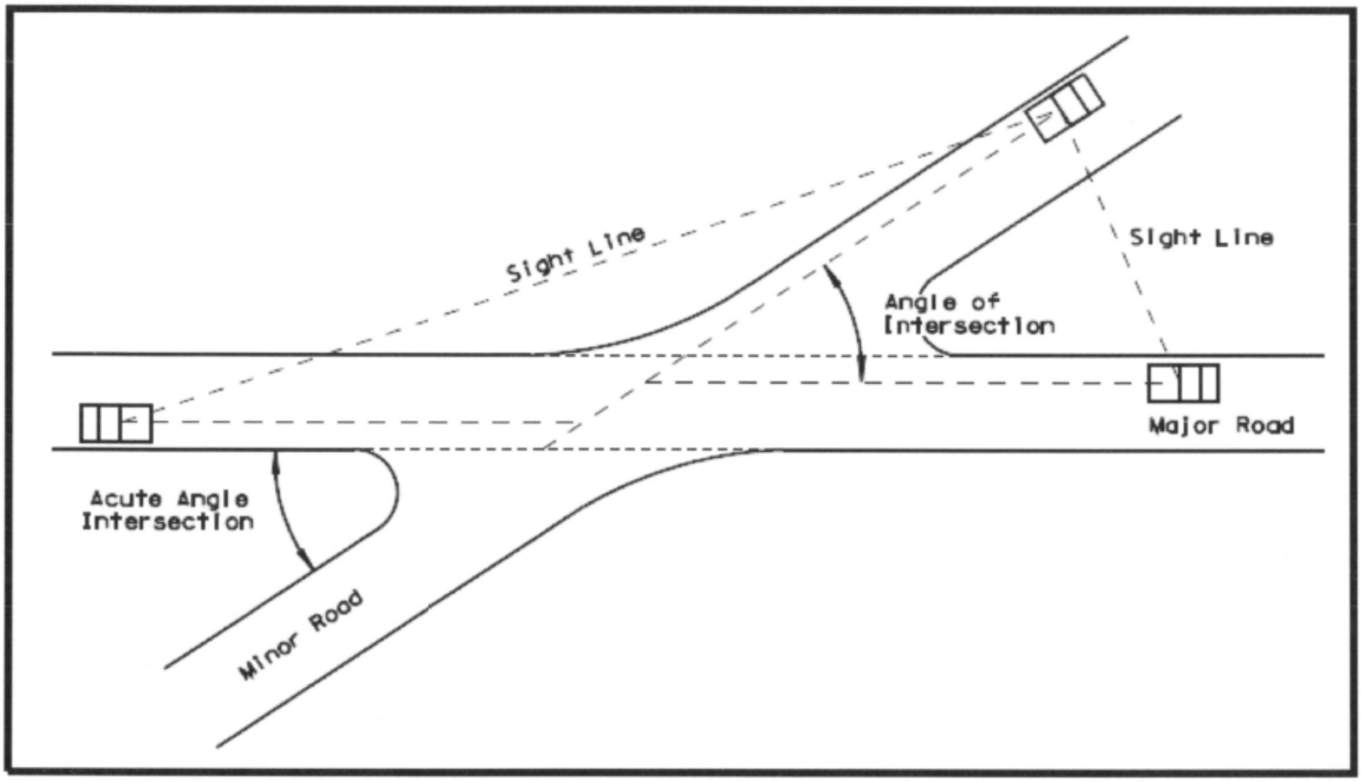
Figure 4.2. Departure Sight Triangles

Source: CTRE – Iowa State University

Recommended sight triangle dimensions vary 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

Section 9.5.3 of the AASHTO "Green Book" presents specific procedures for determining sight distances in each case.



When possible, crossing roadways should intersect at an angle of 90 degrees, and not less than 75 degrees. Intersections with severe skew angles (60 degrees or less) may require adjustment of factors for determining intersection sight distance since they are prone to operational or safety problems.

TURNING ROADWAYS & CHANNELIZATION

Turning roadways are integral parts of roadway intersection design. Their widths are dependent on the types of vehicles and the turning volumes (typically right-turning traffic).

Types of Right-Turning Roadways at Intersections:

- Minimum edge-of-traveled-way design
- Design with corner triangular island
- Free-flow design with simple or compound radii

Corner radii should be based on the minimum turning path of design vehicles at locations requiring minimum space (i.e. unchannelized intersections).

Design Vehicles

P	Passenger car
SU-30	Single-unit truck
SU-40	Single-unit truck (three axle)
CITY-BUS	City transit bus
WB-40	Intermediate semitrailer combination
WB-62 & 65	Interstate semitrailers
WB-92D	Rocky Mountain double semitrailer/trailer
WB-100T	Triple semitrailer/trailers combination
WB-109D	Turnpike double combination
S-BUS36	Conventional school bus
WB-67D	Trucks, articulated buses, motor homes, motor coaches, passenger cars pulling trailers or boats

AASHTO "Green Book" Tables 9-15 and 9-16 show minimum edge-of-traveled-way design values for design vehicles. Figures 2-13 through 2-23 illustrate satisfactory minimum designs – these accommodate the sharpest turns for particular design vehicles. Minimum designs are better suited for sites with low turn speeds, low turn volumes, and high property values. Minimum edge-of-traveled-way designs for turns may be based on turning paths for passenger car, single-unit ruck, and semitrailer combination design vehicles.

Passenger car (P) design vehicles are used for parkway intersections requiring minimum turns, local/major road intersections with occasional turns; and intersections of two minor roads with low volumes. Single-unit truck (SU-30) is preferable if conditions permit. Minimum edge design is typically used since it better fits the design vehicle path.

Single-unit truck (SU-30 and SU-40) vehicles are recommended for minimum edge-of-traveled-way design for rural highways. Crucial turning movements (major highway, large truck volume, etc.) may require speed-change lanes and/or larger radii. Minimum travel way designs for single-unit trucks will also accommodate city transit buses.

Semitrailer combination (WB series) design vehicles are used at locations with repetitive truck combination turns. An asymmetrical setup of three-centered compound curves is better suited for sites with large volumes of smaller truck combinations. Semitrailer combination designs may need larger radii and corner triangular islands due to their large paved areas.

Corner radii for urban arterial intersections should satisfy - driver needs, available right-of-way, angle of turn, pedestrians using the crosswalk, number/width of traffic lanes, and posted speeds.

Channelization

Channelization uses pavement markings and/or traffic islands to define definite travel paths for conflicting traffic. Appropriate channelization not only increases capacity and guides motorists but may also produce significant crash reductions and operational efficiencies.

Design Controls for Channelized Intersections:

- Type of design vehicle
- Crossroads cross sections
- Projected traffic volumes
- Number of pedestrians
- Vehicle speed
- Bus stop locations
- Traffic control devices

Principles of Channelization:

- Do not confront motorists with more than one decision at a time
- Avoid turns greater than 90 degrees or sharp/sudden curves
- Reduce areas of vehicle conflict as much as possible
- Traffic streams that intersect without merging/weaving should intersect at approximately 90 degrees (60° to 120° acceptable)
- Turning roadways should be controlled with a minimum intersection angle of 60 degrees where distances to downstream intersections is less than desirable
- Angles of intersection between merging traffic streams should provide adequate sight distance
- Provide separate refuge areas for turning vehicles
- Channelization islands should not interfere with bicycle lanes
- Prohibited turns should be blocked by channelizing islands
- Traffic control devices should be used as part of the channelized intersection design

Further information regarding channelization devices can be found in the MUTCD and Chapter 10 of the AASHTO “Green Book”.

Islands

Islands are designated areas between roadway lanes used for pedestrian sanctuary and traffic control. Channelized intersections use islands to direct entering traffic into definite travel paths. There is no single physical island type within an intersection; they may be in the form of medians and outer separations or raised curbs and pavement markings. The primary functions of islands include:

Channelization *- Directing and controlling traffic movements*
The shape and size of these islands depend on the conditions and dimensions of the intersection. Corner triangular islands used for separating right-turning traffic from through vehicles are the most common form. The proper course of travel should be obvious, easy to follow, and continuous.

Division *- Dividing directional traffic streams*
These islands at intersections alert drivers to any upcoming crossroads and regulate traffic. Divisional islands are advantageous for controlling left turns and separating roadways for right turns.

Refuge *- Providing pedestrian sanctuary*
These islands are located near crosswalks or bike paths to aid and protect users who cross the roadway. Urban refuge islands are typically used for pedestrian/bicycle crossings for wide streets, transit rider loading zones, or wheelchair ramps. Their size and location depend on crosswalk location and width, transit loading sites and size, and provisional handicap ramps.

Purposes of Channelizing Islands for Intersection Design:

- Separating traffic conflicts
- Controlling conflict angles
- Reducing excessive paving
- Regulating roadway traffic
- Supporting predominant traffic movements
- Protecting pedestrians
- Locating traffic control devices
- Protecting/storing turning and crossing vehicles

Islands are typically elongated or triangular and placed out of vehicle paths. Curbed islands for intersections need to have appropriate lighting or delineation. Painted, flush medians/islands, or transversable medians may be used under certain conditions unsuited for curbs (high speeds, snow areas, small pedestrian volume, few signals, signs, or lights).

Island shapes and sizes differ from one intersection to another. These should be large enough to command attention.

Minimum Curbed Corner Island Area

Urban Intersection	50 ft^2
Rural Intersection	75 ft^2
Preferable	100 ft^2

The sides of corner triangular islands must be a minimum of 12 feet (preferably 15 feet).

Elongated or divisional islands should be a minimum of 4 feet wide and 20 to 25 feet long. These island widths may be reduced to 2 feet where space is limited.

Curbed divisional islands for high speed isolated intersections should be a minimum of 100 feet in length.

AUXILIARY LANES

Auxiliary lanes are typically used for median openings or intersections with right/left-turning movements to increase capacity and reduce crashes.

A minimum auxiliary lane width of 10 feet is desirable and should be equivalent to that for through lanes. Roadway shoulders should also have the same width as adjacent shoulders (6 feet preferred – rural high speed roads). Shoulder widths can be reduced or eliminated in many cases (urban areas, turn lanes, etc.). Paved shoulders of 2 to 4 feet may be required for auxiliary lane locations with heavy vehicle usage or offtracking.

While there are no definite warrants for auxiliary lanes, factors such as roadway capacity, speed, traffic volume, truck percentage, roadway type, right-of-way availability, level of service, and intersection configuration should be considered.

General Auxiliary Lane Guidance

- Auxiliary lanes are needed for high-speed, high volume roadways where a speed change is required for entering/exiting vehicles
- Directional auxiliary lanes with long tapers is adequate for typical driver behavior
- Drivers do not use auxiliary lanes the same way
- The majority of motorists use auxiliary lanes during periods of high volume
- Deceleration lanes prior to intersections may also be used successfully as storage lanes for turning traffic

DECELERATION LANES

The physical length for a deceleration lane entails the following components:

- Entering taper length (L_2)
- Deceleration length (L_3)
- Storage length (L_4)

Moderate rates of deceleration are typically accepted within the through lanes with taper lengths considered as part of the deceleration.

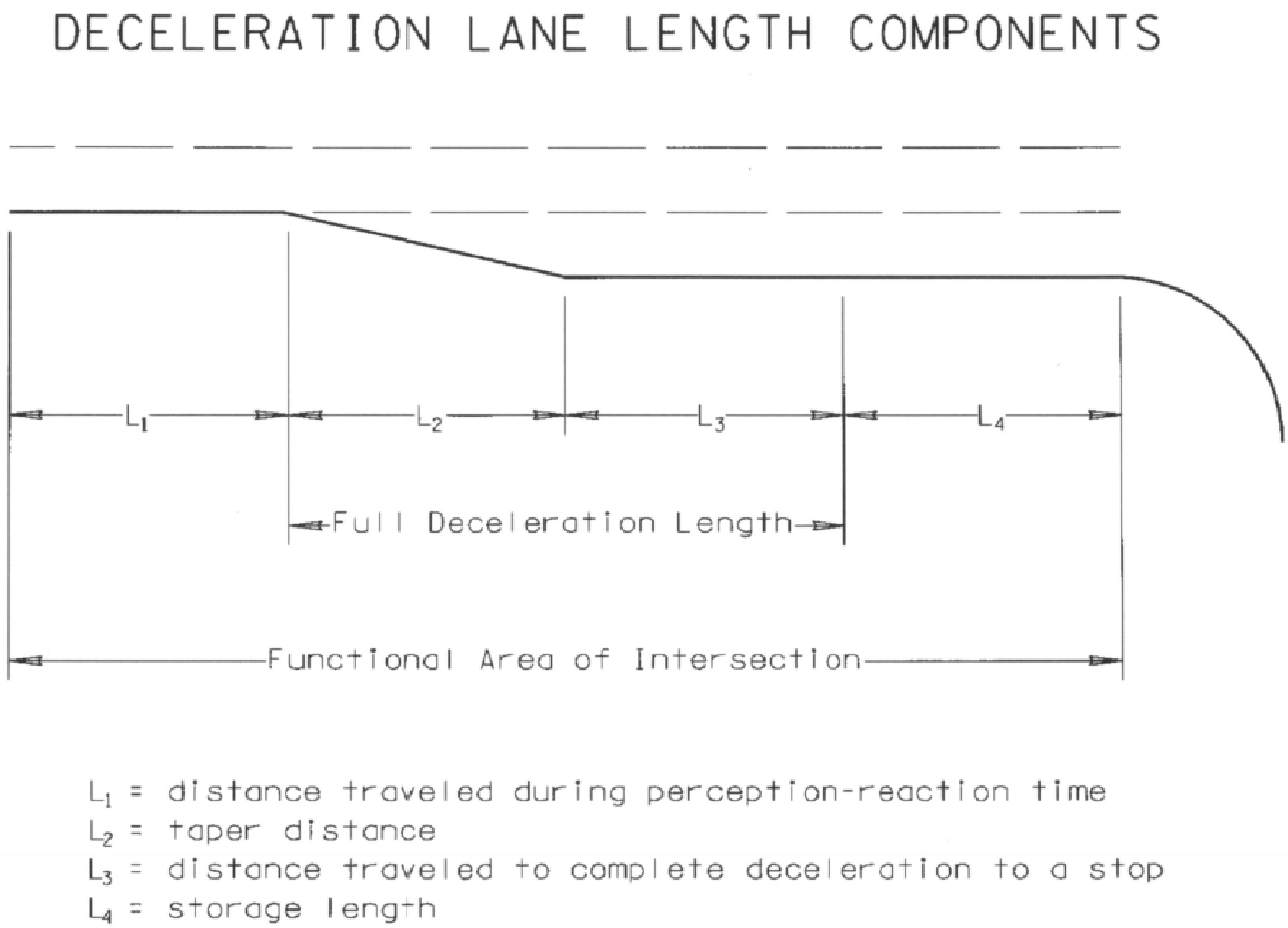


Table 9-22 (AASHTO Green Book) shows the estimated distances needed for maneuvering into a turn bay and braking to a complete stop. These values range from 70 feet at 20 mph to 820 feet at 70 mph. A speed differential of 10 mph is considered acceptable for turning vehicles and through traffic on arterial roadways. Higher speed differentials may be okay for collector roads or streets with slow speeds or higher volumes.

Signalized Intersection Storage Length Factors:

- Intersection traffic analysis
- Spiral cycle length
- Signal phasing arrangement
- Arrivals/departures of left-turning vehicles

Storage length should be based on 1½ to 2 times the average number of stored vehicles per cycle (from design volume).

The storage length for unsignalized intersections should also be determined by an intersection traffic analysis. However, this analysis needs to be based on turning vehicles arriving during an average two-minute period within the peak hour. Provisions should be made for: minimum storage of 2 passenger cars; 10% turning truck traffic; and storing at least one car and one truck.

LEFT-TURN LANE DESIGN

The accommodation of left-turning traffic is the single most important consideration in intersection design. The principal controls for intersection type and design are:

- Design-hour traffic volume
- Traffic character/composition
- Design speed

Traffic volume (actual/relative traffic volumes for turning and through movements) is considered to be the single most significant factor in determining intersection type.

For intersection design, left-turning traffic in through lanes should be avoided, if possible. Left-turn facilities on roadways are typically used to provide reasonable service levels for intersections. Historically, using left-turn lanes has shown to reduce crash rates 20 to 65%.

Various left-turn guidelines (Highway Capacity Manual, Highway Research Record 211, NCHRP Reports 255 and 279) are based on the:

- number of arterial lanes
- design/operating speeds
- left-turn volumes
- opposing traffic volumes

The type of intersection is influenced by roadway design designation, traffic service, right-of-way costs, and physical conditions.

The number of crossroads and intersecting roads should be minimized to benefit through-traffic.

Median left-turn lanes are supplementary lanes used for storage or speed changes of left-turning vehicles within medians or traffic islands. These lanes should be used at locations with high left turn volumes or high vehicle speeds.

Intersections	**Median Width**	**Status**
Single median lane	*20-ft minimum*	*Desirable*
	16 to 18 feet	*Adequate*
Two median lanes	*28-ft minimum*	*Desirable* *(two 12-ft lanes with 4-ft separator)*

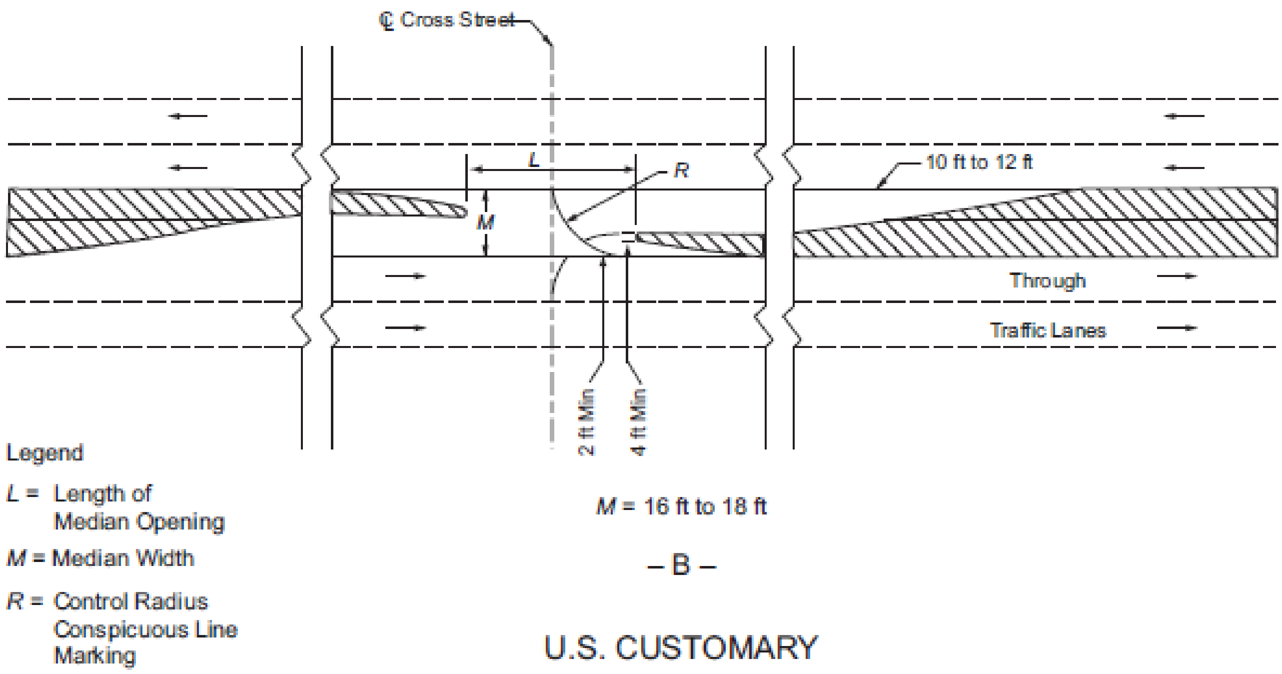


Figure 9-50. 4.2- to 5.4-m [14- to 18-ft] Median Width Left-Turn Design (U.S. Customary) (Continued)

The type of median end treatment adjacent to opposing traffic is dependent on available width. Narrowed medians can be used to:

- Separate opposing traffic
- Protect pedestrians
- Provide space for safety measures
- Highlight lane edges

Minimum Narrowed Median Width*

4 ft	(recommended)
6 to 8 ft	(preferable)

*For medians 16 to 18 ft wide with a 12 ft turning lane

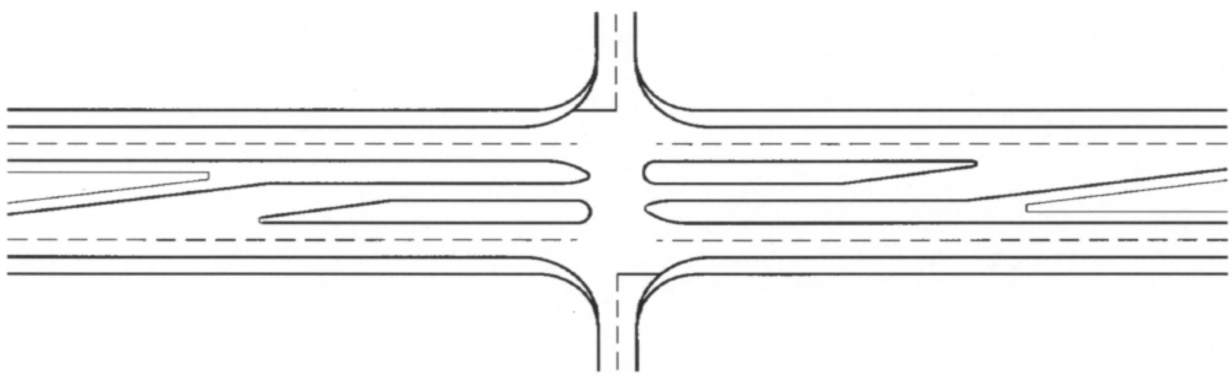
It is preferable to offset left-turn lanes for medians wider than 18 feet. This will reduce the divider width to 6 to 8 feet prior to the intersection and prevent lane alignments parallel or adjacent to the through lanes.

Advantages of Offset Left-turn Lanes:

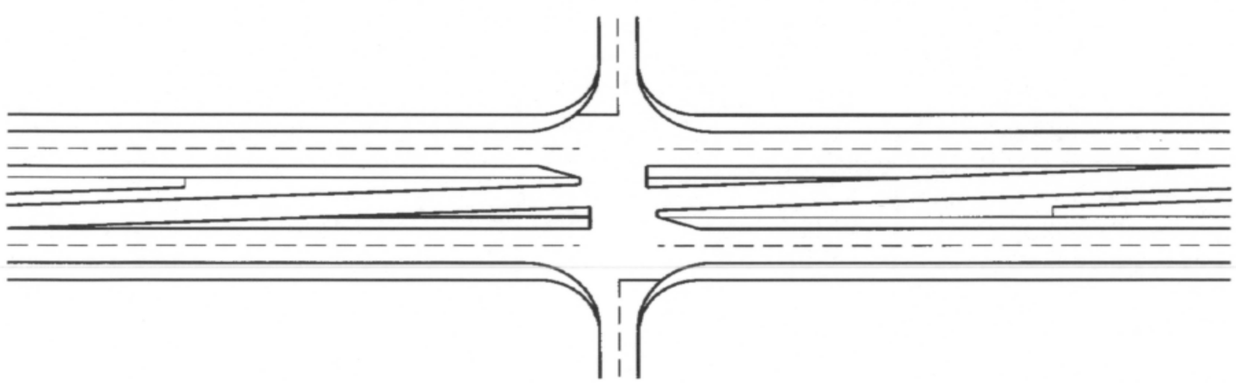
- Better sight distance
- Decreased turning conflict possibility
- Increased left-turn traffic efficiency

The two main types of offset left-turn lane configurations used are **parallel** and **tapered**.

PARALLEL OFFSET LEFT-TURN LANE



TAPERED OFFSET LEFT-TURN LANE



Parallel offset lanes are parallel but offset to the roadway's through lanes while tapered offset lanes diverge from the through lanes and cross the median at a slight angle. These offset lanes should be used in conjunction with painted or raised channelization. While both configurations are used for signalized intersections, parallel offset left-turn lanes may also be suitable for unsignalized ones.

Double and triple turn lanes should only be for signalized intersection locations with separate turning phases. It is recommended that the receiving intersection leg be able to accommodate two lanes of turning vehicles (typically 30 feet). A 90-ft turning radius is preferable for accommodating design vehicles (P through WB-40) within a swept path width of 12 feet. Pavement markings may be used throughout the intersection to provide visual cues.

MEDIAN OPENINGS

Median openings should be consistent with site characteristics, through/turning traffic volumes, type of turning vehicles, and signal spacing criteria. For locations with low traffic volumes where the majority of vehicles travel on the divided roadway, the simplest and most economic design may be adequate. However, at locations with high speed/high volume through traffic or sites with considerable cross and turning movements, the median opening should allow little or no traffic interference or lane encroachment.

Median Opening Design Steps:

- Consider traffic to be accommodated
- Choose a design vehicle
- Determine large vehicle turns without encroachment
- Check for capacity

The design of any median opening should consider the simultaneous occurrences of all traffic movements (volume, composition). Traffic control devices (signs, signals, etc.) can help regulate vehicle movements and improve operational efficiency.

A crucial design consideration for median openings is the path of design vehicles making a minimum 10 to 15 mph left turn. If the type and volume of the turning vehicles require higher than minimum speeds, the appropriate corresponding radius should be used. Low-speed minimum turning paths are needed for minimum designs and larger design vehicles.

Typical intersections for divided highways have guides for the driver at the beginning and end of the left-turn:

- Centerline of an undivided crossroad or median edge of a divided crossroad
- Curved median end

The turn's central part is an open intersection area for maneuvers.

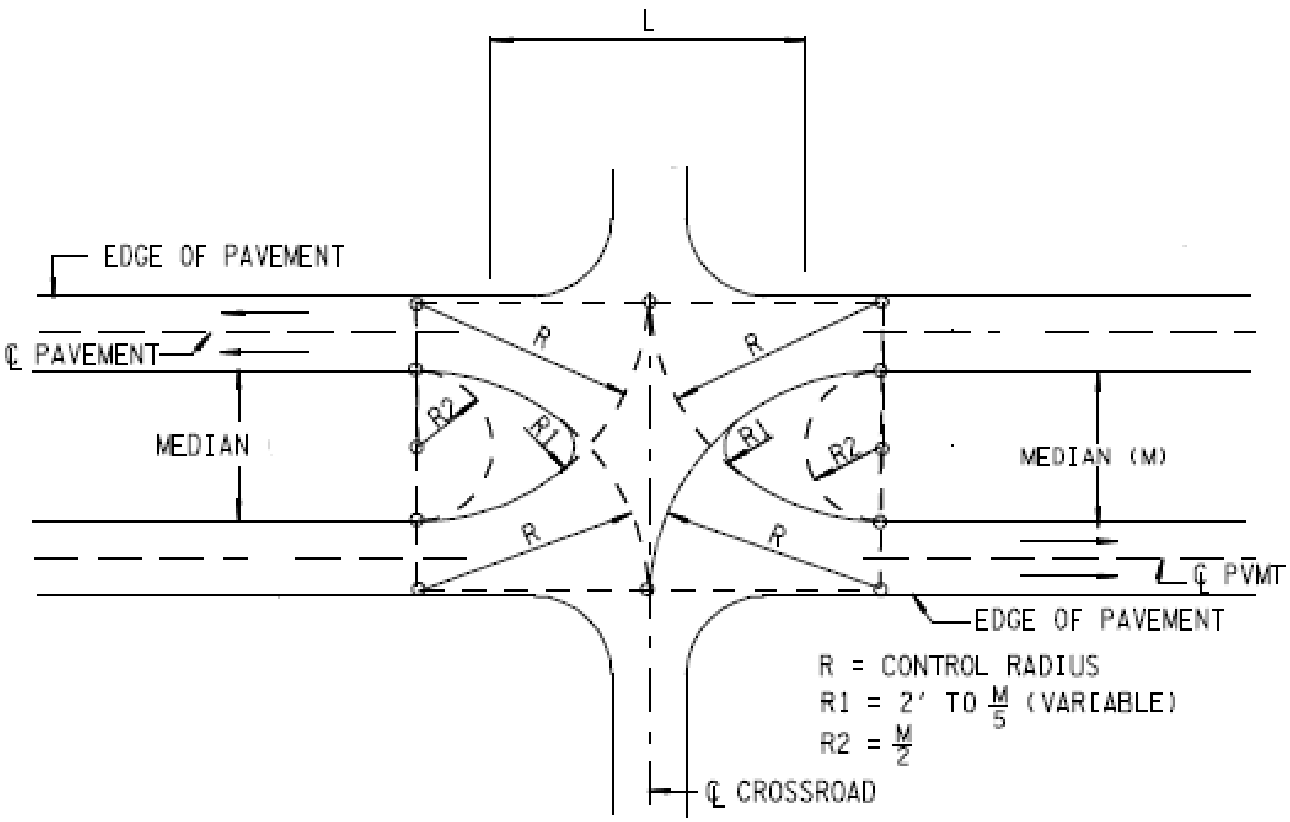
Sufficient pavement is needed for the turning path of occasional large vehicles, as well as appropriate edge markings for desired turning paths (passenger cars) to produce effective sizing for intersections.

The following control radii can be used for minimum practical median end design:

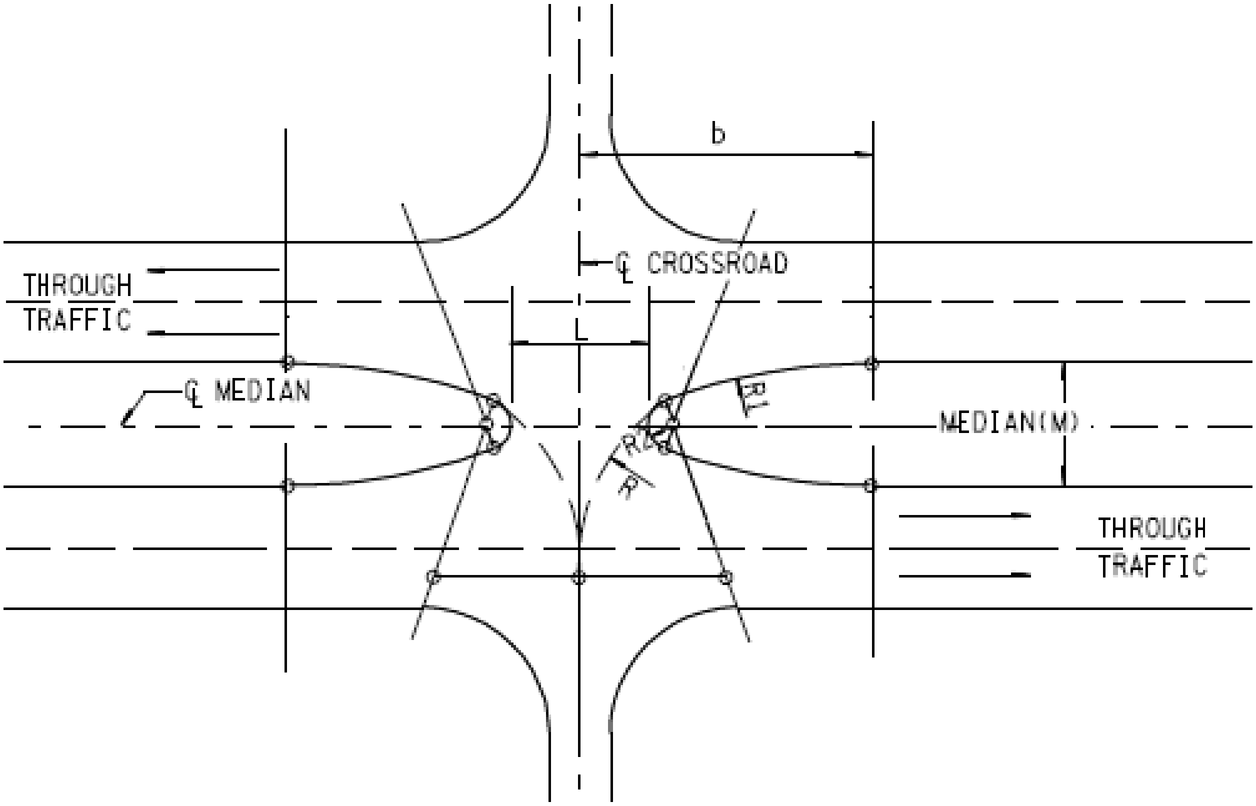
Control Radius	Design Vehicle
40 feet	P, SU-30 (occasional)
50 feet	SU-30, SU-40/WB-40 (occasional)
75 feet	SU-40, WB-40, WB-62
130 feet	WB-62, WB-67 (occasional)

AASHTO "Green Book" Tables 9-25 through 9-27 and Figures 9-55 to 9-58 show these relationships.

The **semicircle median opening** designs are simple for narrow medians. More desirable shapes are typically used for median widths greater than 10 feet.



The **bullet nose** design contains two parts of the control radius arcs with a small radius to round the nose. This form fits the inner rear wheel path with less pavement and shorter opening lengths. The bullet nose is preferable for median widths greater than 10 feet. This design positions left-turning vehicles to or from the crossroad centerline, whereas semicircular forms direct left off movements into the crossroad's opposing traffic lane.



The minimum length of median opening for three or four-leg intersections on divided roadways should be equivalent to the cross road width plus shoulders. The minimum opening length should equal the crossroad widths plus the median for divided roadway crossroads.

Do not use minimum opening length without regard to median width or control radius, except for very minor cross roads. Median openings do not need to be longer than required for rural unsignalized intersections.

Using control radii for minimum design of median openings produces lengths that increase with the intersection skew angle. This skew may introduce alternate designs, depending on median width, skew angle, and control radius.

Semicircular ends	very long openings
	minor left turn channelizing control (< 90° turning angle)
Bullet nose	determined by control radius and point of tangency
	little channelizing control from divided highway

Do not use median opening lengths longer than 80 feet regardless of skew. These types of lengths may require special channelization, left-turn lanes, or skew adjustment to produce an above-minimum design.

Normally, **asymmetrical bullet nose ends** are the preferable type of skewed median end.

Median openings that allow vehicles to use minimum paths at 10 to 15 mph are suitable for intersections with a majority of through traffic. Locations with high speeds and through volumes plus important left-turns should have median openings that do not create adjacent lane encroachment. The general minimum design procedure can be used with larger dimensions to enable turns at greater speeds and provide adequate space for vehicle protection.

Various median opening designs may be used, depending on control dimensions and design vehicle size. Median opening length is governed by the radii.

INDIRECT LEFT TURNS & U-TURNS

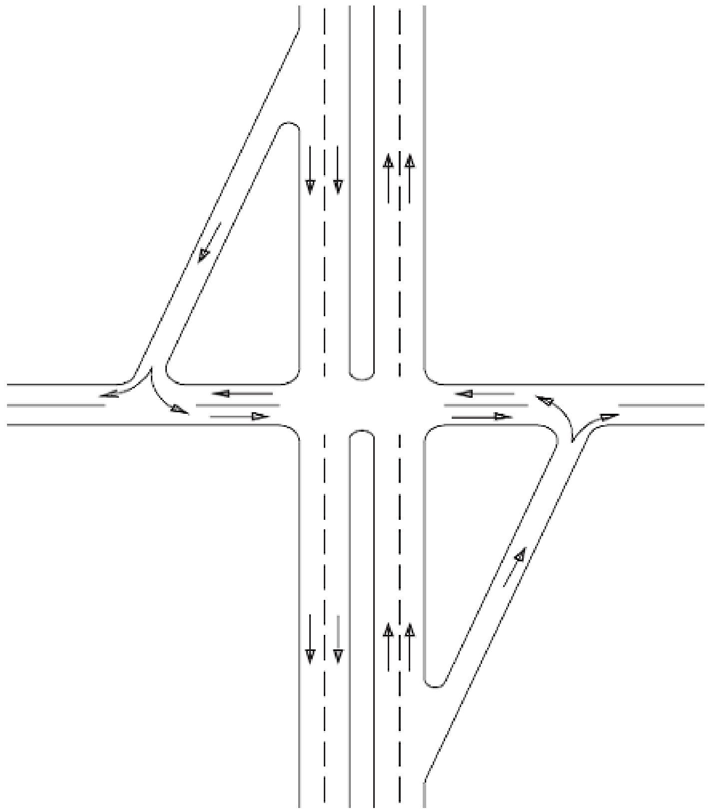
Median openings provide access for crossing traffic plus left-turns and U-turns. Since conventional intersection designs may not be appropriate for all intersections, innovative and unconventional treatments are being explored. These strategies share many of the following principles:

- Design and operations emphasis on through-traffic movements along the arterial corridor
- Reduction in the number of signal phases at major cross street intersections and increased green time for arterial through movements
- Reduction in the number of intersection conflict points and separation of the conflict points that remain

The product of these is to furnish an indirect path for left-turns.

Jughandles

Jughandles are one-way roadways used in different quadrants of intersections to separate left-turning vehicles from through traffic by forcing all turns to be made from the right side (right turns, left turns, U-turns). Road users wanting to turn left must first exit right from the major road and then turn left onto the minor roadway. Although less right-of-way may be required along the road due to no left-turn lanes, more land may be needed at the intersection for the jughandles.



Jughandle Considerations:

- Intersections with high major street movements
- Locations with low-to-median left turns from the major street
- Sites with low-to-median left turns from the minor street
- Any amount of minor street through volumes
- Intersections with too narrow medians for left turns

Jughandles can improve safety and operationability by reducing left-turn collisions and providing more green time for through movements.

Displaced Left-Turn Intersections
[Continuous-Flow Intersection (CFI) or Crossover-Displaced Left-Turn Intersection (XDL)]

Displace left-turn intersections using left-turn bays on the left of oncoming traffic to remove the potential hazard between left-turning and oncoming vehicles at main roadway intersections. These left-turn bays may be accessed at a midblock signalized intersection approach where continuous flow is wanted. Stops for left-turns may occur for the following instances:

- Midblock signal on approach
- Main intersection on departure

Signals need to be coordinated to minimize the number of stops, especially at main intersections.

Two-Phase Signal Operation for Displaced Left-Turn Intersection

Signal Phase 1	Serves cross street traffic
	Traffic allowed to enter left-turn by crossing oncoming traffic lanes
Signal Phase 2	Serves through traffic
	Protects left-turn movements

Displaced left-turn intersections are suitable for locations with high through and left-turn volumes. Adjacent right-of-way may be required for the proposed left-turn roadways.

Median U-Turn Crossover Roadways

Median U-Turn crossovers move left-turning traffic to median crossover roadways beyond intersections. For major road crossovers, drivers pass through the intersection and turn left to make a U-turn at the crossover, and veer right at the cross road. For minor road median crossovers, major road traffic turns right on the minor road, and then left through the crossover roadway. Roundabouts may be considered to be a variation of U-turn crossovers.

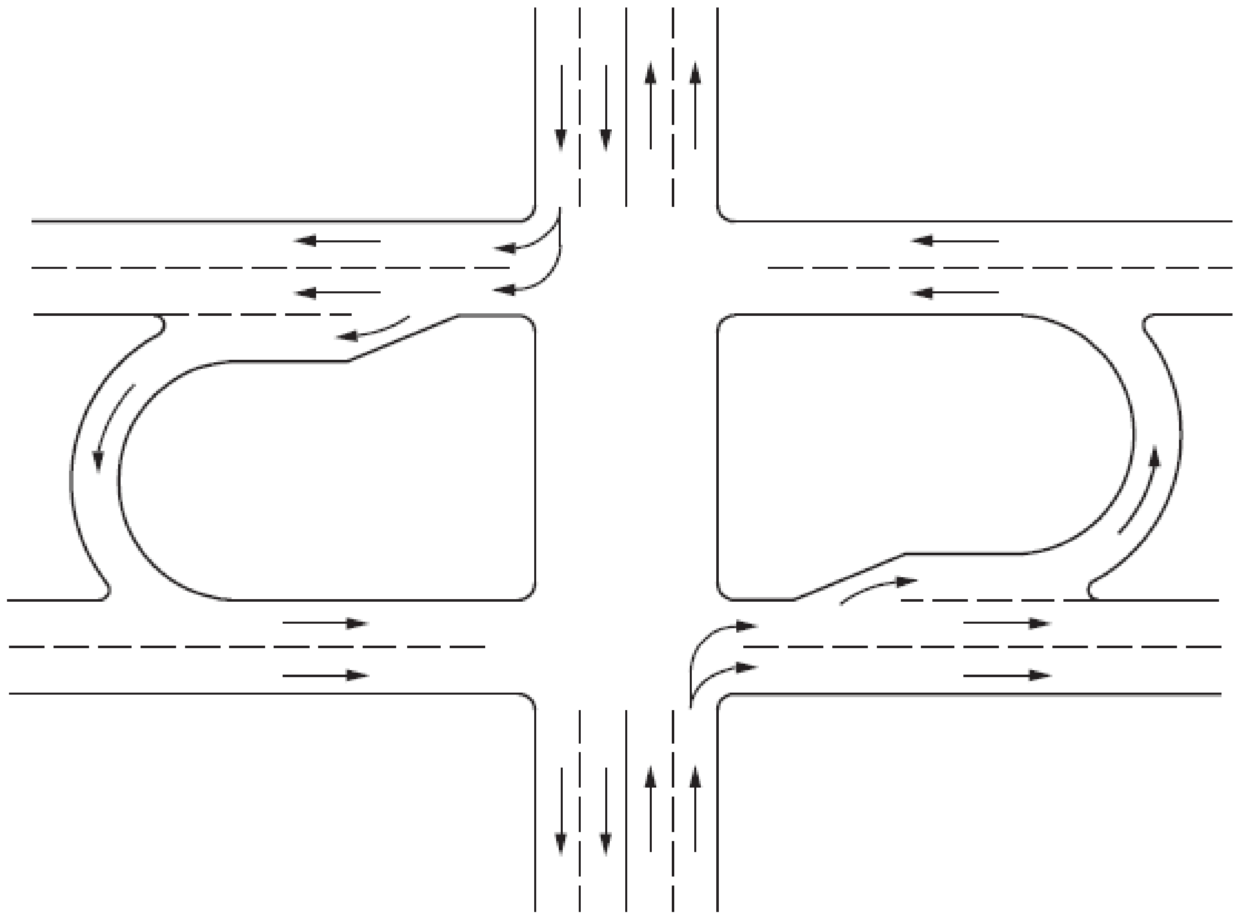


Figure 9-65. Typical Arrangement of U-Turn Roadways for Indirect Left Turns on Arterials with Wide Medians

Median U-Turn crossovers require a wide median due to their design. These roadways are more suitable for intersections with high major-street through movements, low-to-medium left turns from the major street, low-to-medium left turns from the minor street, and any amount of minor street through volumes. Locations with high left-turn volumes should be avoided.

Key Design Features:

- Must accommodate design vehicle
- Deceleration/storage lengths must be based on design volume and traffic control
- Optimum location is 660 feet from the main intersection
- Four-lane arterial medians must be 60 feet wide to accommodate tractor-semitrailer combination truck design vehicle

ROUNDABOUT DESIGN

The “modern roundabout” was a British solution to the problems associated with rotary intersections. The resulting design is a one-way, circular intersection with traffic flow around a central island. The U.K. adopted a mandatory “give-way” rule for entering traffic at all circular intersections to yield to circulating traffic. This rule greatly reduced the number and severity of vehicle crashes.

Basic Principles for Modern Roundabouts:

1) **Yield control at all entry points** – All approaching traffic is required to yield to vehicles on the roundabout’s circulatory roadway before entering the circle. Yield signs are used primarily as entry control. Weaving maneuvers are not considered a design or capacity factor.

2) **Traffic deflection** – Entering vehicles are directed to the right (in the U.S.) by channelization or splitter islands onto the roundabout’s circulating roadway avoiding the central island. No entrance traffic is permitted to travel a straight route through the roundabout.

3) **Geometric curvature** – Entry design and the radius of the roundabout’s circulating roadway can be designed to slow the speeds for entering and circulating traffic.

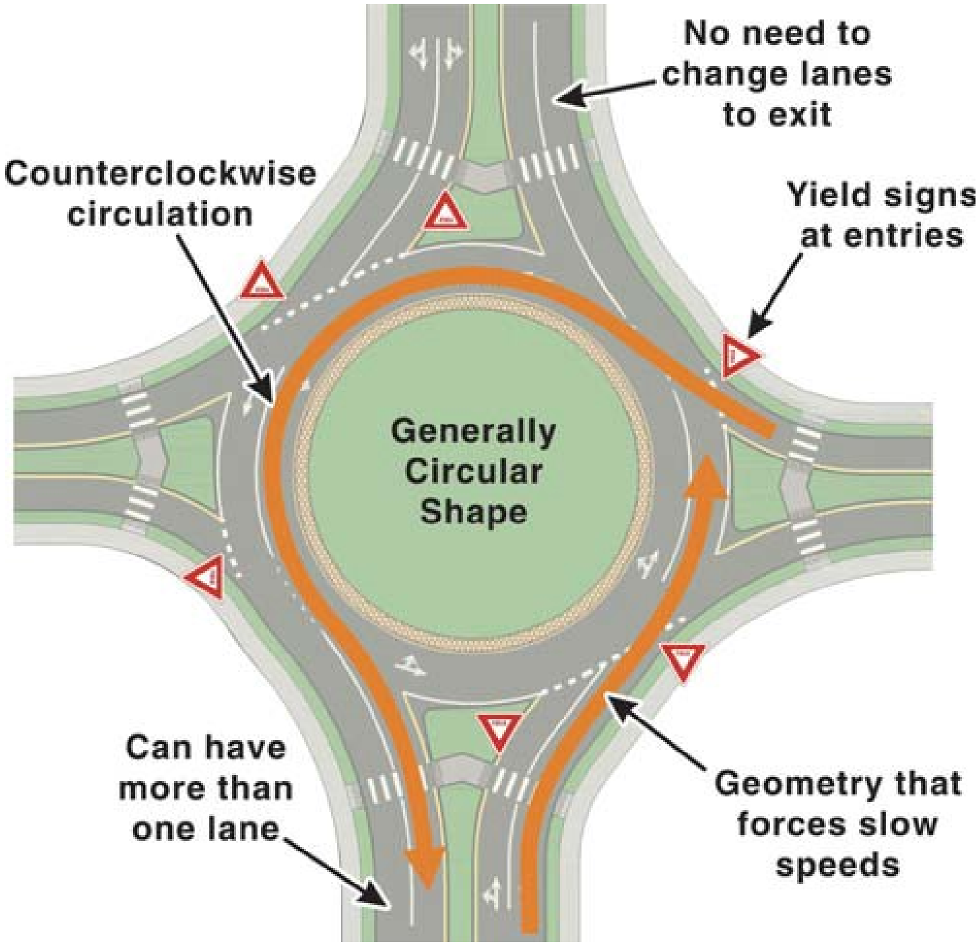


Exhibit 1-1
Key Roundabout Characteristics
(FHWA. NCHRP Report 672 Roundabouts: An Informational Guide. 2010)

Roundabout geometric design is a combination of balancing operational and capacity performances with the safety enhancements. Roundabouts operate best when approaching vehicles enter and circulate at slow speeds. By using low-speed design elements (horizontal curvature and narrow pavement widths for slower speeds), the capacity of the roundabout may be negatively affected. Many of the geometric criteria used in design of roundabouts are also governed by the accommodation of over-sized vehicles expected to travel through the intersection.

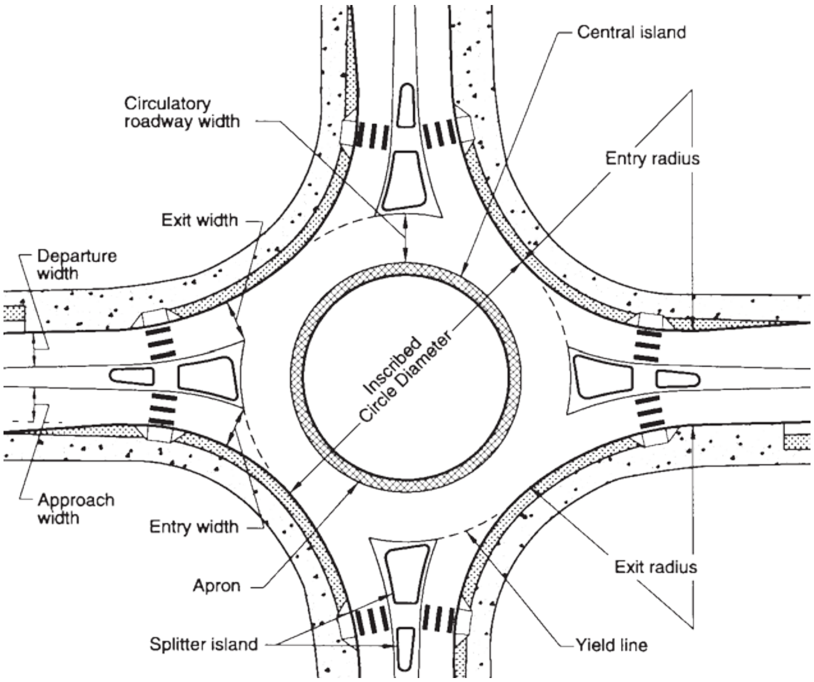


Exhibit 6-1. Basic Geometric Elements of a Roundabout.
(FHWA. Roundabouts: An Informational Guide. 2000)

Roundabout Geometric Elements:

Central Island: Raised area (not necessarily circular) in the center of the roundabout which is bordered by circulating traffic.

Splitter Island: Raised or painted approach area for delineating, deflecting and slowing traffic. It also permits non-motorist crossings.

Circulatory Roadway: Curved vehicle path for counterclockwise travel around the central island.

Apron: Optional mountable part of the central island for accommodating larger vehicle wheel tracking.

Yield Line: Pavement marking for entry point to the circulatory roadway. Entry vehicles must yield to circulating traffic before crossing the yield line onto the circulatory path.

Accessible Pedestrian Crossings: Non-motorist access that is setback from the entrance line and cut through the splitter island.

Landscape Strip: Optional areas for separating vehicle/non-motorist traffic, designating crossing locations, and providing aesthetic improvements.

Roundabout design is a creative process that is specific for each individual intersection. No standard template or "cookie-cutter" method exists for all locations. Geometric designs can range from easy (mini-roundabouts) to moderate (single lane roundabouts) to very complex (multi-lane roundabouts). How the intersection functions as a single traffic control unit is more important than the actual values of the individual design components. It is crucial that these individual geometric parts interact with each other within acceptable ranges in order to succeed.

Speed Management

The design speed of vehicles is a critical factor for roundabout design. Speed management is often a combination of managing speeds at the roundabout plus the approaching legs. Forecasting these vehicular speeds when traveling through a proposed roundabout is fundamental for attaining good safety performance.

Maximum entering design speeds of 20 to 25 mph are recommended for single-lane roundabouts. For multi-lane roundabouts, these maximum entering design speeds increase to 25 to 30 mph (based on the theoretical fastest path). Exhibit 6-4 shows the recommended design speeds for different types of roundabouts.

Site Category	Recommended Maximum Entry Design Speed
Mini-Roundabout	25 km/h (15 mph)
Urban Compact	25 km/h (15 mph)
Urban Single Lane	35 km/h (20 mph)
Urban Double Lane	40 km/h (25 mph)
Rural Single Lane	40 km/h (25 mph)
Rural Double Lane	50 km/h (30 mph)

Exhibit 6-4. Recommended maximum entry design speeds.
(FHWA. Roundabouts: An Informational Guide. 2000)

Another important objective is to produce consistent speeds for all roundabout movements which along with overall speed reduction can help to minimize the crash rate between conflicting traffic. For any design, it is desirable to minimize the relative speeds between consecutive geometric elements and conflicting traffic streams.

Lane Arrangements

The entry movements assigned to each lane within a roundabout are critical to its overall design. An operational analysis can help determine the required number of entry lanes for each approach. Pavement marking may also be used in the preliminary phase to ensure lane continuity through the various design iterations.

Roundabouts are typically designed to accommodate design year traffic volumes (normally projected 20 years in the future). This design may produce more entering, exiting, and circulating lanes than needed at the start of operation. It may be necessary to use a phased design that initially uses fewer entering and circulating lanes while maximizing potential safety. In order for lane expansion at a later phase, an optimal roundabout configuration (including horizontal and vertical design) needs to be considered as early as possible in the initial design. Lanes may then be removed from the optimal roundabout design to provide the necessary initial capacity. This phased method ensures that adequate right-of-way is acquired and any revisions to the original roundabout are minimized.

Appropriate Path Alignment

The fastest speed path is a basic principle in the geometric design of roundabouts. This path is the fastest and smoothest path possible for a single vehicle to travel through the entry, around the central island, and out the exit of a roundabout. Its purpose is to restrict operating speed by deflecting the paths of entering and circulating vehicles. Typically, the through movement will be the **critical fastest path**. However, in some cases it may be a right turn movement.

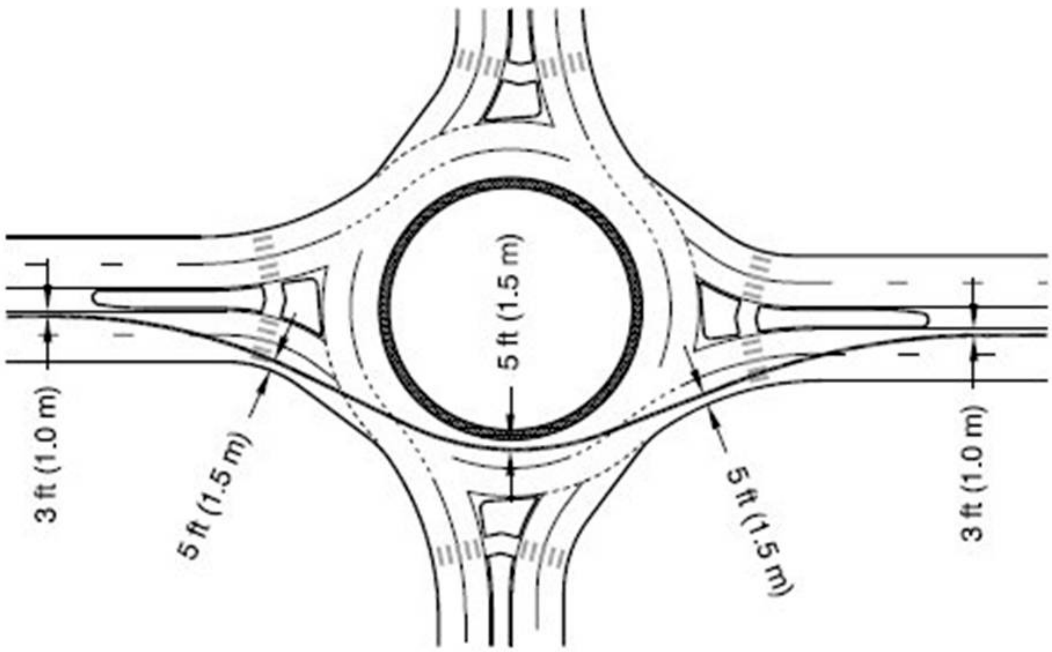


Figure 7: Fastest Vehicle Path through a Single-Lane Roundabout
(FHWA. Roundabouts: Technical Summary. 2010)

A good entry and exit design permits appropriate lane alignment throughout the roundabout. Engineers may improve the operations and safety of a roundabout design by analyzing the traffic path alignments. Approaching traffic will be channelized by lane markings to the roundabout's entry and then continue onto the circulatory roadway. Natural path interference or overlap reduces the safety and efficiency of the roundabout. Exit geometry also affects the natural travel path and possible vehicle overlap.

Design Vehicle
A primary factor in determining the design of a roundabout is the choice of the largest vehicle (design vehicle) that will use the facility. Turning path requirements will have a direct effect on many of the dimensions of the roundabout (inscribed circle diameter, approach re-alignment, etc.).
The appropriate design vehicle consideration is dependent on the following criteria:

- Roadway classification
- Input from local authorities
- Surrounding environmental characteristics

For rural areas, agricultural machinery may determine design vehicle requirements while emergency, mass transit and delivery vehicles should be considered in urban environments. Local emergency agencies need to be involved in any plans for designing a roundabout in their area.

The AASHTO Green Book recommends using the following guidelines when choosing a design vehicle:

Design Vehicle	**Location**
Passenger Car (P)	Parking lots or series of parking lots
Single-unit Truck (SU)	Residential streets and park roads
City Transit Bus (CITY-BUS)	Highway intersections with city streets designated bus routes
Large or Conventional School Bus (S-BUS36 or 40)	Highway intersections with local roads under 400 ADT
Interstate Semitrailer (WB-65 or 67)	Freeway ramps with arterial crossroads or high volume traffic roadways

For most cases, the *Intermediate Semi-trailer (WB-50)* is the largest design vehicle for urban collectors/arterials. It is also considered to be the minimum design vehicle for all turning movements for roundabouts on the state highway system.

Non-motorized Design Users
Roundabouts are designed to meet the needs of all facility users. The safe and efficient accommodation of all non-motorized users (bicyclists, drivers, pedestrians, disabled or impaired persons, strollers, skaters, etc.) is as important as the considerations made for vehicles. The potential for any conflicting traffic or severe crashes is substantially reduced by forcing roundabout traffic to enter or exit only through right turns. The low-

speeds through roundabouts allow more user reaction time resulting in fewer crashes involving pedestrians.

User	Dimension	Affected Roundabout Features
Bicyclist		
Length	5.9 ft	Splitter island width at crosswalk
Minimum operating width	4 ft	Bike lane width on approach roadways; shared use path width
Pedestrian (walking)		
Width	1.6 ft	Sidewalk width, crosswalk width
Wheelchair user		
Minimum width	2.5 ft	Sidewalk width, crosswalk width
Operating width	3.0 ft	Sidewalk width, crosswalk width
Person pushing stroller		
Length	5.6 ft	Splitter island width at crosswalk
Skaters		
Typical operating width	6 ft	Sidewalk width

Exhibit 6-7. Key Dimensions of Non-Motorized Design Users
(FHWA. NCHRP Report 672 Roundabouts: An Informational Guide. 2010)

Pedestrian Design

Pedestrian needs should be addressed and controlled to maximize safety and minimize conflicts with other traffic flows. Pavement marking inside the crosswalk area is recommended to improve safety. Many cities and suburban areas have gone to the next level by adding aesthetic treatments to their crosswalk designs.

Pedestrian Crosswalk Considerations:

- Should be located at intersections
- Have appropriate curb ramps for accessibility
- Should be highly visible

Pedestrians are accommodated by crosswalks and sidewalks around the perimeter of the roundabout. Sidewalks (5 ft minimum, 6 ft recommended) should be set back from the edge of the circulatory roadway (2 ft minimum, 5 ft recommended) with a landscape strip. Low shrubs or grass may be planted in the strip between the sidewalks and curb. This setback discourages pedestrians from cutting across the roundabout's central island and guides visually-impaired pedestrians to the designated cross-walks. Fencing or other barriers may be necessary in heavy pedestrian traffic areas to guide users to the appropriate crossings.

The *Americans with Disabilities Act* requires that all new or modified roundabouts be accessible to and usable by disabled individuals. Visually impaired pedestrians may have more difficulty crossing roundabouts since these intersections do not typically include the normal audible and tactile cues used to successfully maneuver crosswalks.

Pedestrian signals should be coordinated with traffic lights at all signalized intersections with pedestrian activity. Push buttons can be used for isolated intersections or locations where traffic warrants maximum vehicle travel time through the intersection. Fixed time traffic signals with short cycle lengths are more appropriate for urban or downtown environments.

Bicycle Design Considerations
Research has shown that bicyclists are the most vulnerable users of roundabouts with over 50 percent of bike crashes at roundabouts involving entering vehicles and circulating bicycles.

Modern roundabouts are typically designed to accommodate bicyclists of different skills and experience levels.

When designing a roundabout for bicycle safety and travel, the following general methods may be used to accommodate bicyclists:

1) ***Motor Vehicle Method*** *- mixed flow with regular traffic*
   Typical bicycle (12 – 20 mph) and design vehicle entry (20 – 30 mph) speeds are similar and compatible for low-speed, single-lane roundabouts with low potential conflicts.

2) ***Pedestrian Method*** *- shared use paths*
   Bicycle safety tends to deteriorate at high-speed, multiple lane roundabouts and many cyclists may be more comfortable and safer using bike ramps connected to a sidewalk or shared use path around the outside of the roundabout. The typical sidewalk width should be a minimum of 10 ft in order to accommodate both pedestrians and bicyclists. Bicycle lanes or shoulders used on approach roadways, should end at least 100 feet before the edge of the circulatory roadway. A taper rate of 7:1 is recommended to transition the combined travel/bike lane width down to the appropriate width for the desired vehicle speeds on the approach. Bicycle ramps may be provided to allow

access to the sidewalk or a shared use path at the roundabout. These ramps should only be used where the design complexity or vehicle speed is incompatible for some cyclists. AASHTO's *Guide for Development of Bicycle Facilities* provides specific details for designing shared-use paths.

Sight Distance and Visibility

Adequate visibility and sight distance for approaching vehicles is crucial for providing safe roundabout operation. For roundabouts, the two most relevant parts of sight distance are stopping sight distance and intersection sight distance.

Stopping sight distance is the distance required for a driver to see and react to an object in the roadway and then brake to a complete stop. Stopping sight distance should be provided within a roundabout and on each entry and exit leg. The required distance is based on speed data from the fastest path speed checks.

Speed (km/h)	Computed Distance* (m)	Speed (mph)	Computed Distance* (ft)
10	8.1	10	46.4
20	18.5	15	77.0
30	31.2	20	112.4
40	46.2	25	152.7
50	63.4	30	197.8
60	83.0	35	247.8
70	104.9	40	302.7
80	129.0	45	362.5
90	155.5	50	427.2
100	184.2	55	496.7

Exhibit 6-54
Computed Values for Stopping Sight Distance
(FHWA. NCHRP Report 672 Roundabouts: An Informational Guide. 2010)

* Assumes 2.5 s perception–braking time, 3.4 m/s^2 (11.2 ft/s^2) driver deceleration

AASHTO recommends using an assumed height of **driver's eye of 3.5 ft** and an assumed **object height of 2 ft** for stopping sight distances. Three critical roundabout locations should be checked for sight distance:

- Approaches
- Circulatory Roadway
- Exit Crosswalks

Intersection sight distance is the distance required for a driver to anticipate and avoid conflicting vehicles. Adequate intersection sight distance ensures drivers can safely enter the circulatory roadway without impeding traffic flow. Entry roadways are the only roundabout locations requiring evaluation of intersection sight distance.

Sight triangles are used to measure intersection sight distance. This triangle consists of a boundary defining a distance away from the intersection on each approach and by a line connecting those two limits. The distance between the entering vehicle and the circulatory roadway is fixed while the other legs of the sight triangle are based on two conflicting approaches:

1. **Entering stream of vehicles from the immediate upstream entry.** The approximate speed can be calculated using the average values for the entering and circulating speeds.

2. **Circulating stream of vehicles entering the roundabout prior to the immediate upstream entry.** The speed can be approximated from the speed of left turning vehicles.

In both cases the distance is a function of vehicular speed and a reasonable design value of the critical headway for the drivers. These sight triangle legs should follow the curvature of the roadway, and not be measured as straight lines but as distances along the vehicle path.

In some cases, sight distance at the roundabout may be increased at the expense of the roundabout's visibility. Normally, it is desirable to allow no more than the minimum required intersection sight distance for each approach. Excessive visibility may result in higher speeds and safety reduction for the roundabout.

The AASHTO "Green Book" recommends that intersection sight distance should be measured using an assumed height of **driver's eye of 3.5 ft** and an assumed **object height of 3.5 ft.**

Angles of Visibility

The intersection angle at roundabouts is measured between the vehicular alignment at the entry and the sight line required. This angle must allow drivers to comfortably turn their heads to view oncoming traffic upstream. Current guidelines recommend using an **intersection angle of 75˚** to design for older driver and pedestrian needs.

Size, Position, and Alignment of Approaches
The design of a roundabout involves optimizing the following design decisions to balance design principles and objectives:

- Size
- Position
- The alignment of the approach legs

Creating the best design will often be based upon the constraints of the project site balanced with the ability to control traffic speeds, accommodate over-sized vehicles, and meet other design criterion.

Road Type	**Normal Capacity**
Single-lane circulatory road	*1400 to 2400 vehicles/hour*
Two-lane circulatory road	*2200 to 4000 vehicles/hour*

Road type	**Maximum Capacity**
Single-lane entry	*1300 vehicles/hour*
Two-lane entry	*1800 vehicles/hour*

Inscribed Circle Diameter
The inscribed circle is the entire area within a roundabout between all approaches and exits. Its diameter consists of the distance across the central island (including the truck apron) bordered by the outer curb of the circulatory roadway. A number of design objectives determine the inscribed circle diameter and designers often have to experiment with varying dimensions before determining the optimal roundabout size.

For single-lane roundabouts, the inscribed circle's size depends on the design vehicle's turning requirements: circulatory roadway width, entry/exit widths, radii and angles.

For multilane roundabouts, the size is dependent on balancing deflection with aligning natural vehicle paths.

Capacity

A roundabout's capacity and size depends on the number of lanes required to handle future traffic. Exhibit 3-12 illustrates a simple, conservative way to estimate roundabout lane requirements. It is applicable for the following conditions:

Ratio of peak-hour to daily traffic (K)	0.09 to 0.10
Acceptable volume-to-capacity ratio	0.85 to 1.00
Ratio of minor street to total entering traffic	0.33 to 0.50
Direction distribution of traffic (D)	0.52 to 0.58

Alignment of Approaches

The entry alignment of the approaching legs to a roundabout affects the deflection and speed control achieved, accommodation for the design vehicle, sight angles to drivers, and property impacts/costs.

Although it is desirable for these alignments of the roundabout approaches to pass through the center of the inscribed circle, it is not mandatory for a successful design.

SINGLE-LANE ROUNDABOUTS

Single-lane roundabout design consists of single-lane approaches at all legs and a single-lane circulatory roadway around a central island. This design permits slightly higher operation speeds for the entry, exit and the circulatory roadway. Like all roundabouts, the size of single-lane design is largely dependent on the type of design vehicle and available right-of-way.

Single-lane Geometric Design Characteristics:

- Larger inscribed circle diameters
- Raised splitter islands
- Non-traversable central island
- Crosswalks
- Truck apron

Exhibit 1-12 illustrates the distinguishing features of typical single-lane roundabouts.

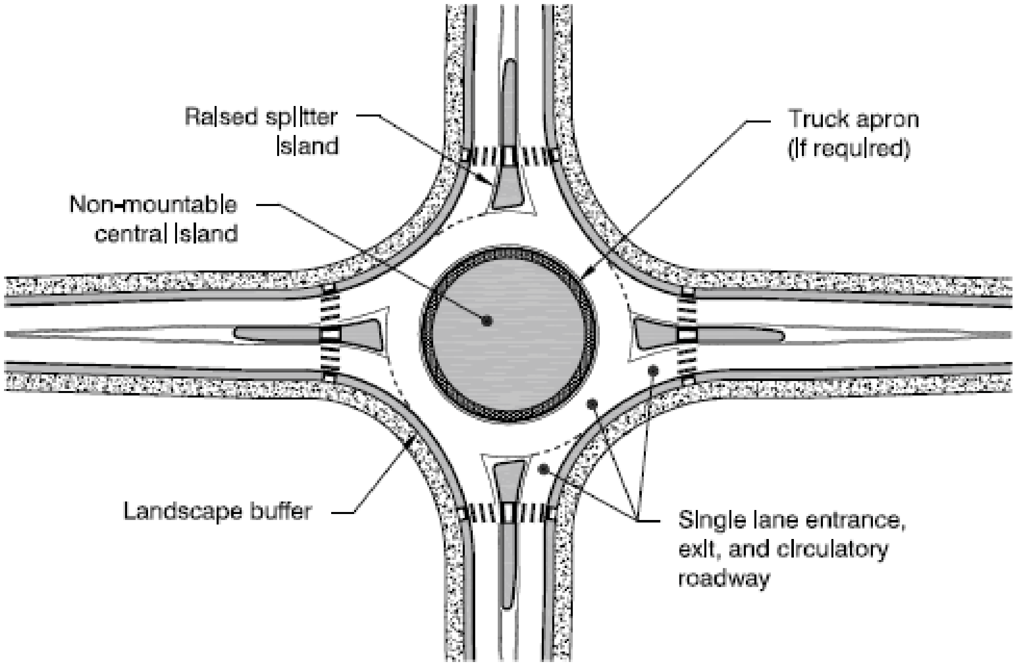


Exhibit 1-12
Features of Typical Single-Lane Roundabout
(FHWA. NCHRP Report 672 Roundabouts: An Informational Guide. 2010)

MULTILANE ROUNDABOUTS

Multilane roundabouts contain a minimum of one entry (two or more lanes) and require wider circulatory roadways to accommodate more than one vehicle traveling side by side. The roundabouts may have a different number of lanes or transitions on one or more legs. The number of lanes should be the minimum needed for the anticipated traffic demand. The design speeds at the entry, on the circulatory roadway, and at the exit may be slightly higher than those for single-lane roundabouts. Multilane roundabouts include raised splitter islands, truck aprons, a non-traversable central island, and appropriate entry path deflection.

The size of a multilane roundabout is typically determined by balancing two critical design objectives:

- The need to achieve deflection; and
- Providing sufficient natural vehicle path alignment.

To achieve both of these objectives, a diameter larger than those used for single-lane roundabouts is required. Generally, the inscribed circle diameter of a multilane roundabout ranges from 150 to 220 ft (two-lane) and 200 to 300 ft (three-lane) for achieving adequate speed control and alignment. Truck aprons are recommended to accommodate larger design vehicles and keep the inscribed circle diameter reasonable.

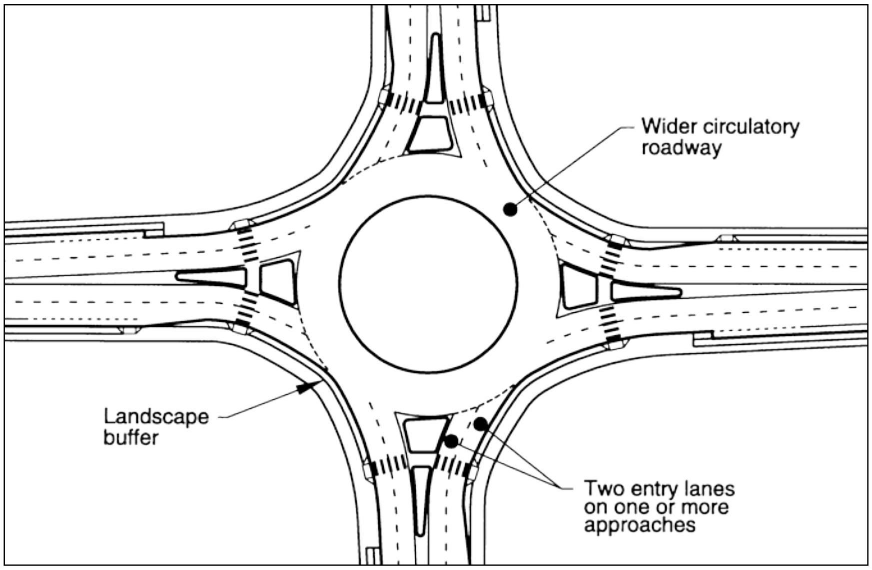


Exhibit 1-11
Typical Urban Double-Lane Roundabout
(FHWA. Roundabouts: An Informational Guide. 2000)

MINI-ROUNDABOUTS

Mini-roundabouts are small intersection designs with a fully traversable central island that are commonly used in low-speed urban environments (average operating speeds of 30 mph or less). The small footprint of a mini-roundabout (inscribed circle diameter less than 90 ft) can be useful in such environments where conventional roundabout design is limited by right-of-way constraints. The small diameter is made possible by using a fully traversable central island for accommodating heavy vehicles. Passenger cars should be able to exit the mini-roundabout without running over the central island. The overall design should naturally guide entering vehicles along their intended path and minimize traversing the central island.

Mini-roundabouts are very popular for retrofit applications due to their low cost from requiring minimal additional pavement at the intersecting roads and minor widening at the corner curbs. Small, mini-roundabouts are also seen as pedestrian-friendly with short crossing distances and very low vehicle entry/exit speeds.

Limitations of mini-roundabouts are due to the reduced ability to control speeds with the traversable central island. Therefore, it is important to consider the advantages and limitations of mini-roundabouts versus the larger-diameter roundabouts and intersection designs based upon site-specific conditions.

Figure 1 (Mini-Roundabouts Technical Summary) shows the distinctive features for a typical mini-roundabout.

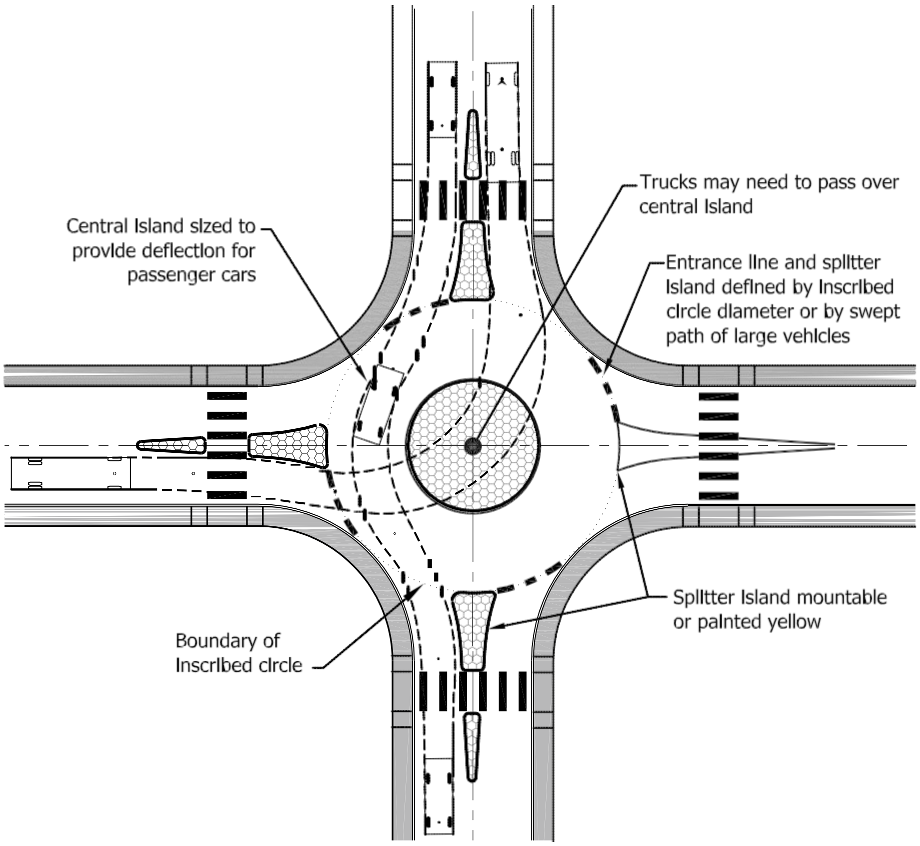


Figure 1.
Design Features of a Mini-Roundabout
(FHWA. Mini-Roundabouts Technical Summary. 2010)

FRONTAGE ROADS

Frontage roads preserve the character of the highway and prevent impacts of road development. These roads are used most frequently on freeways to distribute and collect roadway traffic between local streets and freeway interchanges. Frontage roads are typically used adjacent to arterials/freeways where property owners are denied direct access.

A minimum spacing of 150 feet between arterial and frontage roads is recommended in urban areas to lengthen the spacing between successive intersections along the crossroads.

This dimension is based on the following criteria:

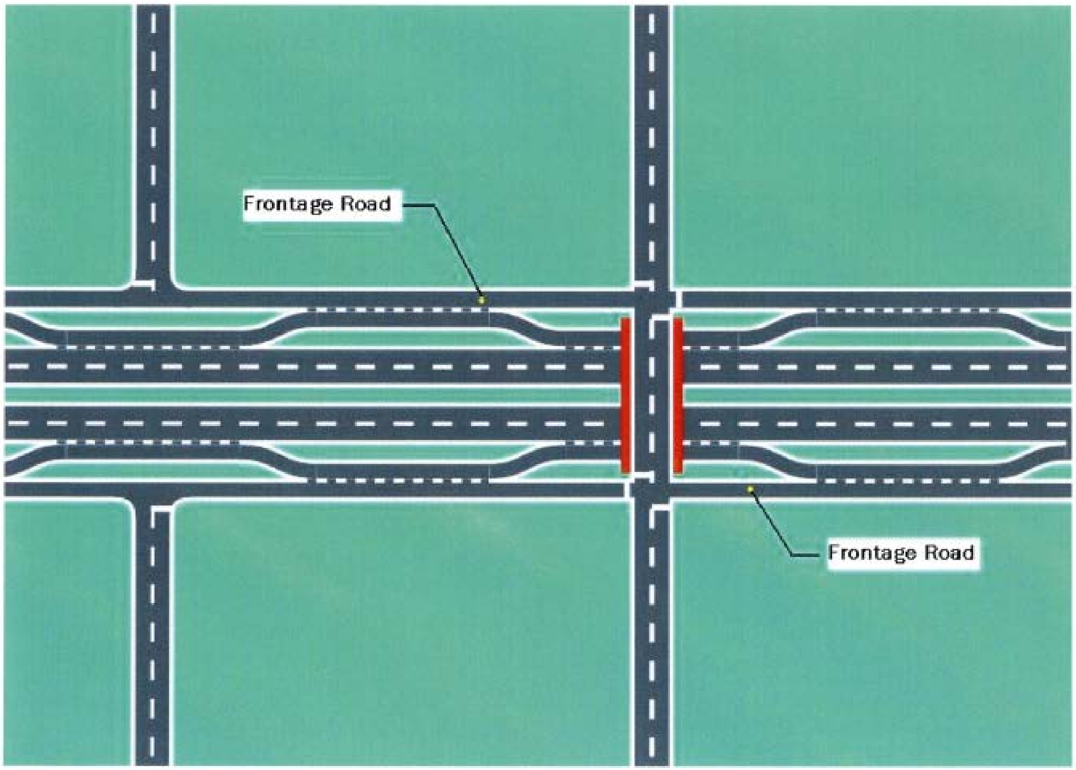
- Provides shortest acceptable length needed for signs and traffic control devices
- Allows acceptable storage space on crossroad in advance of main intersection
- Enables turning movements from the main road onto frontage road
- Facilitates U-turns between main lanes and two-way frontage roads
- Alleviates potential wrong-way entry onto highway

Frontage roads are typically parallel to the freeway:

- Either one or both sides
- Continuous or non-continuous

Arterial and frontage road connections are a crucial element of design. For slow-moving traffic and one-way frontage roads, simple openings may be adequate. On high-speed roadways, ramps should be designed for speed changes and storage.

Frontage road design is also impacted by its intended type of service. It can assume the character of a major route or a local street.



Typical Frontage Road Example

Outer Separations

The "outer separation" is the buffer area between through traffic on a roadway and local traffic on a frontage road. The wider the separation, the lesser the influence on through traffic. Wide separations are particularly advantageous at intersections with cross streets to minimize vehicular and pedestrian conflicts. Separations of 300 feet allow for minimal vehicle storage and overlapping left-turn lanes.

The cross-section of an outer separation is dependent on:

- Width
- Type of Arterial
- Frontage Road Type

The AASHTO "Green Book" provides further information on these types of separations.

PEDESTRIAN FACILITIES

Sidewalks

The safe and efficient accommodation of pedestrians along the traveled way is equally important as the provisions for vehicles. By separating pedestrians and vehicles, sidewalks increase pedestrian safety and help vehicular capacity. Sidewalks are typically an integral part of the transportation system in central business districts. Data suggests that providing sidewalks along highways in rural and suburban areas results in a reduction in pedestrian accidents.

Early consideration of pedestrian needs during the project development process may also streamline compliance with accessibility requirements of the *Americans with Disabilities Act Accessibility Guidelines (ADAAG)*. Intersections designed with proper curb ramps, sidewalks, pedestrian signals, and refuge islands can also aid in furnishing a pedestrian-friendly environment.

Sidewalks are typically placed along roadways without shoulders, even at locations with light pedestrian traffic. For sidewalk locations along high-speed roads, buffer areas may be utilized to distance the sidewalk from the traveled way.

Sidewalks should be wide enough for the volume and type of expected pedestrian traffic. Typical residential sidewalks vary in width from 4 to 8 feet. The *Americans with Disabilities Act Accessibility Guidelines (ADAAG)* require passing sections for sidewalks with widths less than 5 feet spaced every 200 feet. An optional planted strip may be provided between the sidewalk and the curb (2 ft minimum width) to allow for maintenance activities. At locations with sidewalks adjacent to the curb, the width should be 2 feet wider than the minimum width required.

Advantages of Buffer Areas:

- Increased pedestrian distance from moving traffic
- Aesthetics of the facility
- Reduced width of hard surface space
- Space for snow storage

A major disadvantage of buffers or plant strips is the possibility of requiring additional right-of-way.

The wider the sidewalk, the more room there is for street furniture, trees, utilities, and pedestrians, plus it is easier to maneuver around these fixed objects. It is important to maintain an unobstructed pathway.

Grade-Separated Pedestrian Crossings
A grade-separated pedestrian facility (either over or under the roadway) permits pedestrian and vehicle crossings at different levels without interference. These structures may be used at locations where pedestrian/traffic volumes, intersection capacity, etc. encourage their construction. Governmental regulations and codes can provide additional design guidance when considering these facilities. The *AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities* provides more specific information for these structures.

Pedestrian walkways should be a minimum of 8 feet wide. Wider walkways may be used for tunnels, high pedestrian traffic areas, and overpasses with a tunnel effect (from screens).

Vandalism is a legitimate concern for pedestrian/vehicle overpass structures, where individuals drop objects onto oncoming traffic. While there is no universal deterrent, options have been developed to deal with this problem, including:

- Solid plastic enclosures
- Screens

Possible Overpass Locations (with screens):

- Schools, playgrounds, etc., where children may be unaccompanied
- Large urban pedestrian overpasses, not under police surveillance
- Where history indicates a need

Curb Ramps
Curb ramps provide access between sidewalks and streets at pedestrian crossings. Basic curve types have been developed for use according to the intersection geometric characteristics.

Curb Ramp Design Considerations:

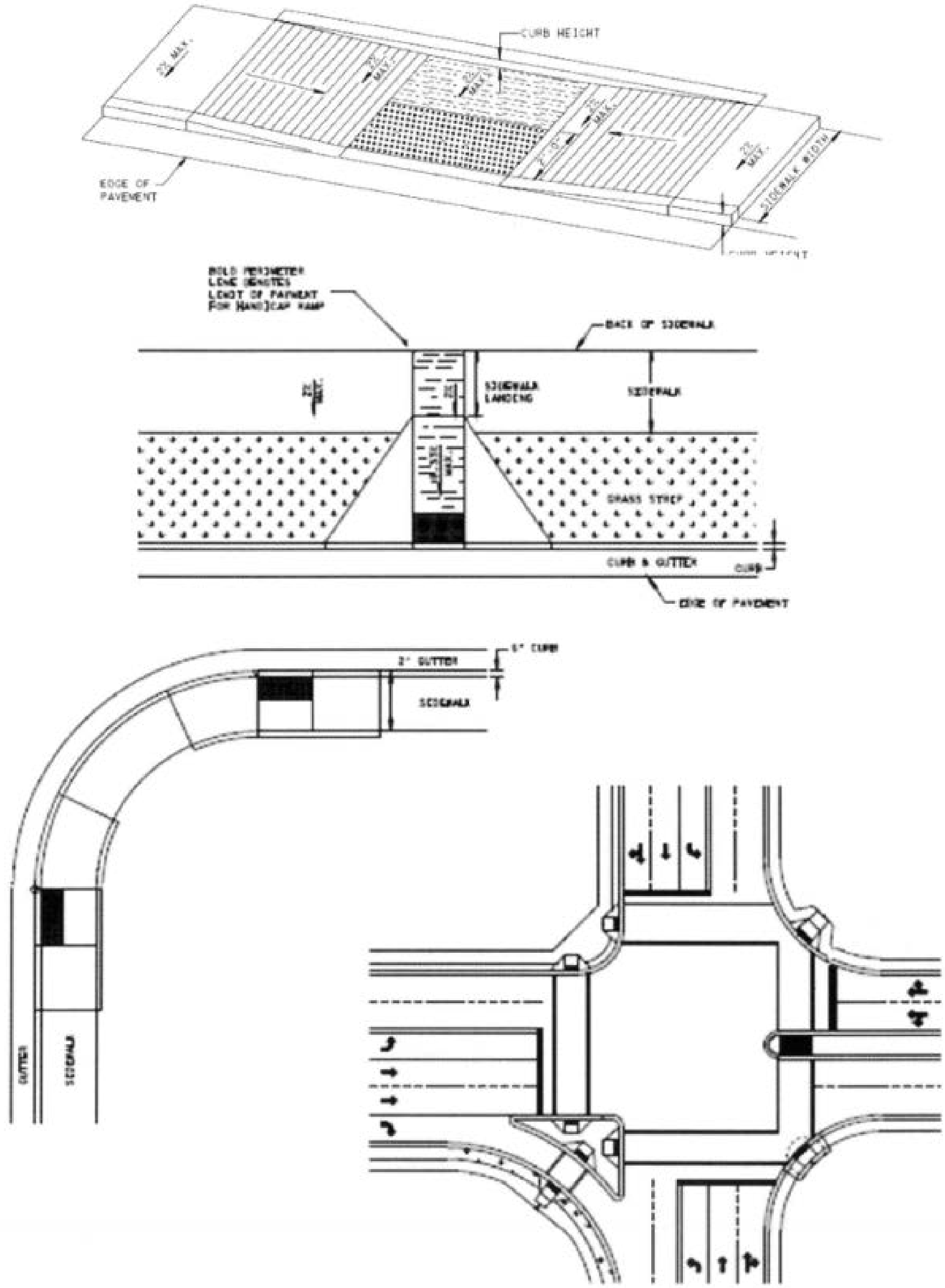
- Sidewalk width
- Sidewalk location

- Curb height and width
- Turning radius and curve length
- Street intersection angle
- Sign and signal locations
- Drainage inlets
- Utilities
- Sight obstructions
- Street width
- Border width

The *Public Rights-of-Way Accessibility Guidelines* provide the following guidance for curb ramps:

Minimum curb ramp width	4 ft
Maximum curb ramp grade	8.33%
Sidewalk cross slopes	2% maximum
Top level landing area	4 ft x 4 ft (with no obstructions, 2% max. cross slope)

Curb ramp locations should be closely integrated with the pedestrian crosswalk by having the curb ramp bottom within the crosswalk's parallel boundaries, and perpendicular to the curb face. These ramps are typically placed within the corner radius or beyond the radius on the tangent section.



Curb Ramp Examples

BICYCLE FACILITIES

Due to the bicycle's popularity as a mode of transportation, their needs should be considered when designing roadways. The main factors to consider for accommodating bicycles include:

- Type of bicyclist being served by the route (experienced, novice, children)
- Type of roadway project (widening, new construction, resurfacing)
- Traffic operations and design characteristics (traffic volume, sight distance, development)

The basic types of bicycle facilities include:

Shared lane: typical travel lane shared by both bicycles and vehicles
Wide outside lane: outside travel lane (14 ft min.) for both bicycles and vehicles
Bicycle lane: part of roadway exclusively designated for bicycles, etc.
Shoulder: roadway paving to the right of traveled way for usage
Multiuse path: physically separated facility for bicycles, etc.

Transportation planners and designers list the following factors that have a great impact on bicycle lanes: traffic volume, average operating speed, traffic mix, on-street parking, sight distance, and number of intersections.

RAILROAD-HIGHWAY GRADE CROSSINGS

The geometric roadway design for a railroad crossing should draw motorists' attention to roadway conditions. The major consideration is to enable highway traffic to move more efficiently.

Horizontal Alignment Guidelines

Intersect tracks at right angles and avoid nearby intersections or ramps:

- Enhances sight distance
- Reduces conflicting vehicle movements
- Preferable for cyclists

Avoid locating crossings on highway or railroad curves:

- Curvature inhibits driver's perception and sight distance
- Causes poor rideability and maintenance challenges (superelevation)

Where possible, the vertical alignment for a railroad-highway crossing should be as level as practical to enhance rideability, sight distance, acceleration, and braking. Limitations for the roadway surface include:

- Being on the same plane as the rail tops for a minimum of 2 feet outside the rails
- Limited to 3 inches higher or lower than the top of the nearest rail at 30 feet from the rail

Grade crossing geometric design consists of utilizing alignments (horizontal and vertical), sight distance and cross-sections. This design may change with the type of warning devices used.

Railroad-highway grade crossing traffic control devices may consist of passive warning devices (signs, pavement markings) and/or active warning devices (flashing light signals, automatic gates). Guidelines regarding these devices are covered fully in the MUTCD.

At railroad-highway grade crossings without train-activated warning devices, the following two scenarios are typically used to determine sight distances:

- Vehicle can see the approaching train with a sight line adequate to pass the crossing prior to the train's arrival (GO)
- Vehicle can see the approaching train with a sight line adequate to stop prior to crossing (STOP)

The following texts provide a complete discussion of railroad-highway grade crossing sight distances:

- NCHRP Report 288
- Railroad-Highway Grade Crossing Surfaces

SUMMARY

This course summarized and highlighted the basic elements of at-grade intersection design. There are clearly many considerations, including costs, maintenance, adjacent land uses, operational and safety impacts, environmental impacts, and infrastructure needs. The designer's task requires balancing trade-offs in order to provide safe, efficient, and cost-effective transportation of people and goods.

Intersections are similar to other major infrastructure projects by consuming valuable resources and often adversely affecting the users or those in close proximity to them. All parties charged with resource protection normally expect any adverse effects to be addressed in the planning and design of highways.

The mere application of design standards and criteria to 'solve' a problem is inadequate. The various complex safety and operational relationships behind the design guidelines and criteria must be clearly understood. Designers must be prepared to present the reasons for a design and to develop any alternatives. This is possible only if the designer understands how all elements of the roadway (horizontal and vertical alignment, cross section, intersections and interchanges) contribute to its safety and operation.

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(Note: All figures, illustrations, tables, etc. contained within this course are from this text unless noted otherwise.)

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