U.S. Department of Transportation

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Roundabouts:

An Informational Guide

U.S. Department of Transportation

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16. Abstract

The guidance supplied in this document, *Roundabouts: An Informational Guide,* is based on established international and U.S. practices and is supplemented by recent research. The guide is comprehensive in recognition of the diverse needs of transportation professionals and the public for introductory material through design detail, as well as the wide range of potential applications of roundabout intersections. The following topics are addressed: definition of a roundabout and what distinguishes roundabouts from traffic circles; public acceptance and legal issues associated with roundabouts; consideration of all user modes, including heavy vehicles, buses, transit, bicycles, and pedestrians; a methodology for identifying appropriate sites for roundabouts and the range of conditions for which roundabouts offer optimal performance; methodologies for estimating roundabout capacity, delays, and queues with reference to the *Highway Capacity Manual*; design principles and guidance on safety and geometric design, with reference to applicable national standards such as the *AASHTO Policy on Geometric Design of Highways and Streets*; guidelines for control features such as signing and pavement markings, with reference to the *Manual on Uniform Traffic Control Devices*; illumination; and landscaping.

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Roundabouts
An Informational Guide

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Foreword

Roundabouts are a form of intersection control in common use throughout the world. Until recently, many transportation professionals and agencies in the United States have been hesitant to recommend and install roundabouts, however, due to a lack of objective nationwide guidelines on planning, performance, and design of roundabouts. Prior to the development of this guide, transportation professionals who were interested in roundabouts had to rely on foreign roundabout design guides, consultants with roundabout experience, or in some States, statewide roundabout design guides. To facilitate safe, optimal operation and designs that are both consistent at a national level and consequential for driver expectation and safety, the Federal Highway Administration (FHWA) developed this informational guide on roundabouts.

The information supplied in this document, *Roundabouts: An Informational Guide,* is based on established international and U.S. practices and is supplemented by recent research. The guide is comprehensive in recognition of the diverse needs of transportation professionals and the public for introductory material through design detail, as well as the wide range of potential applications of roundabout intersections.

Roundabout operation and safety performance are particularly sensitive to geometric design elements. Uncertainty regarding evaluation procedures can result in over-design and less safety. The "design problem" is essentially one of determining a design that will accommodate the traffic demand while minimizing some combination of delay, crashes, and cost to all users, including motor vehicles, pedestrians, and bicyclists. Evaluation procedures are suggested, or information is provided, to quantify and cost how well a design achieves each of these aims.

Since there is no absolutely optimum design, this guide is not intended as an inflexible "rule book," but rather attempts to explain some principles of good design and indicate potential tradeoffs. In this respect, the "design space" consists of performance evaluation models and design principles such as those provided in this guide, combined with the expert heuristic knowledge of a designer. Adherence to these principles still does not ensure good design, which remains the responsibility of the designer.

Michael F. Trentacoste
Director, Office of Safety Research and Development

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Photo Credits

Barry Crown: Exhibits 8-6, 8-7

Ken Courage: Exhibit 1-5 (g, Portland)

Lee Rodegerdts: Exhibits 1-5 (all except g, Portland), 1-6 (all except Fort Pierce), 2-4 (all except Fort Pierce), 3-3, 3-4, 6-23, 6-42, 7-10 (all), 7-11 (all), 7-14 (all), 7-16 (all), 7-22, 8-7, 8-8, 8-9, C-3 (a, d–i, k–n)

Paul Ryus: Exhibits 1-6 (Fort Pierce), 2-4 (Fort Pierce), C-3 (b, c, j)

1 Introduction

Chapter 1 Introduction

Circular intersections were first introduced in the U.S. in 1905.

Traffic circles have been part of the transportation system in the United States since 1905, when the Columbus Circle designed by William Phelps Eno opened in New York City. Subsequently, many large circles or rotaries were built in the United States. The prevailing designs enabled high-speed merging and weaving of vehicles. Priority was given to entering vehicles, facilitating high-speed entries. High crash experience and congestion in the circles led to rotaries falling out of favor in America after the mid-1950's. Internationally, the experience with traffic circles was equally negative, with many countries experiencing circles that locked up as traffic volumes increased.

The modern roundabout was developed in the United Kingdom in the 1960's.

The modern roundabout was developed in the United Kingdom to rectify problems associated with these traffic circles. In 1966, the United Kingdom adopted a mandatory "give-way" rule at all circular intersections, which required entering traffic to give way, or yield, to circulating traffic. This rule prevented circular intersections from locking up, by not allowing vehicles to enter the intersection until there were sufficient gaps in circulating traffic. In addition, smaller circular intersections were proposed that required adequate horizontal curvature of vehicle paths to achieve slower entry and circulating speeds.

Modern roundabouts provide substantially better operational and safety characteristics than older traffic circles and rotaries.

These changes improved the safety characteristics of the circular intersections by reducing the number and particularly the severity of collisions. Thus, the resultant modern roundabout is significantly different from the older style traffic circle both in how it operates and in how it is designed. The modern roundabout represents a substantial improvement, in terms of operations and safety, when compared with older rotaries and traffic circles (1, 2, 3). Therefore, many countries have adopted them as a common intersection form and some have developed extensive design guides and methods to evaluate the operational performance of modern roundabouts.

1.1 Scope of the Guide

This guide provides information and guidance on roundabouts, resulting in designs that are suitable for a variety of typical conditions in the United States. The scope of this guide is to provide general information, planning techniques, evaluation procedures for assessing operational and safety performance, and design guidelines for roundabouts.

International consensus has not been achieved on some aspects of roundabout design.

This guide has been developed with the input from transportation practitioners and researchers from around the world. In many cases, items from national and international practice and research indicate considerable consensus, and these items have been included in this guide. However, other items have generated considerable differences of opinion (e.g., methods of estimating capacity), and some practices vary considerably from country to country (e.g., marking of the circulatory roadway in multilane roundabouts). Where international consensus is not apparent, a reasoned approach is presented that the authors believe is currently most appropriate for the United States. As more roundabouts are built, the opportunity to conduct research to refine—or develop better—methods will enable future editions of this guide to improve.

Despite the comprehensive nature of this document, it cannot discuss every issue related to roundabouts. In particular, it does not represent the following topics:

Topics not discussed in this guide.

- *Nonmountable traffic calming circles.* These are small traffic circles with raised central islands. They are typically used on local streets for speed and volume control. They are typically not designed to accommodate large vehicles, and often left-turning traffic is required to turn left in front of the circle. Mini-roundabouts, which are presented, may be an appropriate substitute.
- *Specific legal or policy requirements and language.* The legal information that is provided in this guide is intended only to make the reader aware of potential issues. The reader is encouraged to consult with an attorney on specific legal issues before adopting any of the recommendations contained herein. Similarly, regarding policy information, the guide refers to or encompasses applicable policies, such as those of the American Association of State Highway and Transportation Officials (AASHTO) (4). It does not, however, establish any new policies.
- *Roundabouts with more than two entry lanes on an approach.* While acknowledging the existence and potential of such large roundabouts, the guide does not provide specific guidance on the analysis or design of such roundabouts. However, the design principles contained in this document are also applicable to larger roundabouts. The relative safety advantages of roundabout intersections diminish at high traffic flows, particularly with regard to pedestrians and bicyclists. The advantages of larger roundabouts are their higher capacities that may make them attractive alternatives at sites with high traffic volumes. More intricate design is required to ensure adequate operational and safety performance. Therefore, expert operations and design advice should be sought and roundabout analysis software should be utilized in such circumstances. As users and designers in the United States become more familiar with roundabouts, this experience may then be extended to such applications.

1.2 Organization of the Guide

This guide has been structured to address the needs of a variety of readers including the general public, policy-makers, transportation planners, operations and safety analysts, conceptual and detailed designers. This chapter distinguishes roundabouts from other traffic circles and defines the types of roundabouts addressed in the remainder of the guide. The remaining chapters in this guide generally increase in the level of detail provided.

Chapter 2—Policy Considerations: This chapter provides a broad overview of the performance characteristics of roundabouts. The costs associated with roundabouts versus other forms of intersections, legal issues, and public involvement techniques are discussed.

Chapter 3—Planning: This chapter discusses general guidelines for identifying appropriate intersection control options, given daily traffic volumes, and procedures for evaluating the feasibility of a roundabout at a given location. Chapters 2 and 3 provide sufficient detail to enable a transportation planner to decide under which circumstances roundabouts are likely to be appropriate, and how they compare to alternatives at a specific location.

Chapter 4—Operational Analysis: Methods are presented for analyzing the operational performance of each category of roundabout in terms of capacity, delay, and queuing.

Chapter 5—Safety: This chapter discusses the expected safety performance of roundabouts.

Chapter 6—Geometric Design: Specific geometric design principles for roundabouts are presented. The chapter then discusses each design element in detail, along with appropriate parameters to use for each type of roundabout.

Chapter 7—Traffic Design and Landscaping: This chapter discusses a number of traffic design aspects once the basic geometric design has been established. These include signs, pavement markings, and illumination. In addition, the chapter provides discussion on traffic maintenance during construction and landscaping.

Chapter 8—System Considerations: This chapter discusses specific issues and treatments that may arise from the systems context of a roundabout. The material may be of interest to transportation planners as well as operations and design engineers. Signal control at roundabouts is discussed. The chapter then considers the issue of rail crossings through the roundabout or in close proximity. Roundabouts in series with other roundabouts are discussed, including those at freeway interchanges and those in signalized arterial networks. Finally, the chapter presents simulation models as supplementary operational tools capable of evaluating roundabout performance within an overall roadway system.

Appendices: Three appendices are provided to expand upon topics in certain chapters. Appendix A provides information on the capacity models in Chapter 4. Appendix B provides design templates for each of the categories of roundabout described in Chapter 1, assuming four perpendicular legs. Appendix C provides information on the alternative signing and pavement marking in Chapter 7.

Margin notes have been used to highlight important points.

Several typographical devices have been used to enhance the readability of the guide. Margin notes, such as the note next to this paragraph, highlight important points or identify cross-references to other chapters of the guide. References have been listed at the end of each chapter and have been indicated in the text using numbers in parentheses, such as: (3). New terms are presented in *italics* and are defined in the glossary at the end of the document.

1.3 Defining Physical Features

A roundabout is a type of circular intersection, but not all circular intersections can be classified as roundabouts. In fact, there are at least three distinct types of circular intersections:

Types of circular intersections.

- *Rotaries* are old-style circular intersections common to the United States prior to the 1960's. Rotaries are characterized by a large diameter, often in excess of 100 m (300 ft). This large diameter typically results in travel speeds within the circulatory roadway that exceed 50 km/h (30 mph). They typically provide little or no horizontal deflection of the paths of through traffic and may even operate according to the traditional "yield-to-the-right" rule, i.e., circulating traffic yields to entering traffic.
- *Neighborhood traffic circles* are typically built at the intersections of local streets for reasons of traffic calming and/or aesthetics. The intersection approaches may be uncontrolled or stop-controlled. They do not typically include raised channelization to guide the approaching driver onto the circulatory roadway. At some traffic circles, left-turning movements are allowed to occur to the left of (clockwise around) the central island, potentially conflicting with other circulating traffic.
- *Roundabouts* are circular intersections with specific design and traffic control features. These features include yield control of all entering traffic, channelized approaches, and appropriate geometric curvature to ensure that travel speeds on the circulatory roadway are typically less than 50 km/h (30 mph). Thus, roundabouts are a subset of a wide range of circular intersection forms.

Key roundabout features include:

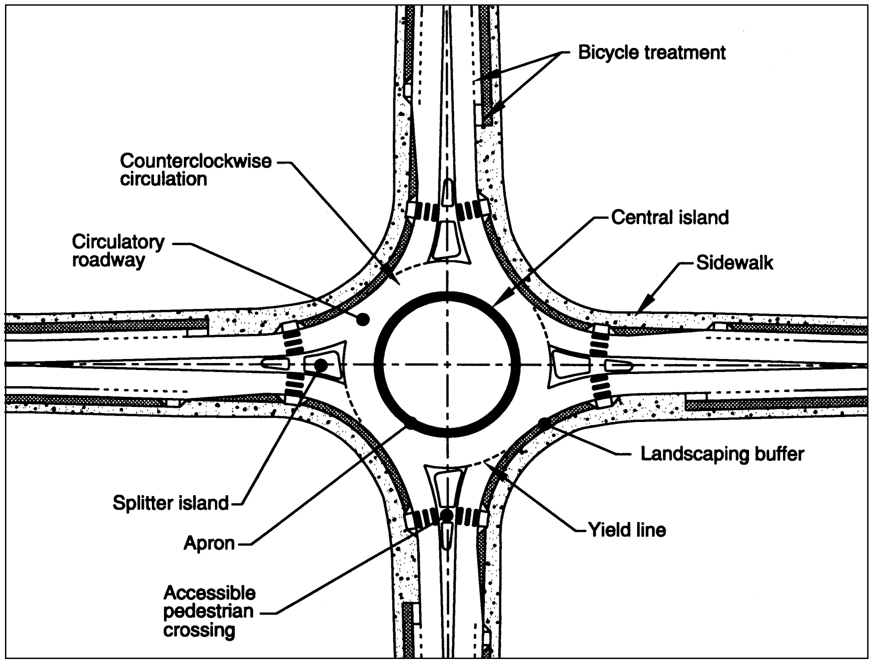
- **Yield control of entering traffic**
- **Channelized approaches**
- **Appropriate geometric curvature to slow speeds**

To more clearly identify the defining characteristics of a roundabout, consistent definitions for each of the key features, dimensions, and terms are used throughout this guide. Exhibit 1-1 is a drawing of a typical roundabout, annotated to identify the key features. Exhibit 1-2 provides a description of each of the key features.

1.4 Key Dimensions

For operational analysis and design purposes, it is useful to define a number of key dimensions. Exhibit 1-3 shows a number of key dimensions that are described in Exhibit 1-4. Note that these exhibits do not present all of the dimensions needed in the detailed analysis and design of roundabouts; these will be presented and defined in later chapters as needed.

Exhibit 1-1. Drawing of key roundabout features.



Splitter islands have multiple roles. They:

- **Separate entering and exiting traffic**
- **Deflect and slow entering traffic**
- **Provide a pedestrian refuge**

Exhibit 1-2. Description of key roundabout features.

Feature	Description
Central island	The *central island* is the raised area in the center of a roundabout around which traffic circulates.
Splitter island	A *splitter island* is a raised or painted area on an approach used to separate entering from exiting traffic, deflect and slow entering traffic, and provide storage space for pedestrians crossing the road in two stages.
Circulatory roadway	The *circulatory roadway* is the curved path used by vehicles to travel in a counter-clockwise fashion around the central island
Apron	If required on smaller roundabouts to accommodate the wheel tracking of large vehicles, an *apron* is the mountable portion of the central island adjacent to the circulatory roadway.
Yield line	A *yield line* is a pavement marking used to mark the point of entry from an approach into the circulatory roadway and is generally marked along the inscribed circle. Entering vehicles must yield to any circulating traffic coming from the left before crossing this line into the circulatory roadway.
Accessible pedestrian crossings	*Accessible pedestrian crossings* should be provided at all roundabouts. The crossing location is set back from the yield line, and the splitter island is cut to allow pedestrians, wheelchairs, strollers, and bicycles to pass through.
Bicycle treatments	*Bicycle treatments* at roundabouts provide bicyclists the option of traveling through the roundabout either as a vehicle or as a pedestrian, depending on the bicyclist's level of comfort.
Landscaping buffer	*Landscaping buffers* are provided at most roundabouts to separate vehicular and pedestrian traffic and to encourage pedestrians to cross only at the designated crossing locations. Landscaping buffers can also significantly improve the aesthetics of the intersection.

Exhibit 1-3. Drawing of key roundabout dimensions.

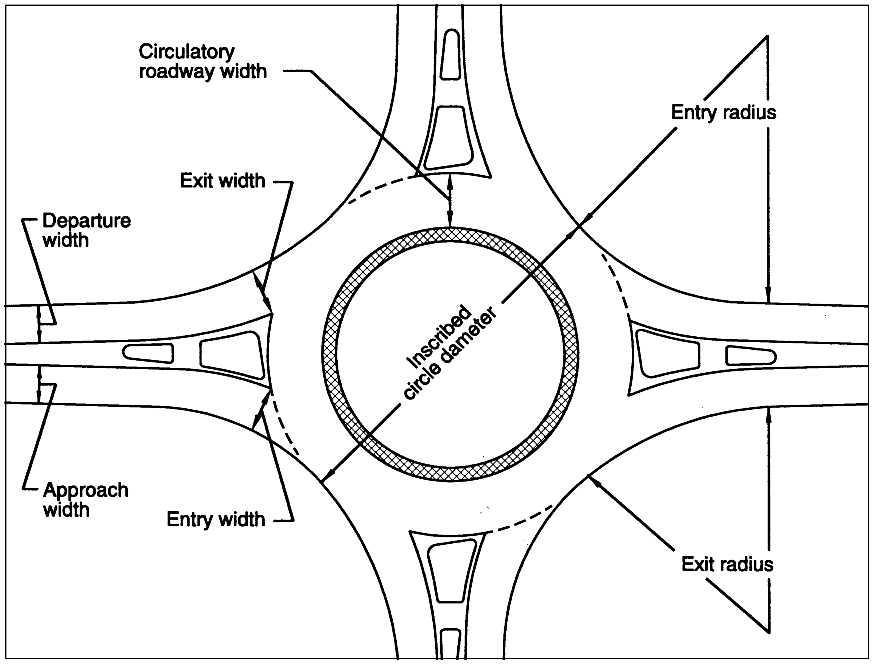


Exhibit 1-4. Description of key roundabout dimensions.

Dimension	Description
Inscribed circle diameter	The *inscribed circle diameter* is the basic parameter used to define the size of a roundabout. It is measured between the outer edges of the circulatory roadway.
Circulatory roadway width	The *circulatory roadway width* defines the roadway width for vehicle circulation around the central island. It is measured as the width between the outer edge of this roadway and the central island. It does not include the width of any mountable apron, which is defined to be part of the central island.
Approach width	The *approach width* is the width of the roadway used by approaching traffic upstream of any changes in width associated with the roundabout. The approach width is typically no more than half of the total width of the roadway.
Departure width	The *departure width* is the width of the roadway used by departing traffic downstream of any changes in width associated with the roundabout. The departure width is typically less than or equal to half of the total width of the roadway.
Entry width	The *entry width* defines the width of the entry where it meets the inscribed circle. It is measured perpendicularly from the right edge of the entry to the intersection point of the left edge line and the inscribed circle.
Exit width	The *exit width* defines the width of the exit where it meets the inscribed circle. It is measured perpendicularly from the right edge of the exit to the intersection point of the left edge line and the inscribed circle.
Entry radius	The *entry radius* is the minimum radius of curvature of the outside curb at the entry.
Exit radius	The *exit radius* is the minimum radius of curvature of the outside curb at the exit.

1.5 Distinguishing Roundabouts from Other Circular Intersections

Circular intersections that do not conform to the characteristics of modern roundabouts are called "traffic circles" in this guide.

Since the purpose of this guide is to assist in the planning, design, and performance evaluation of roundabouts, not other circular intersections, it is important to be able to distinguish between them. Since these distinctions may not always be obvious, the negative aspects of rotaries or neighborhood traffic circles (hereafter referred to as "*traffic circles*") may be mistaken by the public for a roundabout. Therefore, the ability to carefully distinguish roundabouts from traffic circles is important in terms of public understanding.

How then does one distinguish a roundabout from other forms of circular intersection? Exhibit 1-5 identifies some of the major characteristics of roundabouts and contrasts them with other traffic circles. Note that some of the traffic circles shown have many of the features associated with roundabouts but are deficient in one or more critical areas. Note also that these characteristics apply to yield-controlled roundabouts; signalized roundabouts are a special case discussed in Chapter 8.

Exhibit 1-5. Comparison of roundabouts with traffic circles.

Roundabouts must have all of the characteristics listed in the left column.

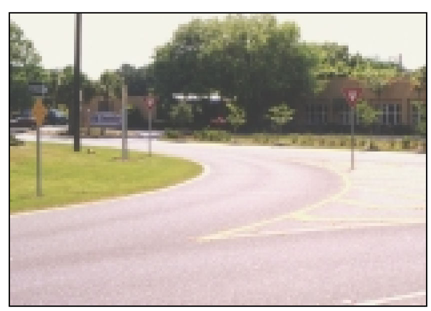
Chapter 8 discusses signalization at roundabouts.

Roundabouts	Traffic Circles

(a) Traffic control

Yield control is used on all entries. The circulatory roadway has no control. *Santa Barbara, CA*

Some traffic circles use stop control, or no control, on one or more entries. *Hagerstown, MD*



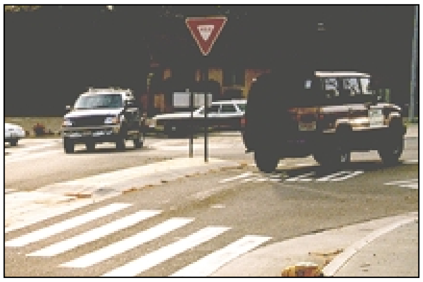
(b) Priority to circulating vehicles

Circulating vehicles have the right-of-way. *Santa Barbara, CA*

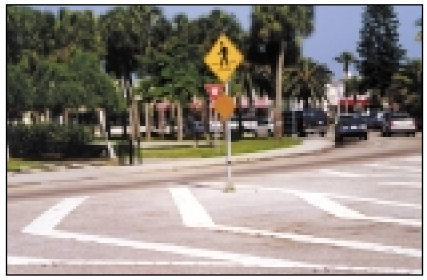
Some traffic circles require circulating traffic to yield to entering traffic. *Sarasota, FL*

Exhibit 1-5. (continued). Comparison of roundabouts with traffic circles.

Roundabouts	Traffic Circles



(c) Pedestrian access
Pedestrian access is allowed only across the legs of the roundabout, behind the yield line. *Santa Barbara, CA*



Some traffic circles allow pedestrian access to the central island. *Sarasota, FL*

(d) Parking
No parking is allowed within the circulatory roadway or at the entries. *Avon, CO*

Some traffic circles allow parking within the circulatory roadway. *Sarasota, FL*

All traffic circulates counter-clockwise around a roundabouts central island.

(e) Direction of circulation
All vehicles circulate counter-clockwise and pass to the right of the central island. *Naples, FL*

Some neighborhood traffic circles allow left-turning vehicles to pass to the left of the central island. *Portland, OR*

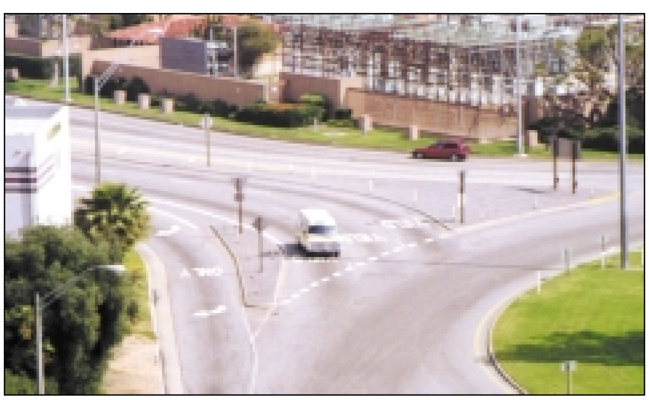
In addition to the design elements identified in Exhibit 1-5, roundabouts often include one or more additional design elements intended to enhance the safety and/or capacity of the intersection. However, their absence does not necessarily preclude an intersection from operating as a roundabout. These additional elements are identified in Exhibit 1-6.

Exhibit 1-6. Common design elements at roundabouts.

Roundabouts may have these additional design features.

Characteristic	Description
(a) Adequate speed reduction	 Good roundabout design requires entering vehicles to negotiate a small enough radius to slow speeds to no greater than 50 km/h (30 mph). Once within the circulatory roadway, vehicles' paths are further deflected by the central island. *West Boca Raton, FL*
	 Some roundabouts allow high-speed entries for major movements. This increases the risk for more severe collisions for vehicles, bicycles, and pedestrians. *Bradenton Beach, FL*

Exhibit 1-6 (continued). Common design elements at roundabouts.

Characteristic	Description
(b) Design vehicle	 Good roundabout design makes accommodation for the appropriate design vehicle. For small roundabouts, this may require the use of an apron. *Lothian, MD*
	 Some roundabouts are too small to accommodate large vehicles that periodically approach the intersection. *Naples, FL*
(c) Entry flare	 Flare on an entry to a roundabout is the widening of an approach to multiple lanes to provide additional capacity and storage at the yield line. *Long Beach, CA*

Aprons can be used in small roundabouts to accommodate the occasional large vehicle that may use the intersection.

Exhibit 1-6 (continued). Common design elements at roundabouts.

Characteristic	Description
(d) Splitter island	 All except mini-roundabouts have raised splitter islands. These are designed to separate traffic moving in opposite directions, deflect entering traffic, and to provide opportunities for pedestrians to cross in two stages. Mini-roundabouts may have splitter islands defined only by pavement markings. *Tavares, FL*
(e) Pedestrian crossing locations	 Pedestrian crossings are located at least one vehicle length upstream of the yield point. *Fort Pierce, FL*

1.6 Roundabout Categories

For the purposes of this guide, roundabouts have been categorized according to size and environment to facilitate discussion of specific performance or design issues. There are six basic categories based on environment, number of lanes, and size:

This guide uses six basic roundabout categories.

- Mini-roundabouts
- Urban compact roundabouts
- Urban single-lane roundabouts
- Urban double-lane roundabouts
- Rural single-lane roundabouts
- Rural double-lane roundabouts

Multilane roundabouts with more than two approach lanes are possible, but not explicitly covered in this guide.

Multilane roundabouts with more than two approach lanes are possible, but they are not covered explicitly by this guide, although many of the design principles contained in this guide would still apply. For example, the guide provides guidance on the design of flaring approaches from one to two lanes. Although not explicitly discussed, this guidance could be extended to the design of larger roundabout entries.

Note that separate categories have not been explicitly identified for suburban environments. Suburban settings may combine higher approach speeds common in rural areas with multimodal activity that is more similar to urban settings. Therefore, they should generally be designed as urban roundabouts, but with the high-speed approach treatments recommended for rural roundabouts.

Suburban roundabouts incorporate elements of both urban and rural roundabouts.

In most cases, designers should anticipate the needs of pedestrians, bicyclists, and large vehicles. Whenever a raised splitter island is provided, there should also be an at-grade pedestrian refuge. In this case, the pedestrian crossing facilitates two separate moves: curb-to-island and island-to-curb. The exit crossing will typically require more vigilance from the pedestrian and motorist than the entry crossing. Further, it is recommended that all urban crosswalks be marked. Under all urban design categories, special attention should be given to assist pedestrian users who are visually impaired or blind, through design elements. For example, these users typically attempt to maintain their approach alignment to continue across a street in the crosswalk, since the crosswalk is often a direct extension of the sidewalk. A roundabout requires deviation from that alignment, and attention needs to be given to providing appropriate informational cues to pedestrians regarding the location of the sidewalk and the crosswalk, even at mini-roundabouts. For example, appropriate landscaping is one method of providing some information. Another is to align the crosswalk ramps perpendicular to the pedestrian's line of travel through the pedestrian refuge.

Roundabout design should generally accommodate pedestrian, bicycle, and large vehicle use.

1.6.1 Comparison of roundabout categories

Exhibit 1-7 summarizes and compares some fundamental design and operational elements for each of the six roundabout categories developed for this guide. The following sections provide a qualitative discussion of each category.

Exhibit 1-7. Basic design characteristics for each of the six roundabout categories.

Design Element	Mini-Roundabout	Urban Compact	Urban Single-Lane	Urban Double-Lane	Rural Single-Lane	Rural Double-Lane
Recommended maximum entry design speed	25 km/h (15 mph)	25 km/h (15 mph)	35 km/h (20 mph)	40 km/h (25 mph)	40 km/h (25 mph)	50 km/h (30 mph)
Maximum number of entering lanes per approach	1	1	1	2	1	2
Typical inscribed circle diameter[1]	13 m to 25 m (45 ft to 80 ft)	25 to 30 m (80 to 100 ft)	30 to 40 m (100 to 130 ft)	45 to 55 m (150 to 180 ft)	35 to 40 m (115 to 130 ft)	55 to 60 m (180 to 200 ft)
Splitter island treatment	Raised if possible, crosswalk cut if raised	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised and extended, with crosswalk cut	Raised and extended, with crosswalk cut
Typical daily service volumes on 4-leg roundabout (veh/day)	10,000	15,000	20,000	Refer to Chapter 4 procedures	20,000	Refer to Chapter 4 procedures

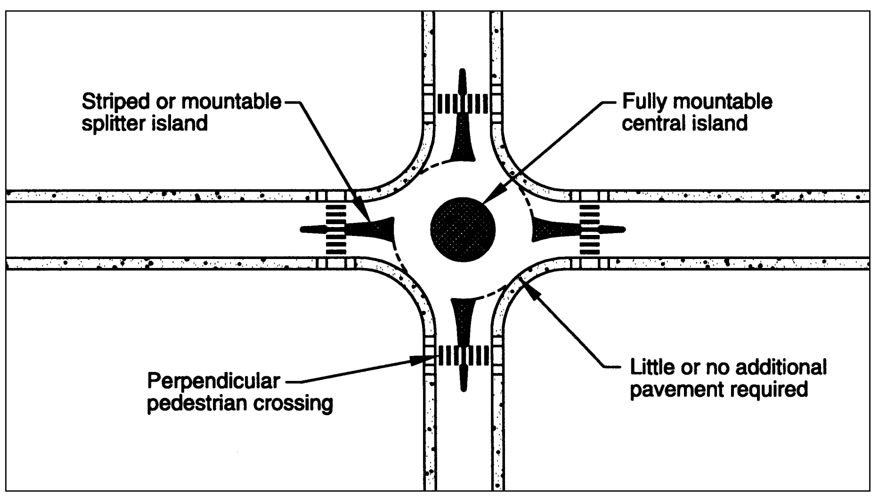
1. Assumes 90-degree entries and no more than four legs.

1.6.2 Mini-roundabouts

Mini-roundabouts can be useful in low-speed urban environments with right-of-way constraints.

Mini-roundabouts are small roundabouts used in low-speed urban environments, with average operating speeds of 60km/h (35mph) or less. Exhibit 1-8 provides an example of a typical mini-roundabout. They can be useful in low-speed urban environments in cases where conventional roundabout design is precluded by right-of-way constraints. In retrofit applications, mini-roundabouts are relatively inexpensive because they typically require minimal additional pavement at the intersecting roads-for example, minor widening at the corner curbs. They are mostly recommended when there is insufficient right-of-way for an urban compact roundabout. Because they are small, mini-roundabouts are perceived as pedestrian-friendly with short crossing distances and very low vehicle speeds on approaches and exits. The mini-roundabout is designed to accommodate passenger cars without requiring them to drive over the central island. To maintain its perceived compactness and low speed characteristics, the yield lines are positioned just outside of the swept path of the largest expected vehicle. However, the central island is mountable, and larger vehicles may cross over the central island, but not to the left of it. Speed control around the mountable central island should be provided in the design by requiring horizontal deflection. Capacity for this type of roundabout is expected to be similar to that of the compact urban roundabout. The recommended design of these roundabouts is based on the German method, with some influence from the United Kingdom.

Exhibit 1-8. Typical mini-roundabout.



1.6.3 Urban compact roundabouts

Like mini-roundabouts, urban compact roundabouts are intended to be pedestrian- and bicyclist-friendly because their perpendicular approach legs require very low vehicle speeds to make a distinct right turn into and out of the circulatory roadway. All legs have single-lane entries. However, the urban compact treatment meets all the design requirements of effective roundabouts. The principal objective of this design is to enable pedestrians to have safe and effective use of the intersection. Capacity should not be a critical issue for this type of roundabout to be considered. The geometric design includes raised splitter islands that incorporate at-grade pedestrian storage areas, and a nonmountable central island. There is usually an apron surrounding the nonmountable part of the compact central island to accommodate large vehicles. The recommended design of these roundabouts is similar to those in Germany and other northern European countries. Exhibit 1-9 provides an example of a typical urban compact roundabout.

Urban compact roundabouts are intended to be pedestrian-friendly; capacity should not be a critical issue when considering this type.

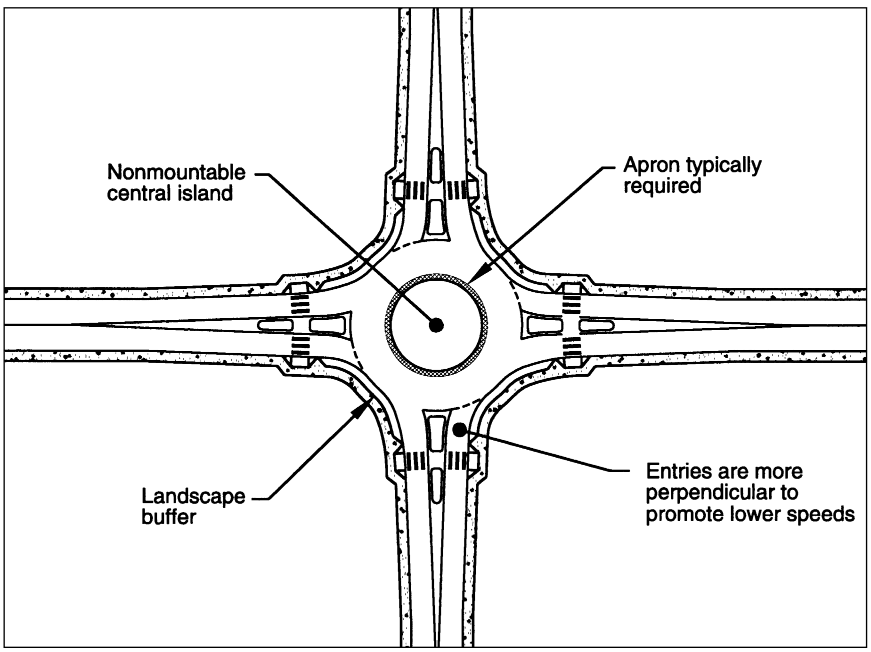


Exhibit 1-9. Typical urban compact roundabout.

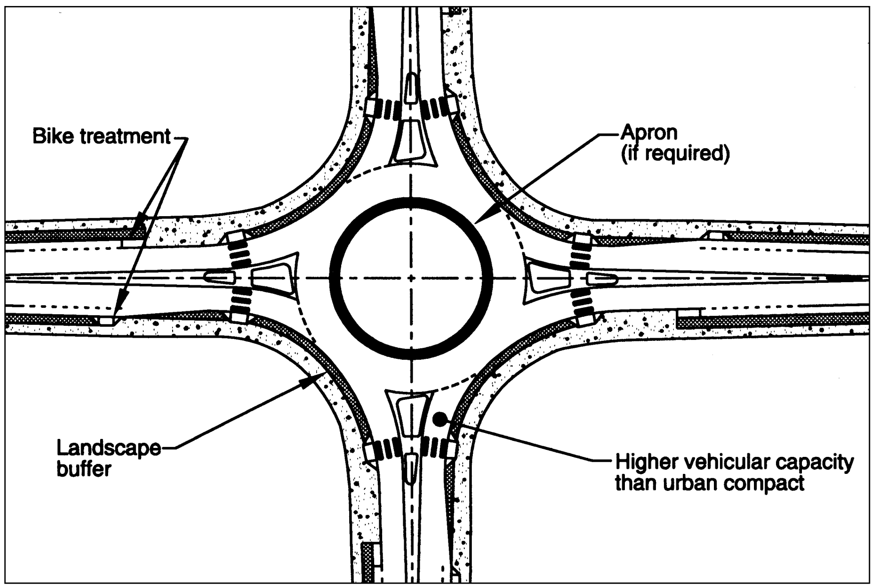
1.6.4 Urban single-lane roundabouts

Urban single-lane roundabouts have slightly higher speeds and capacities than urban compact roundabouts.

This type of roundabout is characterized as having a single lane entry at all legs and one circulatory lane. Exhibit 1-10 provides an example of a typical urban single-lane roundabout. They are distinguished from urban compact roundabouts by their larger inscribed circle diameters and more tangential entries and exits, resulting in higher capacities. Their design allows slightly higher speeds at the entry, on the circulatory roadway, and at the exit. Notwithstanding the larger inscribed circle diameters than compact roundabouts, the speed ranges recommended in this guide are somewhat lower than those used in other countries, in order to enhance safety for bicycles and pedestrians. The roundabout design is focused on achieving consistent entering and circulating vehicle speeds. The geometric design includes raised splitter islands, a nonmountable central island, and preferably, no apron. The design of these roundabouts is similar to those in Australia, France, and the United Kingdom.

The design focuses on consistent entering and exiting speeds.

Exhibit 1-10. Typical urban single-lane roundabout.



1.6.5 Urban double-lane roundabouts

Urban double-lane roundabouts include all roundabouts in urban areas that have at least one entry with two lanes. They include roundabouts with entries on one or more approaches that flare from one to two lanes. These require wider circulatory roadways to accommodate more than one vehicle traveling side by side. Exhibit 1-11 provides an example of a typical urban multilane roundabout. The speeds at the entry, on the circulatory roadway, and at the exit are similar to those for the urban single-lane roundabouts. Again, it is important that the vehicular speeds be consistent throughout the roundabout. The geometric design will include raised splitter islands, no truck apron, a nonmountable central island, and appropriate horizontal deflection.

The urban double-lane roundabout category includes roundabouts with one or more entries that flare from one to two lanes.

Alternate routes may be provided for bicyclists who choose to bypass the roundabout. Bicycle and pedestrian pathways must be clearly delineated with sidewalk construction and landscaping to direct users to the appropriate crossing locations and alignment. Urban double-lane roundabouts located in areas with high pedestrian or bicycle volumes may have special design recommendations such as those provided in Chapters 6 and 7. The design of these roundabouts is based on the methods used in the United Kingdom, with influences from Australia and France.

See Chapters 6 and 7 for special design considerations for pedestrians and bicycles.

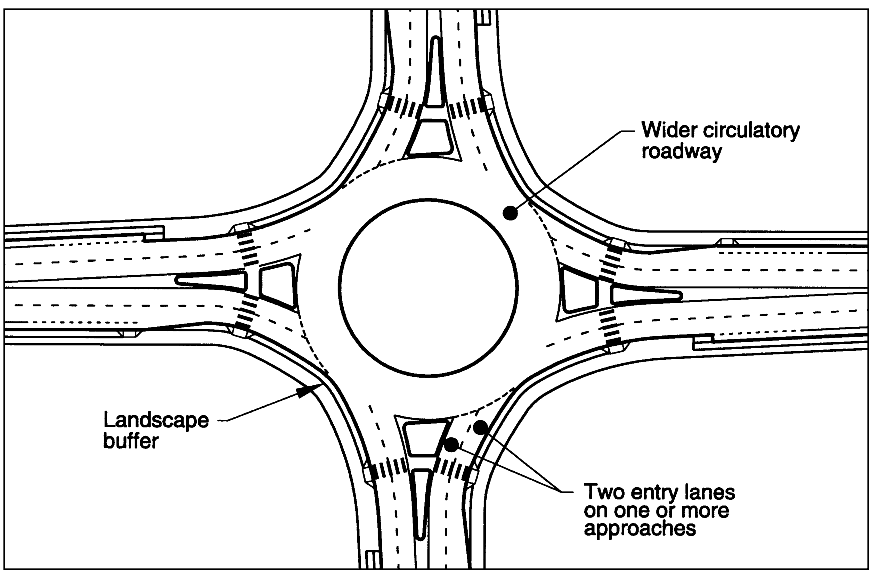


Exhibit 1-11. Typical urban double-lane roundabout.

1.6.6 Rural single-lane roundabouts

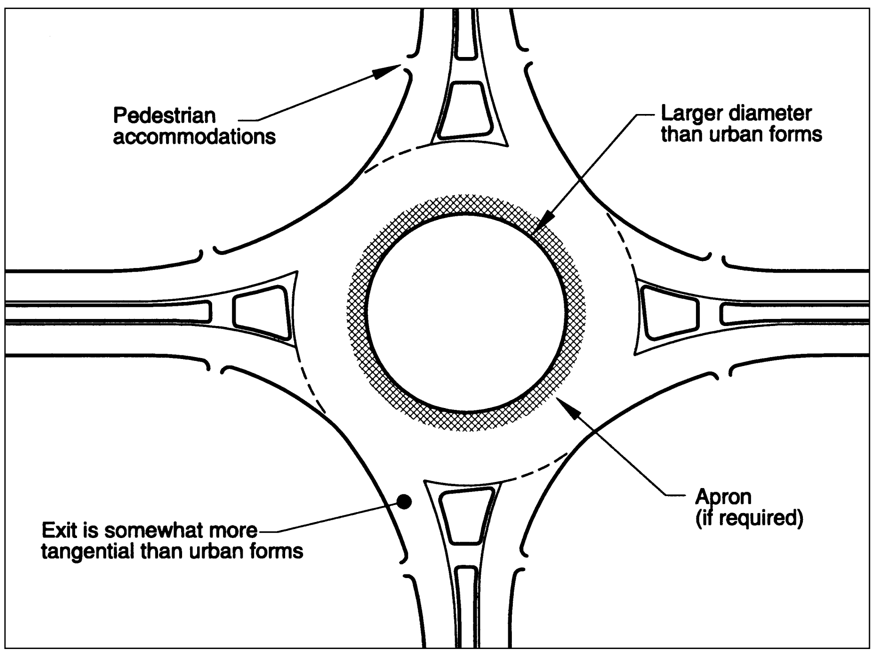
Because of their higher approach speeds, rural single-lane roundabouts require supplementary geometric and traffic control device treatments on the approaches.

Rural single-lane roundabouts generally have high average approach speeds in the range of 80 to 100 km/h (50 to 60 mph). They require supplementary geometric and traffic control device treatments on approaches to encourage drivers to slow to an appropriate speed before entering the roundabout. Rural roundabouts may have larger diameters than urban roundabouts to allow slightly higher speeds at the entries, on the circulatory roadway, and at the exits. This is possible if few pedestrians are expected at these intersections, currently and in future. There is preferably no apron because their larger diameters should accommodate larger vehicles. Supplemental geometric design elements include extended and raised splitter islands, a nonmountable central island, and adequate horizontal deflection. The design of these roundabouts is based primarily on the methods used by Australia, France, and the United Kingdom. Exhibit 1-12 provides an example of a typical rural single-lane roundabout.

Rural roundabouts that may become part of an urbanized area should include urban roundabout design features.

Rural roundabouts that may one day become part of an urbanized area should be designed as urban roundabouts, with slower speeds and pedestrian treatments. However, in the interim, they should be designed with supplementary approach and entry features to achieve safe speed reduction.

Exhibit 1-12. Typical rural single-lane roundabout.



1.6.7 Rural double-lane roundabouts

Rural double-lane roundabouts have speed characteristics similar to rural single-lane roundabouts with average approach speeds in the range of 80 to 100 km/h (50 to 60 mph). They differ in having two entry lanes, or entries flared from one to two lanes, on one or more approaches. Consequently, many of the characteristics and design features of rural double-lane roundabouts mirror those of their urban counterparts. The main design differences are designs with higher entry speeds and larger diameters, and recommended supplementary approach treatments. The design of these roundabouts is based on the methods used by the United Kingdom, Australia, and France. Exhibit 1-13 provides an example of a typical rural double-lane roundabout. Rural roundabouts that may one day become part of an urbanized area should be designed for slower speeds, with design details that fully accommodate pedestrians and bicyclists. However, in the interim they should be designed with approach and entry features to achieve safe speed reduction.

Rural double-lane roundabouts have higher entry speeds and larger diameters than their urban counterparts.

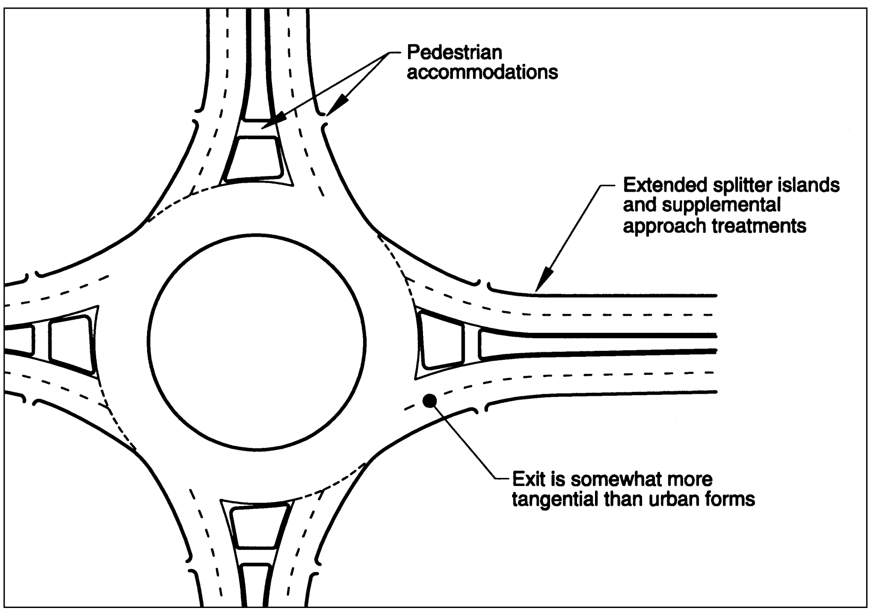


Exhibit 1-13. Typical rural double-lane roundabout.

1.7 References

1. Brown, M. *TRL State of the Art Review—The Design of Roundabouts.* London: HMSO, 1995.
2. Todd, K. "A history of roundabouts in Britain." *Transportation Quarterly,* Vol. 45, No. 1, January 1991.
3. Jacquemart, G. *Synthesis of Highway Practice 264: Modern Roundabout Practice in the United States.* National Cooperative Highway Research Program. Washington, D.C: National Academy Press, 1998.
4. American Association of State Highway and Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets.* Washington, D.C.: AASHTO, 1994.

2 Policy Considerations

Chapter 2 Policy Considerations

Roundabouts have unique characteristics that warrant consideration by developers and managers of the road system. This chapter provides a general overview of the characteristics of roundabouts and policy considerations pertaining to them. The information may be useful to policy makers and the general public. The reader is encouraged to refer to later chapters on the specifics associated with planning, operation, safety, and design of roundabouts.

2.1 Characteristics

The previous chapter described the physical features of a roundabout. This section describes performance characteristics that need to be considered, either at a policy level when introducing roundabouts into a region or at specific locations where a roundabout is one of the alternatives being considered.

2.1.1 Safety

This section provides an overview of the safety performance of roundabouts and then discusses the general characteristics that lead to this performance. It does not attempt to discuss all of the issues related to safety; the reader is encouraged to refer to Chapter 5 for a more detailed discussion.

Roundabouts are generally safer than other forms of intersection in terms of aggregate crash statistics for low and medium traffic capacity conditions (1). Injury crash rates for motor vehicle occupants are generally lower, although the proportion of single-vehicle crashes is typically higher. However, bicyclists and pedestrians are involved in a relatively higher proportion of injury accidents than they are at other intersections (2).

Roundabouts have been demonstrated to be generally safer for motor vehicles and pedestrians than other forms of at-grade intersections.

Exhibit 2-1 presents comparisons of before and after aggregate crash frequencies (average annual crashes per roundabout) involving users of eleven roundabouts constructed in the United States (3). The decrease in severe injury crashes is noteworthy. However, the "before" situation at these intersections required mitigation for safety. Therefore, some other feasible alternatives may also be expected to have resulted in a reduction in the crash frequencies. This study yielded insufficient data to draw conclusions regarding the safety of bicyclists and pedestrians.

Exhibit 2-1. Average annual crash frequencies at 11 U.S. intersections converted to roundabouts.

Type of roundabout	Sites	Before roundabout			Roundabout			Percent change		
		Total	Inj.[3]	PDO[4]	Total	Inj.	PDO	Total	Inj.	PDO
Single-Lane[1]	8	4.8	2.0	2.4	2.4	0.5	1.6	-51%	-73%	-32%
Multilane[2]	3	21.5	5.8	15.7	15.3	4.0	11.3	-29%	-31%	-10%
Total	11	9.3	3.0	6.0	5.9	1.5	4.2	-37%	-51%	-29%

Notes:
1. Mostly single-lane roundabouts with an inscribed circle diameter of 30 to 35 m (100 to 115 ft).
2. Multilane roundabouts with an inscribed circle diameter greater than 50 m (165 ft).
3. Inj. = Injury crashes.
4. PDO = Property Damage Only crashes.

Source: (3)

Good roundabout designs encourage speed reduction and speed consistency.

Good roundabout design places a high priority on speed reduction and speed consistency. Such designs require that vehicles negotiate the roundabout through a series of turning maneuvers at low speeds, generally less than 30 km/h (20 mph). Speed consistency refers to the design objective of slowing vehicles in stages down to the desired negotiating speed to be consistent with the expectations of drivers. Speed control is provided by geometric features, not only by traffic control devices or by the impedance of other traffic. Because of this, speed reduction can be achieved at all times of day. If achieved by good design, then in principle, lower vehicle speeds should provide the following safety benefits:

Potential safety benefits of low vehicle speeds.

- Reduce crash severity for pedestrians and bicyclists, including older pedestrians, children, and impaired persons;
- Provide more time for entering drivers to judge, adjust speed for, and enter a gap in circulating traffic;
- Allow safer merges into circulating traffic;
- Provide more time for all users to detect and correct for their mistakes or mistakes of others;
- Make collisions less frequent and less severe; and
- Make the intersection safer for novice users.

Visually impaired pedestrians are not provided with audible cues from vehicle streams.

For example, Exhibit 2-2 shows that a pedestrian is about three times more likely to die when struck at 50 km/h (30 mph) than at 32 km/h (20 mph), across a range of only 18 km/h (10 mph) difference in speed (4). Typical commuter bicyclist speeds are in the range of 20 to 25 km/h (12 to 15 mph). Therefore, the difference in design speed is critical to all users who are not within the protective body of a motorized vehicle. The minor additional delay or inconvenience to drivers of lower-speed roundabout designs (as compared to higher-speed roundabout designs) is a tradeoff for the substantial safety benefit to pedestrians and bicyclists. Older drivers may benefit from the additional time to perceive, think, react, and correct for errors (as may all users). It should be clarified that there has been no specific research performed on older drivers, older pedestrians, and older bicyclists at roundabouts. It should also be noted that visually impaired pedestrians are not provided the audible cues from vehicle streams that are available at a signal controlled intersection. For example, at roundabout exits, it may be difficult to discern the sound of vehicles which will continue to circulate from those exiting the roundabout. Therefore, information needs to be provided to these users through various appropriate design features to assist them in safely locating and navigating the crossings at roundabouts.

Lower circulating speeds can provide greater capacity.

Furthermore, the operational efficiency (capacity) of roundabouts is probably greater at lower circulating speed, because of these two phenomena:

- The faster the circulating traffic, the larger the gaps that entering traffic will comfortably accept. This translates to fewer acceptable gaps and therefore more instances of entering vehicles stopping at the yield line.
- Entering traffic, which is first stopped at the yield line, requires even larger gaps in the circulating traffic in order to accelerate and merge with the circulating traffic. The faster the circulating traffic, the larger this gap must be. This translates into even fewer acceptable gaps and therefore longer delays for entering traffic.

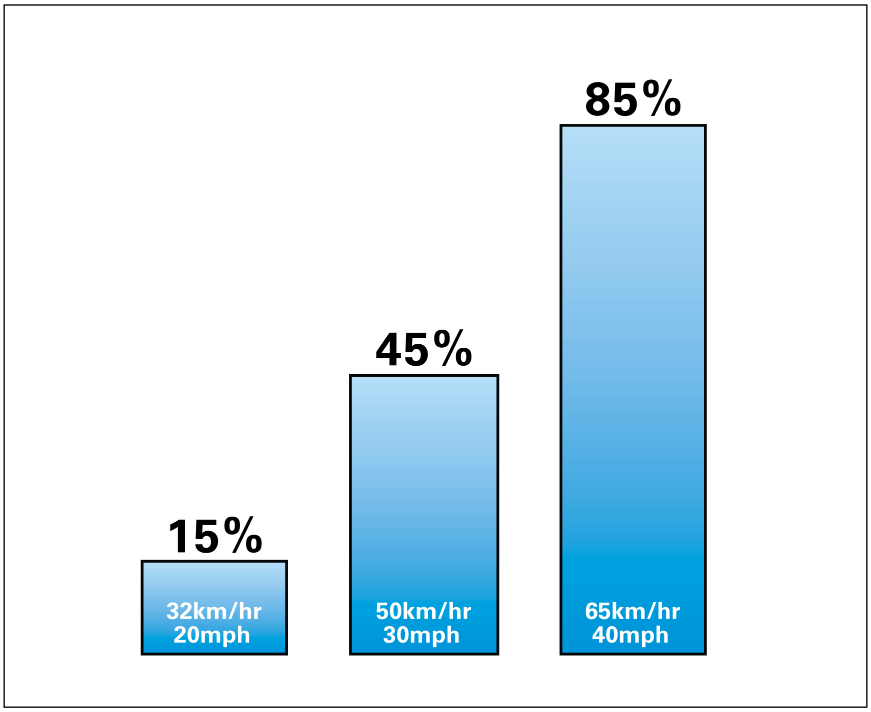


Exhibit 2-2. Pedestrian's chances of death if hit by a motor vehicle.

Source: United Kingdom (4)

2.1.1.1 Single-lane roundabouts

The safety characteristics of single-lane and multilane roundabouts are somewhat different and are discussed separately. Single-lane roundabouts are the simplest form of roundabout and thus are a good starting point for discussing the safety characteristics of roundabouts relative to other forms of intersections.

Roundabouts bring the simplicity of a "T" intersection to intersections with more than three legs.

The *frequency* of crashes at an intersection is related to the number of *conflict points* at an intersection, as well as the magnitude of conflicting flows at each conflict point. A conflict point is a location where the paths of two vehicles, or a vehicle and a bicycle or pedestrian diverge, merge, or cross each other. For example, Exhibit 2-3 presents a diagram of vehicle-vehicle conflict points for a traditional four-leg intersection and a four-leg roundabout intersection of two-lane roads. The number of vehicle-vehicle conflict points for four-leg intersections drops from thirty-two to eight with roundabouts, a 75 percent decrease. Fewer conflict points means fewer opportunities for collisions. These are not the only conflict points at roundabouts or traditional intersections, but are illustrative of the differences between intersection types. Chapter 5 contains a more detailed comparison of conflicts at more complex intersections and for pedestrians and bicyclists.

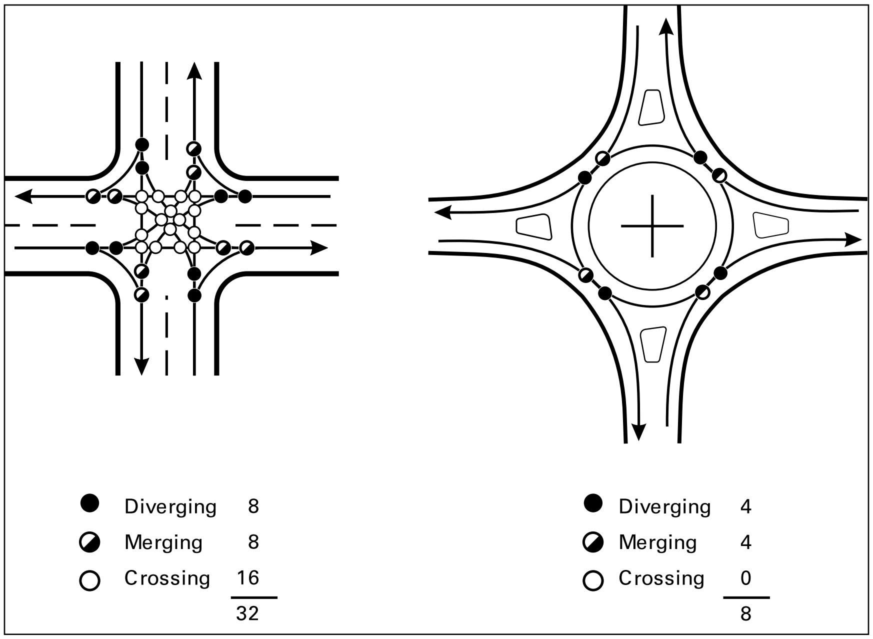
A four-leg intersection has 75 percent fewer conflicts between vehicles and pedestrians and other vehicles, compared to a conventional four-leg intersection.

See Chapter 5 for a comparison of intersection conflicts.

The *severity* of a collision is determined largely by the speed of impact and the angle of impact. The higher the speed, the more severe the collision. The higher the angle of impact, the more severe the collision. Roundabouts reduce in severity or eliminate many severe conflicts that are present in traditional intersections.

Exhibit 2-3. Comparisons of vehicle-vehicle conflict points for intersections with four single-lane approaches.

Types of intersection conflicts.



Roundabouts eliminate crossing conflicts by converting all movements to right turns.

As Exhibit 2-3 shows, a roundabout eliminates vehicle-vehicle crossing conflicts by converting all movements to right turns. Separate turn lanes and traffic control (stop signs or signalization) can often reduce but not eliminate the number of crossing conflicts at a traditional intersection by separating conflicts in space and/or time. However, the most severe crashes at signalized intersections occur when there is a violation of the traffic control device designed to separate conflicts by time (e.g., a right-angle collision due to a motorist running a red light, or vehicle-pedestrian collisions). The ability of roundabouts to reduce conflicts through physical, geometric features has been demonstrated to be more effective than the reliance on driver obedience to traffic control devices. At intersections with more than four legs, a roundabout or pair of roundabouts may sometimes be the most practical alternative to minimize the number of conflicts.

Drivers approaching a single-lane roundabout have five basic decisions regarding other users. First, drivers must be mindful of any bicyclists merging into motor vehicle traffic from the right side of the road or a bicycle lane or shoulder. Then they must yield to any pedestrians crossing at the entry. Third, they must choose an acceptable gap in which to enter the roundabout. Then they must choose the correct exit, and finally, they must yield to any pedestrians crossing the exit lane.

By contrast, a driver making a left turn from the minor leg of a two-way stop-controlled intersection has to yield to pedestrians and bicyclists, and judge gaps in both of the major street through movements from both directions, as well as the major street left and right turns and opposing minor through and right turns.

Signalized intersections have simplified the decision-making process for drivers, especially at locations where protected left-turn phasing is provided, by separating conflicts in time and space. However, the rules and driver decisions for negotiating signalized intersections are still quite complex when all the possible signal phasing schemes are accounted for. For signals with permitted left-turn phasing, the driver must be cognizant of the opposing traffic including pedestrians, and the signal indication (to ensure a legal maneuver). At roundabouts, once at the yield line, the entering driver can focus attention entirely on the circulating traffic stream approaching from the left. A driver behind the entering driver can focus entirely on crossing pedestrians.

2.1.1.2 Double-lane roundabouts

As discussed in Chapter 1, double-lane roundabouts are those with at least one entry that has two lanes. In general, double-lane roundabouts have some of the same safety characteristics for vehicle occupants as their less complicated single-lane counterparts. However, due to the presence of multiple entry lanes and the accompanying need to provide wider circulatory and exit roadways, double-lane roundabouts have complications that result in poorer safety characteristics, particularly for bicyclists and pedestrians, than single-lane roundabouts serving similar traffic demands. This makes it important to use the minimum number of entry, circulating, and exit lanes, subject to capacity considerations.

Increasing the number of lanes increases the number of conflict points.

Due to their typically larger size compared to single-lane roundabouts, double-lane roundabouts often cannot achieve the same levels of speed reduction as their single-lane counterparts. Wider entering, circulating, and exiting roadways enable a vehicle to select a path that crosses multiple lanes, as shown in Exhibit 2-4. Because of the higher-speed geometry, single-vehicle accidents can be more severe. However, design of double-lane roundabouts according to the procedures in Chapter 6, especially the approach and entry, can substantially reduce the speeds of entering vehicles and consequently reduce the severity of conflicts. Even so, speed control cannot occur to the extent possible with single-lane roundabouts.

The design of double-lane roundabouts to control the speed of the fastest vehicle path is covered in Chapter 6.

Pedestrians crossing double-lane roundabouts are exposed for a longer time and to faster vehicles. They can also be obscured from, or not see, approaching vehicles in adjacent lanes if vehicles in the nearest lane yield to them. Children, wheel-

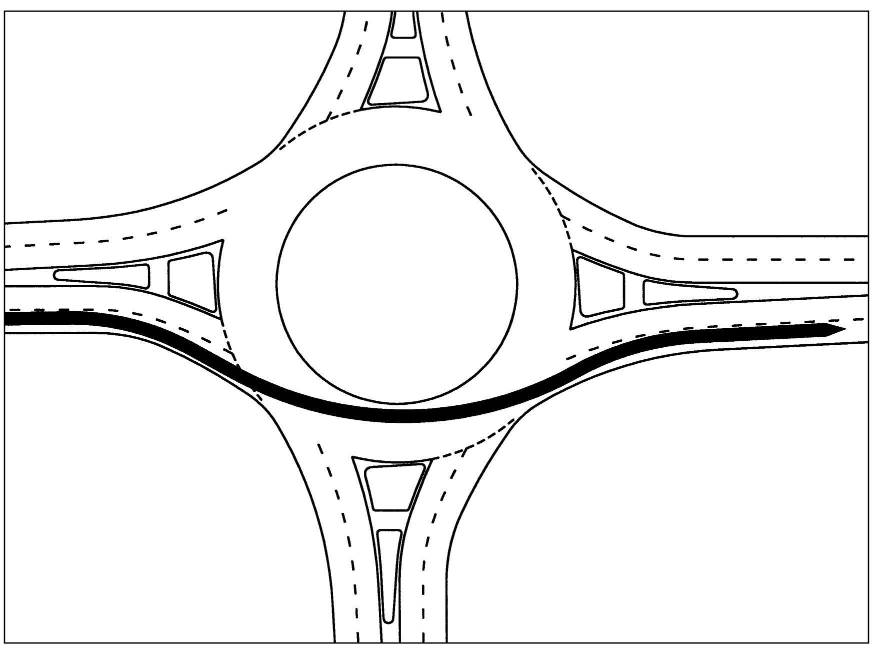


Exhibit 2-4. Fastest vehicle path through a double-lane roundabout.

chair users, and visually impaired pedestrians face particular risks. Bicycles are also more exposed to severe conflicts when choosing to circulate with motor vehicles.

Double-lane roundabouts can be confusing without proper engineering and user education.

Driver decisions are more complex at double-lane roundabouts. The requirement to yield to pedestrians still applies. The primary additional decisions are the choices of the proper lane for entering, lateral position for circulating, and proper lane for exiting the roundabout. Lane choice on approaching a double-lane roundabout is no different from approaching a signalized intersection: to turn left, stay left; to turn right, stay right. However, the decisions for circulating within and especially exiting a double-lane roundabout are unique.

Consider guide signs for roundabouts with skewed approaches or more than four legs.

Sections 2.5 and 2.6 cover user education topics.

Double-lane roundabouts with legs aligned at approximately 90-degree angles allow motorists to determine the appropriate lane choice for their path through the roundabout in a relatively easy manner. Double-lane roundabouts with more than four legs and/or with legs aligned at angles significantly different from 90 degrees make driver decisions more complicated. This occurs because it can be difficult on some legs to determine which movements are left, through, and right. For this reason, it is desirable that multilane roundabouts be limited to a maximum of four legs, with legs aligned at approximately 90-degree angles. If this is not possible, special advance guide signs showing appropriate lane choice should be considered.

When double-lane roundabouts are first introduced to an area, there is a need for adequate user education. Recommendations for user education material specifically related to this issue are presented later in this chapter.

2.1.2 Vehicle delay and queue storage

Techniques for estimating delay are given in Chapter 4.

When operating within their capacity, roundabout intersections typically operate with lower vehicle delays than other intersection forms and control types. With a roundabout, it is unnecessary for traffic to come to a complete stop when no conflicts present themselves, or else deceleration will avoid a conflict. When there are queues on one or more approaches, traffic within the queues usually continues to move, and this is typically more tolerable to drivers than a stopped or standing queue. The performance of roundabouts during off-peak periods is particularly good in contrast to other intersection forms, typically with very low average delays.

2.1.3 Delay of major movements

Since all intersection movements at a roundabout have equal priority, major street movements may be delayed more than desired.

Roundabouts tend to treat all movements at an intersection equally. Each approach is required to yield to circulating traffic, regardless of whether the approach is a local street or major arterial. In other words, all movements are given equal priority. This may result in more delay to the major movements than might otherwise be desired. This problem is most acute at the intersection of high-volume major streets with low- to medium-volume minor streets (e.g., major arterial streets with minor collectors or local streets). Therefore, the overall street classification system and hierarchy should be considered before selecting a roundabout (or stop-controlled) intersection. This limitation should be specifically considered on emergency response routes in comparison with other intersection types and control. The delays depend on the volume of turning movements and should be analyzed individually for each approach, according to the procedures in Chapter 4.

2.1.4 Signal progression

It is common practice to coordinate traffic signals on arterial roads to minimize stops and delay to through traffic on the major road. By requiring coordinated platoons to yield to traffic in the circulatory roadway, the introduction of a roundabout into a coordinated signal system may disperse and rearrange platoons of traffic if other conflicting flows are significant, thereby reducing progressive movement. To minimize overall system delay, it may be beneficial to divide the signal system into subsystems separated by the roundabout, assigning each subsystem its own cycle. The traffic performance of the combination roundabout-signal system should be tested in advance with signal systems and roundabout analysis tools. In some cases, total delay, stops, and queues will be reduced by the roundabout. The number of available gaps for midblock unsignalized intersections and driveways may also be reduced by the introduction of roundabouts, although this may be offset by the reduced speeds near roundabouts. In addition, roundabouts can enable safe and quick U-turns that can substitute for more difficult midblock left turns, especially where there is no left turn lane.

2.1.5 Environmental factors

Roundabouts may provide environmental benefits if they reduce vehicle delay and the number and duration of stops compared with an alternative. Even when there are heavy volumes, vehicles continue to advance slowly in moving queues rather than coming to a complete stop. This may reduce noise and air quality impacts and fuel consumption significantly by reducing the number of acceleration/deceleration cycles and the time spent idling.

In general, if stop or yield control is insufficient, traffic through roundabouts generates less pollution and consumes less fuel than traffic at fixed-time signalized intersections. However, vehicle-actuated signals typically cause less delay, less fuel consumption, and less emissions than roundabouts as long as traffic volumes are low. During busy hours, vehicle-actuated signals tend to operate like fixed-time signals, and the percentage of cars that must stop becomes high (5).

2.1.6 Spatial requirements

Roundabouts usually require more space for the circular roadway and central island than the rectangular space inside traditional intersections. Therefore, roundabouts often have a significant right-of-way impact on the corner properties at the intersection, especially when compared with other forms of unsignalized intersection. The dimensions of a traditional intersection are typically comparable to the envelope formed by the approaching roadways. However, to the extent that a comparable roundabout would outperform a signal in terms of reduced delay and thus shorter queues, it will require less queue storage space on the approach legs. If a signalized intersection requires long or multiple turn lanes to provide sufficient capacity or storage, a roundabout with similar capacity may require less space on the approaches. As a result, roundabouts may reduce the need for additional right-of-way on the links between intersections, at the expense of additional right-of-way requirements at the intersections themselves (refer to Chapters 3 and 8). The right-of-way savings between intersections may make it feasible to accommodate parking, wider sidewalks, planter strips, wider outside lanes, and/or bicycle lanes in order to better accommodate pedestrians and/or bicyclists. Another space-saving strategy is the use of flared approach lanes to provide additional capacity at the intersection while maintaining the benefit of reduced spatial requirements upstream and downstream of an intersection.

At interchange ramp terminals, paired roundabouts have been used to reduce the number of lanes in freeway over- and underpasses. In compact urban areas, there are typically signalized intersections at both ends of overpass bridges, necessitating two additional overpass lanes to provide capacity and storage at the signalized intersections.

2.1.7 Operation and maintenance costs

Compared to signalized intersections, a roundabout does not have signal equipment that requires constant power, periodic light bulb and detection maintenance, and regular signal timing updates. Roundabouts, however, can have higher landscape maintenance costs, depending on the degree of landscaping provided on the central island, splitter islands, and perimeter. Illumination costs for roundabouts and signalized intersections are similar. Drivers sometimes face a confusing situation when they approach a signalized intersection during a power failure, but such failures have minimal temporary effect on roundabouts or any other unsignalized intersections, other than the possible loss of illumination. The service life of a roundabout is significantly longer, approximately 25 years, compared with 10 years for a typical signal (6).

2.1.8 Traffic calming

Series of roundabouts can have secondary, traffic calming effects on streets by reducing vehicle speeds. As discussed previously, speed reduction at roundabouts is caused by geometry rather than by traffic control devices or traffic volume. Consequently, speed reduction can be realized at all times of day and on streets of any traffic volume. It is difficult to speed through an appropriately designed roundabout with raised channelization that forces vehicles to physically change direction. In this way, roundabouts can complement other traffic calming measures.

By reducing speeds, roundabouts complement other traffic calming measures.

Roundabouts have also been used successfully at the interface between rural and urban areas where speed limits change. In these applications, the traffic calming effects of roundabouts force drivers to slow and reinforce the notion of a significant change in the driving environment.

2.1.9 Aesthetics

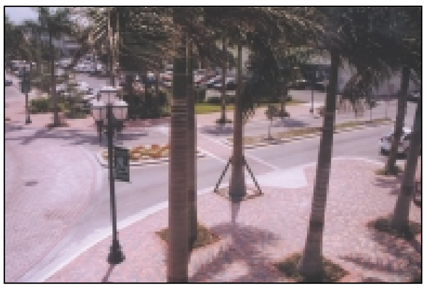
Landscaping issues are discussed in detail in Chapter 7.

Roundabouts offer the opportunity to provide attractive entries or centerpieces to communities. However, hard objects in the central island directly facing the entries are a safety hazard. The portions of the central island and, to a lesser degree, the splitter islands that are not subject to sight-distance requirements offer opportunities for aesthetic landscaping. Pavement textures can be varied on the aprons as well. Exhibit 2-5 presents examples of the aesthetic treatments that have been applied to roundabouts. They can also be used in tourist or shopping areas to facilitate safe U-turns and to demarcate commercial uses from residential areas. They have been justified as a spur to economic development, conveying to developers that the area is favorable for investment in redevelopment. Some are exhibited as a “signature” feature on community postcards, advertisements, and travelogues.

Exhibit 2-5. Examples of aesthetic treatments.

(a) West Boca Raton, FL

(b) Santa Barbara, CA



(c) Fort Pierce, FL

(d) Vail, CO

2.1.10 Design for older drivers

In the United States, there is a trend toward an aging population, as well as individuals, continuing to drive until an older age. This trend has implications for all roadway design, including roundabout design, ranging from operations through geometric and sign design. In this regard, designers should consult available documents such as the Federal Highway Administration (FHWA) *Older Driver Highway Design Handbook* (7):

- The single greatest concern in accommodating older road users, both drivers and pedestrians, is the ability of these persons to safely maneuver through intersections.
- Driving situations involving complex speed-distance judgments under time constraints are more problematic for older drivers and pedestrians than for their younger counterparts.
- Older drivers are much more likely to be involved in crashes where the drivers were driving too fast for the curve or, more significantly, were surprised by the curved alignment.
- Many studies have shown that loss-of-control crashes result from an inability to maintain lateral position through the curve because of excessive speed, with inadequate deceleration in the approach zone. These problems in turn stem from a combination of factors, including poor anticipation of vehicle control requirements, induced by the driver's prior speed, and inadequate perception of the demands of the curve.
- Older drivers have difficulties in allocating attention to the most relevant aspects of novel driving situations.
- Older drivers generally need more time than average drivers to react to events.

While the *Handbook* is not specific to roundabouts, and since no age-related research has been conducted with U.S. roundabouts to date, these findings may apply to older persons encountering roundabouts, as well. The excerpts above all imply that lower, more conservative design speeds are appropriate. Roundabouts designed for low, consistent speeds cater to the preferences of older drivers: slower speeds; time to make decisions, act, and react; uncomplicated situations to interpret; simple decision-making; a reduced need to look over one's shoulder; a reduced need to judge closing speeds of fast traffic accurately; and a reduced need to judge gaps in fast traffic accurately. For example, two-way stop-controlled intersections may be appropriate for replacement with a roundabout when a crash analysis indicates that age-related collisions are prevalent.

2.2 Multimodal Considerations

As with any intersection design, each transportation mode present requires careful consideration. This section presents some of the general issues associated with each mode; additional detail on mode-specific safety and design issues is provided in subsequent chapters.

2.2.1 Pedestrians

Pedestrian crossings should be set back from the yield line by one or more vehicle lengths.

Pedestrians are accommodated by crossings around the perimeter of the roundabout. By providing space to pause on the splitter island, pedestrians can consider one direction of conflicting traffic at a time, which simplifies the task of crossing the street. The roundabout should be designed to discourage pedestrians from crossing to the central island, e.g., with landscape buffers on the corners. Pedestrian crossings are set back from the yield line by one or more vehicle lengths to:

- Shorten the crossing distance compared to locations adjacent to the inscribed circle;
- Separate vehicle-vehicle and vehicle-pedestrian conflict points; and
- Allow the second entering driver to devote full attention to crossing pedestrians while waiting for the driver ahead to enter the circulatory roadway.

If sidewalks on the intersecting roads are adjacent to the curbs, this setback may require the sidewalks to deviate from a straight path. This is not the case if sidewalks are separated from the curbs by a generous landscape buffer.

Most intersections are two-way stop-controlled, or uncontrolled. Compared to two-way stop-controlled intersections, roundabouts may make it easier and safer for pedestrians to cross the major street. At both roundabouts and two-way stop-controlled intersections, pedestrians have to judge gaps in the major (uncontrolled) stream of traffic. By reducing stopping distance, the low vehicular speeds through a roundabout generally reduce the frequency and severity of incidents involving pedestrians. In addition, when crossing an exit lane on the minor road, the sight angle is smaller than when watching for left-turning vehicles at a conventional intersection.

The comparison between roundabouts and all-way stop-controlled intersections is less clear. All-way stop control is virtually nonexistent in foreign countries that have roundabouts, and so there is little international experience with which to compare. All-way stop-controlled intersections may be preferred by pedestrians with visual impairment because vehicles are required to stop before they enter the intersection. However, crossing the exit leg of an all-way stop-controlled intersection can be intimidating for a pedestrian since traffic may be turning onto the exit from multiple directions. Roundabouts, on the other hand, allow pedestrians to cross one direction of traffic at a time; however, traffic may be moving (albeit at a slow speed), thus making it more challenging to judge gaps, especially for visually impaired users, children, and the elderly.

The biggest difference may be that all-way stop-controlled intersections, like two-way stops, do not provide positive geometric features to slow vehicles and instead rely entirely on the authority of the traffic control device. The roundabout geometry physically slows and deflects vehicles, reducing the likelihood of a high-speed collision due to a traffic control device violation.

Signalized intersections offer positive guidance to pedestrians by providing visual and occasionally audible pedestrian signal indications. In this respect, the decision process for pedestrians requires less judgment at signalized intersections than at roundabouts, particularly for visually impaired and elderly pedestrians. However, pedestrians are still vulnerable at signalized intersections to right-turn and left-turn movements unprotected by a green arrow. In addition, high-speed collisions are still possible if a vehicle runs through a red indication. In this respect, the roundabout provides a speed-constrained environment for through traffic. At two-way and all-way stop intersections, right-turning motorists often look only to the left in order to check for vehicular conflicts, endangering or inconveniencing pedestrians crossing from the right or on the right. This situation is exacerbated by the fact that many of these drivers do not come to a complete stop if they do not perceive any conflicts. With crosswalks located back from the circulatory roadway, roundabouts place pedestrians in a more visible location.

The two populations at opposite ends of the age continuum—children and the elderly—and people with disabilities are particularly at risk at intersections. Children (owing to their lack of traffic experience, impulsiveness, and small size) and the elderly (owing to their age-related physical limitations) present challenges to the designer. In recognition of pedestrians with disabilities, intersections must comply with Americans with Disabilities Act (ADA) mandated accessibility standards discussed in Section 2.4.5 and Chapter 5.

Elderly pedestrians, children, and the disabled find it more difficult to cross unprotected road crossings. These types of pedestrians generally prefer larger gaps in the traffic stream, and walk at slower speeds than other pedestrians. Multilane roadways entering and exiting double-lane roundabouts require additional skills to cross, since pedestrians need assurance that they have been seen by drivers in each lane they are crossing.

When crossing a roundabout, there are several areas of difficulty for the blind and or visually impaired pedestrian. It is expected that a visually impaired pedestrian with good travel skills must be able to arrive at an unfamiliar intersection and cross it with pre-existing skills and without special, intersection-specific training. Roundabouts pose problems at several points of the crossing experience, from the perspective of information access.

When crossing a roundabout, there are several areas of difficulty for the blind and or visually impaired pedestrian.

Unless these issues are addressed by a design, the intersection is "inaccessible" and may not be permissible under the ADA. Chapters 5, 6, and 7 provide specific suggestions to assist in providing the above information. However, more research is required to develop the information jurisdictions need to determine where roundabouts may be appropriate and what design features may be appropriate for the disabled, such as audible signalized crossings. Until specific standards are adopted, engineers and jurisdictions must rely on existing related research and professional judgment to design pedestrian features so that they are usable by pedestrians with disabilities.

2.2.2 Bicycles

Roundabouts may not provide safety benefits to bicyclists (1). Nevertheless, the recommended roundabout designs discourage erratic or undesirable driver behavior. They slow drivers to speeds more compatible with bicycle speeds, while reducing high-speed conflicts and simplifying turn movements for bicyclists. Typical commuter bicyclist speeds are around 25 km/h (15 mph), so entering a roundabout designed for circulating traffic to flow at similar speeds should be safer compared with larger and faster roundabout designs. Bicyclists require particular attention in two-lane roundabout design, especially in areas with moderate to heavy bicycle traffic.

As with pedestrians, one of the difficulties in accommodating bicyclists is their wide range of skills and comfort levels in mixed traffic. On single-lane roundabouts, bicyclists have the option of either mixing with traffic or using the roundabout like a pedestrian. The former option will likely be reasonably comfortable for experienced cyclists; however, less-experienced cyclists (including children) may have difficulty and discomfort mixing with vehicles and are more safely accommodated as pedestrians.

Bike lanes through roundabouts should never be used.

The complexity of vehicle interactions within a roundabout leaves a cyclist vulnerable, and for this reason, bike lanes within the circulatory roadway should never be used. On double-lane roundabouts, a bicycle path separate and distinct from the circulatory roadway is preferable, such as a shared bicycle-pedestrian path of sufficient width and appropriately marked to accommodate both types of users around the perimeter of the roundabout. While this will likely be more comfortable for the casual cyclist, the experienced commuter cyclist will be significantly slowed down by having to cross as a pedestrian at each approach crossing and may choose to continue to traverse a double-lane roundabout as a vehicle. It may sometimes be possible to provide cyclists with an alternative route along another street or path that avoids the roundabout, which should be considered as part of overall network planning. The provision of alternative routes should not be used to justify compromising the safety of bicycle traffic through the roundabout because experienced cyclists and those with immediately adjacent destinations will use it.

2.2.3 Large vehicles

Design roundabouts to accommodate the largest vehicle that can reasonably be expected.

Roundabouts should always be designed for the largest vehicle that can be reasonably anticipated (the "design vehicle"). For single-lane roundabouts, this may require the use of a mountable apron around the perimeter of the central island to provide the additional width needed for tracking the trailer wheels. At double-lane roundabouts, large vehicles may track across the whole width of the circulatory roadway to negotiate the roundabout. In some cases, roundabouts have been designed with aprons or gated roadways through the central island to accommodate oversized trucks, emergency vehicles, or trains.

2.2.4 Transit

Transit considerations at a roundabout are similar to those at a conventional intersection. If the roundabout has been designed using the appropriate design vehicle, a bus should have no physical difficulty negotiating the intersection. To minimize passenger discomfort, if the roundabout is on a bus route, it is preferable that scheduled buses are not required to use a truck apron if present. Bus stops should be located carefully to minimize the probability of vehicle queues spilling back into the circulatory roadway. This typically means that bus stops located on the far side of the intersection need to have pullouts or be further downstream than the splitter island. Pedestrian access routes to transit should be designed for safety, comfort, and convenience. If demand is significant, such as near a station or terminus, pedestrian crossing capacity should be accounted for.

Public transit buses should not be forced to use a truck apron to negotiate a roundabout.

Roundabouts may provide opportunities for giving transit (including rail) and emergency vehicles priority as can be done at signalized intersections. This may be provided using geometry, or signals. For example, these could include an exclusive right-turn bypass lane or signals holding entering traffic while the transit vehicle enters its own right-of-way or mixed traffic. The roundabout can be supplemented by signals activated by a transit, emergency, or rail vehicle. Chapters 6, 7, and 8 provide more detail on transit treatments.

Chapters 6-8 provide more detail on transit treatments.

2.2.5 Emergency vehicles

The passage of large emergency vehicles through a roundabout is the same as for other large vehicles and may require use of a mountable apron. On emergency response routes, the delay for the relevant movements at a planned roundabout should be compared with alternative intersection types and control. Just as they are required to do at conventional intersections, drivers should be educated not to enter a roundabout when an emergency vehicle is approaching on another leg. Once having entered, they should clear out of the circulatory roadway if possible, facilitating queue clearance in front of the emergency vehicle.

Roundabouts provide emergency vehicles the benefit of lower vehicle speeds, which may make roundabouts safer for them to negotiate than signalized crossings. Unlike at signalized intersections, emergency vehicle drivers are not faced with through vehicles unexpectedly running the intersection and hitting them at high speed.

2.2.6 Rail crossings

Rail crossings through or near a roundabout may involve many of the same design challenges as at other intersections and should be avoided if better alternatives exist. In retrofit, the rail track may be designed to pass through the central island, or across one of the legs. Queues spilling back from a rail blockage into the roundabout can fill the circulatory roadway and temporarily prevent movement on any approach. However, to the extent that a roundabout approach capacity exceeds that of a signal at the same location, queues will dissipate faster. Therefore, a case-specific capacity and safety analysis is recommended. Section 8.2 addresses the design of at-grade rail crossings.

See Section 8.2 for information on designing roundabouts located near at-grade rail crossings.

2.3 Costs Associated with Roundabouts

Many factors influence the amount of economic investment justified for any type of intersection. Costs associated with roundabouts include construction costs, engineering and design fees, land acquisition, and maintenance costs. Benefits may include reduced crash rates and severity, reduced delay, stops, fuel consumption, and emissions. Benefit-cost analysis is discussed further in Chapter 3.

When comparing costs, it is often difficult to separate the actual intersection costs from an overall improvement project. Accordingly, the reported costs of installing roundabouts have been shown to vary significantly from site to site. A roundabout may cost more or less than a traffic signal, depending on the amount of new pavement area and the extent of other roadway work required. At some existing unsignalized intersections, a traffic signal can be installed without significant modifications to the pavement area or curbs. In these instances, a roundabout is likely to be more costly to install than a traffic signal, as the roundabout can rarely be constructed without significant pavement and curb modifications.

Roundabouts may require more pavement area at the intersection, compared to a traffic signal, but less on the approaches and exits.

However, at new sites, and at signalized intersections that require widening at one or more approaches to provide additional turn lanes, a roundabout can be a comparable or less expensive alternative. While roundabouts typically require more pavement area at the intersection, they may require less pavement width on the upstream approaches and downstream exits if multiple turn lanes associated with a signalized intersection can be avoided. The cost savings of reduced approach roadway widths is particularly advantageous at interchange ramp terminals and other intersections adjacent to grade separations where wider roads may result in larger bridge structures. In most cases, except potentially for a mini-roundabout, a roundabout is more expensive to construct than the two-way or all-way stop-controlled intersection alternatives.

Recent roundabout projects in the United States have shown a wide range in reported construction costs. Assuming "1998 U.S. Dollars" in the following examples, costs ranged from $10,000 for a retrofit application of an existing traffic circle to $500,000 for a new roundabout at the junction of two State highways. National Cooperative Highway Research Program (NCHRP) Synthesis 264 (3) reports that the average construction cost of 14 U.S. roundabouts, none being part of an interchange, was approximately $250,000. This amount includes all construction elements, but does not include land acquisition.

The cost of maintaining traffic during construction of a roundabout retrofit can be relatively high.

Higher costs are typically incurred when a substantial amount of realignment, grading, or drainage work is required. The cost of maintaining traffic during construction tends to be relatively high for retrofitting roundabouts. This expense is due mainly to the measures required to maintain existing traffic flow through the intersection while rebuilding it in stages. Other factors contributing to high roundabout costs are large amounts of landscaping in the central and splitter islands, extensive signing and lighting, and the provision of curbs on all outside pavement edges.

Operating and maintenance costs of roundabouts are somewhat higher than for other unsignalized intersections, but less than those for signalized intersections. In addition, traffic signals consume electricity and require periodic service (e.g., bulb replacement, detector replacement, and periodic signal retiming). Operating costs for a roundabout are generally limited to the cost of illumination (similar to signalized alternatives, but typically more than is required for other unsignalized intersections).

Maintenance includes regular restriping and repaving as necessary, as well as snow removal and storage in cold climates (these costs are also incurred by conventional intersections). Landscaping may require regular maintenance as well, including such things as pruning, mowing, and irrigation system maintenance. To the extent that roundabouts reduce crashes compared with conventional intersections, they will reduce the number and severity of incidents that disrupt traffic flow and that may require emergency service.

2.4 Legal Considerations

The legal environment in which roundabouts operate is an important area for jurisdictions to consider when developing a roundabout program or set of guidelines. The rules of the road that govern the operation of motor vehicles in a given State can have a significant influence on the way a roundabout operates and on how legal issues such as crashes involving roundabouts are handled. Local jurisdictions that are interested in developing a roundabout program need to be aware of the governing State regulations in effect. The following sections discuss several of the important legal issues that should be considered. These have been based on the provisions of the 1992 Uniform Vehicle Code (UVC) (8), which has been adopted to varying degrees by each State, as well as the rules of the road, and commentaries thereof, from the United Kingdom (9) and Australia (10, 11). Note that the information in the following sections does not constitute specific legal opinion; each jurisdiction should consult with its attorneys on specific legal issues.

2.4.1 Definition of "intersection"

The central legal issue around which all other issues are derived is the fundamental relationship between a roundabout and the legal definition of an "intersection." A roundabout could be legally defined one of two ways:

- As a single intersection; or
- As a series of T-intersections.

The UVC does not provide clear guidance on the appropriate definition of an intersection with respect to roundabouts. The UVC generally defines an "intersection" as the area bounded by the projection of the boundary lines of the approaching roadways (UVC §1-132a). It also specifies that where a highway includes two roadways 9.1 m (30 ft) or more apart, each crossing shall be regarded as a separate intersection (UVC §1-132b). This may imply that most circular intersections should be regarded as a series of T-intersections. This distinction has ramifications in the interpretation of the other elements identified in this section.

This guide recommends that a roundabout be specifically defined as a single intersection, regardless of the size of the roundabout. This intersection should be defined as the area bounded by the limits of the pedestrian crossing areas around the perimeter of a single central island. Closely spaced roundabouts with multiple central islands should be defined as separate intersections, as each roundabout is typically designed to operate independently.

It is recommended that roundabouts be defined as a single intersection: the area bounded by the limits of the pedestrian crossing areas.

2.4.2 Right-of-way between vehicles

Because of yield-to-the-right laws, yield signs and lines must be used on roundabout entries to assign right-of-way to the circulatory roadway.

The UVC specifies that "when two vehicles approach or enter an intersection from different highways at approximately the same time, the driver of the vehicle on the left shall yield the right-of-way to the vehicle on the right" (UVC §11-401). This runs contrary to the default operation of a roundabout, which assigns the right-of-way to the vehicle on the left and any vehicle in front. This requires the use of yield signs and yield lines at all approaches to a roundabout to clearly define right-of-way.

This guide recommends that right-of-way at a roundabout be legally defined such that an entering vehicle shall yield the right-of-way to the vehicle on the left (France passed such a law in 1984). This definition does not change the recommendation for appropriately placed yield signs and yield lines.

2.4.3 Required lane position at intersections

At a typical intersection with multilane approaches, vehicles are required by the UVC to use the right-most lane to turn right and the left-most lane to turn left, unless specifically signed or marked lanes allow otherwise (e.g., double left-turn lanes) (UVC §11-601). Because multilane roundabouts can be used at intersections with more than four legs, the concept of "left turns" and "right turns" becomes more difficult to legally define. The following language (10) is recommended:

Recommended lane assignments: Exit less than halfway, use the right lane. Exit more than halfway, use the left lane. Exit exactly halfway, use either lane.

Unless official traffic control devices indicate otherwise, drivers must make lane choices according to the following rules:

- *If a driver intends to exit the roundabout less than halfway around it, the right lane must be used.*
- *If a driver intends to exit the roundabout more than halfway around it, the left lane must be used.*

The Australian Traffic Act (10) gives no guidance for straight through movements (movements leaving the roundabout exactly halfway), and the general Australian practice is to allow drivers to use either lane unless signed or marked otherwise. On multilane roundabouts where the intersecting roadways are not at 90-degree angles or there are more than four legs to the roundabout, special consideration should be given to assisting driver understanding through advance diagrammatic guide signs or lane markings on approaches showing the appropriate lane choices.

2.4.4 Priority within the circulatory roadway

For multilane roundabouts, the issue of priority within the circulatory roadway is important. Any vehicle on the inner track on the circulatory roadway (e.g., a vehicle making a left turn) will ultimately cross the outer track of the circulatory roadway to exit. This may cause conflicts with other vehicles in the circulatory roadway.

Consistent with its lack of treatment of roundabouts, the UVC does not provide clear guidance on priority within the circulatory roadway of a roundabout. In general, the UVC provides that all overtaking should take place on the left (UVC §11-303). However, the UVC also specifies the following with respect to passing on the right (UVC §11-304a):

The driver of a vehicle may overtake and pass upon the right of another vehicle only under the following conditions.

1. *When the vehicle overtaken is making or about to make a left turn;*
2. *Upon a roadway with unobstructed pavement of sufficient width for two or more lines of vehicles moving lawfully in the direction being traveled by the overtaking vehicle.*

A case could be made that this provision applies to conditions within a circulatory roadway of a multilane roundabout. Under the definition of a roundabout as a single intersection, a vehicle making a left turn could be overtaken on the right, even though the completion of the left turn requires exiting on the right.

International rules of the road vary considerably on this point. The United Kingdom, for example, requires drivers to "watch out for traffic crossing in front of you on the roundabout, especially vehicles intending to leave by the next exit. Show them consideration." (9, §125) This is generally interpreted as meaning that a vehicle at the front of a bunch of vehicles within the circulatory roadway has the right-of-way, regardless of the track it is on, and following vehicles on any track must yield to the front vehicle as it exits. Australia, on the other hand, does not have a similar statement in its legal codes, and this was one of the factors that led Australians to favor striping of the circulatory roadway in recent years. Further research and legal exploration need to be performed to determine the effect of this legal interpretation on driver behavior and the safety and operation of multilane roundabouts.

For clarity, this guide makes the following recommendations:

- Overtaking within the circulatory roadway should be prohibited.
- Exiting vehicles should be given priority over circulating vehicles, provided that the exiting vehicle is in front of the circulating vehicle.

Recommendations: No overtaking within the circulatory roadway, and exiting vehicles in front of other circulating vehicles have priority when exiting.

2.4.5 Pedestrian accessibility

The legal definition of a roundabout as one intersection or a series of intersections also has implications for pedestrians, particularly with respect to marked and unmarked crosswalks. A portion of the UVC definition of a crosswalk is as follows: ". . . and in the absence of a sidewalk on one side of the roadway, that part of a roadway included within the extension of the lateral lines of the existing sidewalk at right angles to the centerline" (UVC §1-112(a)). Under the definition of a roundabout as a series of T-intersections, this portion of the definition could be interpreted to mean that there are unmarked crosswalks between the perimeter and the central island at every approach. The recommended definition of a roundabout as a single intersection simplifies this issue, for the marked or unmarked crosswalks around the perimeter as defined are sufficient and complete.

In all States, drivers are required to either yield or stop for pedestrians in a crosswalk (however, this requirement is often violated, and therefore it is prudent for pedestrians not to assume that this is the case). In addition, the provisions of the ADA also apply to roundabouts in all respects, including the design of sidewalks, crosswalks, and ramps. Under the ADA, accessible information is required to make the existing public right-of-way an accessible program provided by State and local governments (28 CFR 35.150). Any facility or part of a facility that is newly constructed by a State or local government must be designed and constructed so that it is readily accessible to and usable by people with disabilities (28 CFR 35.151(a)). Alterations to existing facilities must include modifications to make altered areas accessible to individuals with disabilities (28 CFR 735.151 (b)).

Current guidelines do not specifically address ways to make roundabouts accessible. Nonetheless, these provisions mean providing information about safely crossing streets in an accessible format, including at roundabouts. At a minimum, design information should provide for:

- Locating the crosswalk;
- Determining the direction of the crosswalk;
- Determining a safe crossing time; and
- Locating the splitter island refuge.

2.4.6 Parking

Many States prohibit parking within a specified distance of an intersection; others allow parking right up to the crosswalk. The degree to which these laws are in place will govern the need to provide supplemental signs and/or curb markings showing parking restrictions. To provide the necessary sight distances for safe crossings to occur, this guide recommends that parking be restricted immediately upstream of the pedestrian crosswalks.

The legal need to mark parking restrictions within the circulatory roadway may be dependent on the definition of a roundabout as a single intersection or as a series of T-intersections. Using the recommended definition of a roundabout as a single intersection, the circulatory roadway would be completely contained within the intersection, and the UVC currently prohibits parking within an intersection (UVC §11-1003).

2.5 Public Involvement

Public acceptance of roundabouts has often been found to be one of the biggest challenges facing a jurisdiction that is planning to install its first roundabout. Without the benefit of explanation or first-hand experience and observation, the public is likely to incorrectly associate roundabouts with older, nonconforming traffic circles that they have either experienced or heard about. Equally likely, without adequate education, the public (and agencies alike) will often have a natural hesitation or resistance against changes in their driving behavior and driving environment.

A recent survey found negative public attitudes towards roundabouts before construction, but positive attitudes following construction.

In such a situation, a proposal to install a roundabout may initially experience a negative public reaction. However, the history of the first few roundabouts installed in the United States also indicates that public attitude toward roundabouts improves significantly after construction. A recent survey conducted of jurisdictions across the United States (3) reported a significant negative public attitude toward roundabouts prior to construction (68 percent of the responses were negative or very negative), but a positive attitude after construction (73 percent of the responses were positive or very positive).

A wide variety of techniques have been used successfully in the United States to inform and educate the public about new roundabouts. Some of these include public meetings, informational brochures and videos, and announcements in the newspaper or on television and radio. A public involvement process should be initiated as soon as practical, preferably early in the planning stages of a project while other intersection forms are also being considered.

Public meetings, videos and brochures, and media announcements are some of the ways to educate the public about new roundabouts.

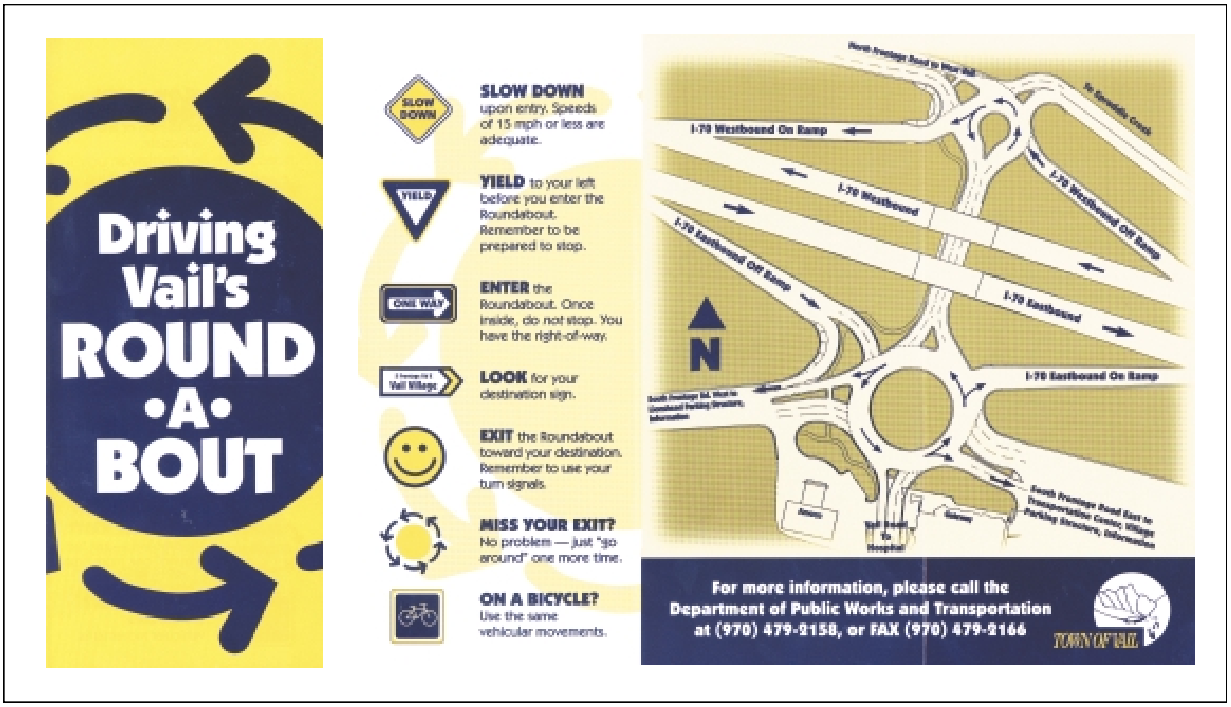
2.5.1 Public meetings

Public meetings can be a good forum for bringing the public into the design process. This allows early identification of potential problems and helps to gain overall acceptance throughout the process. Public input may be useful at various stages in the planning process: data collection, problem definition, generation of design alternatives, selection of preferred alternatives, detailed design, go/no-go decision, construction/opening, and landscape maintenance. Many jurisdictions require or recommend public meetings with the affected neighborhood or businesses prior to approval of the project by elected officials. Even if such meetings are not required, they can be helpful in easing concerns about a new form of intersection for a community.

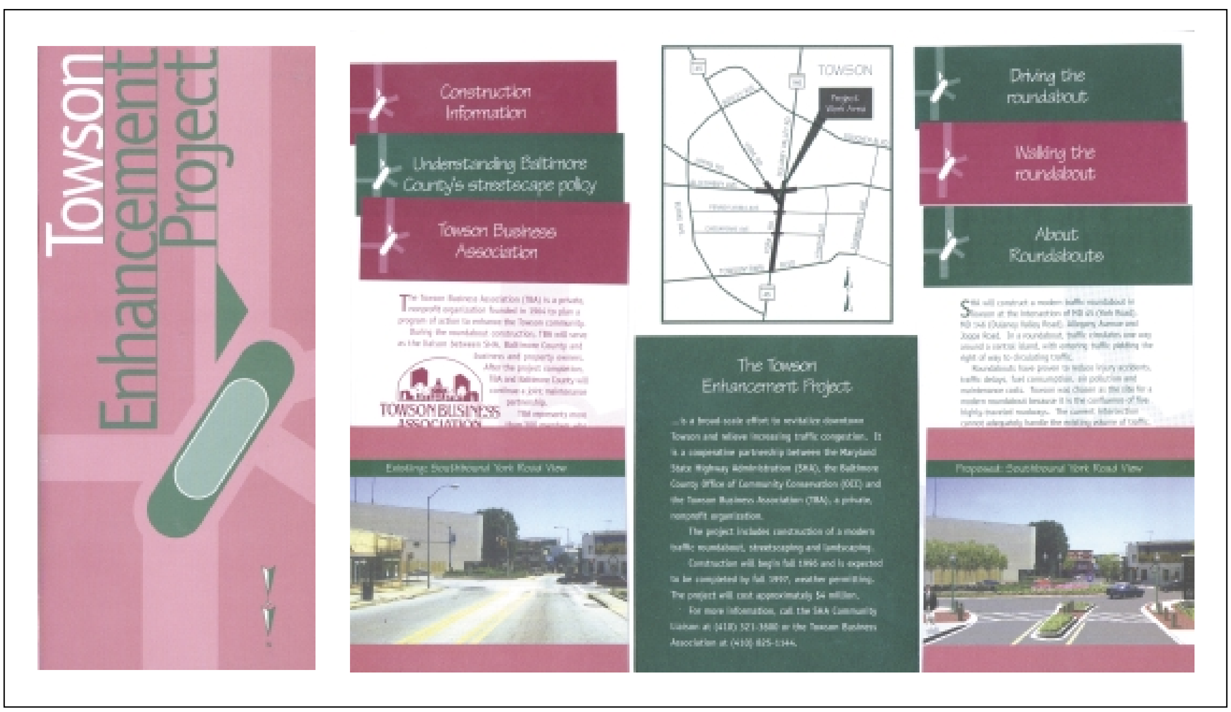
2.5.2 Informational brochures

A number of agencies, including the Maryland State Highway Administration and the City of Montpelier, Vermont, have used informational brochures to educate the public about roundabouts in their communities. Brochures have also been prepared for specific projects. Exhibit 2-6 shows examples from the brochures prepared for the I-70/Vail Road roundabouts in Vail, Colorado, and the Towson Roundabout in Towson, Maryland. These brochures include drawings or photographic simulations of the proposed roundabout. The brochures also typically include general information on roundabouts (what roundabouts are, where they can be found, and the types of benefits that can be expected). Sometimes they also include instructions on how to use the roundabout as a motorist, bicyclist, and pedestrian. The Towson brochure included additional information on the business association in the area, the streetscape policy of the county, and information on the construction phases of the roundabout.

Exhibit 2-6. Examples of informational brochures.



(a) Vail, CO



(b) Towson, MD

2.5.3 Informational videos

A number of agencies and consulting firms have prepared videos to inform the public about roundabouts. These videos are typically 10 to 15 minutes in length and include footage of existing roundabouts and narration about their operational and safety characteristics. These videos have been successfully used at public meetings as an effective means of introducing the public to roundabouts.

2.5.4 Media announcements

Given the new nature of a roundabout in many communities, the local media (newspaper, radio, and television) is likely to become involved. Such interest often occurs early in the process, and then again upon the opening of the roundabout. Radio reading services, telephone information services, and publications intended primarily for individuals with disabilities should be used to communicate with persons who are visually impaired when a roundabout is proposed and when it opens.

2.6 Education

One of the important issues facing a State considering the implementation of roundabouts is the need to provide adequate driver, cyclist, and pedestrian education. To clarify the following tips and instructions, user education should begin by using simple exhibits such as those in Chapter 1 to familiarize them with the basic physical features of a roundabout intersection. Users should also familiarize themselves with the instructions for all other modes so that they understand the expectations of each other. The following sections provide instructional material and model language for drivers, cyclists, and pedestrians that can be adapted to drivers manuals. These have been adapted from similar rules of the road and drivers manuals used for roundabouts in the United Kingdom (9), Australia (10), and the State of Victoria, Australia (11).

The following sample instructions assume that readers have already seen introductory material on roundabouts, such as the brochures depicted in the previous section.

2.6.1 Driver education

2.6.1.1 Approaching the roundabout

On approaching a roundabout, decide as early as possible which exit you need to take and get into the correct lane (refer to the section below on "Turning at roundabouts"). Reduce your speed. Bicyclists are vehicles and need to share the lane at intersections. Therefore, allow bicycles to enter the roadway from any bicycle lane. The law gives pedestrians the right-of-way in a crosswalk. Yield to pedestrians waiting to cross or crossing on the approach. Watch out for and be particularly considerate of people with disabilities, children, and elderly pedestrians. Always keep to the right of the splitter island (either painted or raised) on the approach to the roundabout.

2.6.1.2 Entering the roundabout

Upon reaching the roundabout yield line, yield to traffic circulating from the left unless signs or pavement markings indicate otherwise. Do not enter the roundabout beside a vehicle already circulating within the roundabout, as a vehicle near the central island may be exiting at the next exit. Watch out for traffic already on the roundabout, especially cyclists and motorcyclists. Do not enter a roundabout when an emergency vehicle is approaching on another leg; allow queues to clear in front of the emergency vehicle.

2.6.1.3 Within the roundabout

Within a roundabout, do not stop except to avoid a collision; you have the right-of-way over entering traffic. Always keep to the right of the central island and travel in a counterclockwise direction.

Where the circulatory roadway is wide enough to allow two or more vehicles to travel side-by-side, **do not overtake adjacent vehicles who are slightly ahead of yours as they may wish to exit next.** Watch out for traffic crossing in front of you on the roundabout, especially vehicles intending to leave by the next exit. Do not change lanes within the roundabout except to exit.

When an emergency vehicle is approaching, in order to provide it a clear path to turn through the roundabout, proceed past the splitter island of your exit before pulling over.

2.6.1.4 Exiting the roundabout

Maintain a slow speed upon exiting the roundabout. Always indicate your exit using your right-turn signal. For multilane roundabouts, watch for vehicles to your right, including bicycles that may cross your path while exiting, and ascertain if they intend to yield for you to exit. Watch for and yield to pedestrians waiting to cross, or crossing the exit leg. Watch out for and be particularly considerate of people with disabilities, children, and elderly pedestrians. Do not accelerate until you are beyond the pedestrian crossing point on the exit.

2.6.1.5 Turning at roundabouts

Unless signs or pavement markings indicate otherwise:

- **When turning right or exiting** at the first exit around the roundabout, use the following procedure:
  - Turn on your right-turn signal on the approach.
  - If there are multiple approach lanes, use only the right-hand lane.
  - Keep to the outside of the circulatory roadway within the roundabout and continue to use your right-turn signal through your exit.
  - When there are multiple exit lanes use the right-hand lane.
- **When going straight ahead** (i.e., exiting halfway around the roundabout), use the following procedure (see Exhibit 2-7):
  - **Do not use any turn signals on approach.**
  - If there are two approach lanes, you may use either the left– or right-hand approach lanes.
  - When on the circulatory roadway, turn on your right-turn signal once you have passed the exit before the one you want and continue to use your right-turn signal through your exit.
  - Maintain your inside (left) or outside (right) track throughout the roundabout if the circulatory roadway is wide. This means that if you entered using the inner (left) lane, circulate using the inside track of the circulatory roadway and exit from here by crossing the outside track. Likewise, if you entered using the outer (right) lane, circulate using the outside track of the circulatory roadway and exit directly from here. **Do not change lanes within the roundabout except when crossing the outer circulatory track in the act of exiting.**

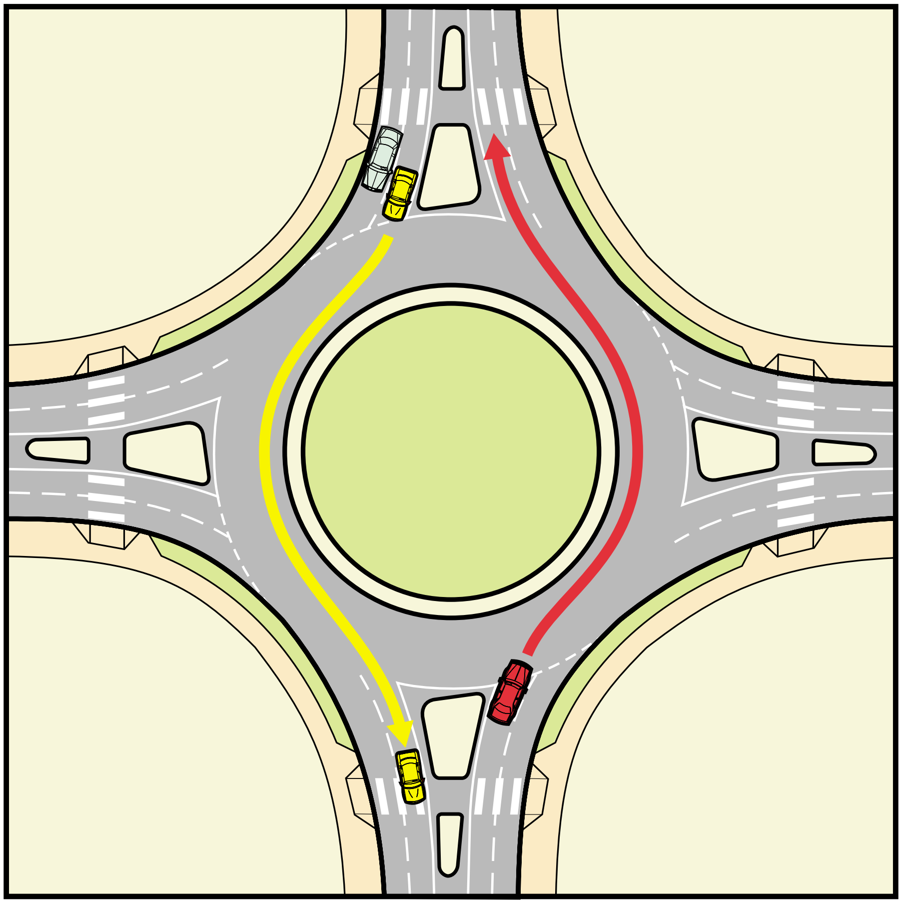


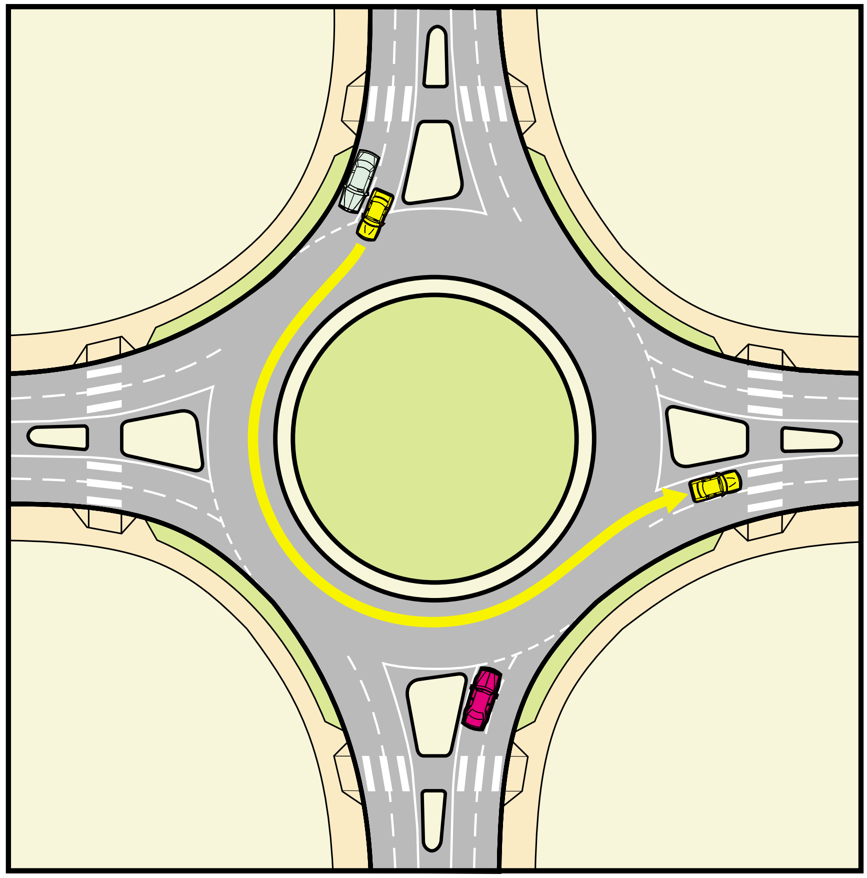
Exhibit 2-7. Driving straight through a roundabout.

Source: *The Highway Code* (UK) (9), converted to right-hand drive

- When exiting the circulatory roadway from the inside track, watch out on the outside track for leading or adjacent vehicles that continue to circulate around the roundabout.
- When exiting the circulatory roadway from the outside track, yield to leading or adjacent vehicles that are exiting into the same lane.

- When turning left or making a U-turn (i.e., exiting more than halfway around the roundabout), use the following procedure (see Exhibit 2-8):
  - Turn on your left turn signal.
  - If there are multiple approach lanes, use only the left-hand lane.
  - Keep to the inner (left) side of the circulatory roadway (nearest the central island).
  - Continue to use your left-turn signal until you have passed the exit before the one you want, and then use your right-turn signal through your exit.
  - When exiting from a multilane roundabout from the inside part of the circulatory roadway, use only the inner lane on the exit (the lane nearest the splitter island). Watch out on the outside part of the circulatory roadway for leading or adjacent vehicles that continue to circulate around the roundabout.

Exhibit 2-8. Turning left at a roundabout.



Source: *The Highway Code* (UK) (9), converted to right-hand drive

- When in doubt about lane choice (especially for roundabouts with legs at angles other than 90½), **use the following general rules to determine which lane you should be in** (unless signs or pavement markings indicate otherwise):
  - If you intend to exit the roundabout less than halfway around it, use the right lane.
  - If you intend to exit the roundabout more than halfway around it, use the left lane.

2.6.1.6 Motorcyclists and bicyclists

Watch out for motorcyclists and bicyclists. Give them plenty of room and show due consideration. Bicyclists may enter the approach roadway from a bicycle lane. Bicyclists will often keep to the right on the roundabout; they may also indicate left to show they are continuing around the roundabout. It is best to treat bicyclists as other vehicles and not pass them while on the circulatory roadway. Motorcyclists should not ride across the mountable truck apron next to the central island, if present.

2.6.1.7 Large vehicles

When car drivers approach a roundabout, do not overtake large vehicles. Large vehicles (for example, trucks and buses) may have to swing wide on the approach or within the roundabout. Watch for their turn signals and give them plenty of room, especially since they may obscure other conflicting users.

To negotiate a roundabout, drivers of large vehicles may need to use the full width of the roadway, including mountable aprons if provided. They should be careful of all other users of the roundabouts and, prior to entering the roundabout, satisfy themselves that other users are aware of them and will yield to them.

2.6.2 Bicyclist education

Bicyclists should likewise be educated about the operating characteristics of roundabouts. Well-designed, low-speed, single-lane roundabouts should not present much difficulty to bicyclists. They should enter these roundabouts just as they enter a stop sign or signal controlled intersection without auxiliary lanes (the bike lane terminates on the approach to these intersections, too). On the approach to the entry, a bicyclist should claim the lane. Right-turning cyclists should keep to the right side of the entry lane; others should be near the center of the lane.

Cyclists have three options upon approaching a roundabout:

- Travel on the circulatory roadway of the roundabout like motorists. When using a double-lane roundabout as a vehicle, obey all rules of the road for vehicles using roundabouts. However, you may feel safer approaching in the right-hand lane and keeping to the right in the roundabout (rather like making two through movements to turn left at a signalized intersection). If you do keep to the right, take extra care when crossing exits and signal left to show you are not leaving. Watch out for vehicles crossing your path to leave or join the roundabout. Watch out for large vehicles on the roundabout, as they need more space to maneuver. It may be safer to wait until they have cleared the roundabout. Or,
- If you are unsure about using the roundabout, dismount and exit the approach lane before the splitter island on the approach, and move to the sidewalk. Once on the sidewalk, walk your bicycle like a pedestrian. Or,
- Some roundabouts may have a ramp that leads to a widened sidewalk or a shared bicycle-pedestrian path that runs around the perimeter of the roundabout. If a ramp access is provided prior to the pedestrian crossing, you may choose to ramp up to curb level and traverse the sidewalk or path while acting courteously to pedestrians. A ramp may also be provided on the exit legs of a roundabout to reenter the roadway, after verifying that it is safe to do so.

2.6.3 Pedestrian education

Pedestrians have the right-of-way within crosswalks at a roundabout; however, pedestrians must not suddenly leave a curb or other safe waiting place and walk into the path of a vehicle if it is so close that it is an immediate hazard. This can be problematic if the design is such that a disabled pedestrian cannot accurately determine the gap. Specific education beyond these general instructions should be provided for disabled pedestrians to use any information provided for them.

- Do not cross the circulatory roadway to the central island. Walk around the perimeter of the roundabout.
- Use the crosswalks on the legs of the roundabout. If there is no crosswalk marked on a leg of the roundabout, cross the leg about one vehicle-length away (7.5 m [25 ft]) from the circulatory roadway of the roundabout. Locate the wheelchair ramps in the curbs. These are built in line with a grade-level opening in the median island. This opening is for pedestrians to wait before crossing the next roadway.

- Roundabouts are typically designed to enable pedestrians to cross one direction of traffic at a time. Look and listen for approaching traffic. Choose a safe time to cross from the curb ramp to the median opening (note that although you have the right-of-way, if approaching vehicles are present, it is prudent to first satisfy yourself that conflicting vehicles have recognized your presence and right to cross, through visual or audible cues such as vehicle deceleration or driver communication). If a vehicle slows for you to cross at a two-lane roundabout, be sure that conflicting vehicles in adjacent lanes have done likewise before accepting the crossing opportunity.
- Most roundabouts provide a raised median island halfway across the roadway; wait in the opening provided and choose a safe time to cross traffic approaching from the other direction.

2.7 References

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3 Planning

Chapter 3 Planning

Chapter 1 presented a range of roundabout categories, and suggested typical daily service volume thresholds below which four-leg roundabouts may be expected to operate, without requiring a detailed capacity analysis. Chapter 2 introduced roundabout performance characteristics, including comparisons with other intersection forms and control, which will be expanded upon in this chapter. This chapter covers the next steps that lead up to the decision to construct a roundabout with an approximate configuration at a specific location, preceding the detailed analysis and design of a roundabout. By confirming that there is good reason to believe that roundabout construction is feasible and that a roundabout offers a sensible method of accommodating the traffic demand, these planning activities make unnecessary the expenditure of effort required in subsequent chapters.

Planning determines whether a roundabout is even feasible, before expending the effort required in subsequent steps.

Planning for roundabouts begins with specifying a preliminary configuration. The configuration is specified in terms of the minimum number of lanes required on each approach and, thus, which roundabout category is the most appropriate basis for design: urban or rural, single-lane or double-lane roundabout. Given sufficient space, roundabouts can be designed to accommodate high traffic volumes. There are many additional levels of detail required in the design and analysis of a high-capacity, multi-lane roundabout that are beyond the scope of a planning level procedure. Therefore, this chapter focuses on the more common questions that can be answered using reasonable assumptions and approximations.

Feasibility analysis requires an approximation of some of the design parameters and operational characteristics. Some changes in these approximations may be necessary as the design evolves. A more detailed methodology for performing the operational evaluation and geometric design tasks is presented later in Chapters 4 and 6 of this guide, respectively.

Some of the assumptions and approximations used in planning may change as the design evolves, but are sufficient at this stage to answer many common questions.

3.1 Planning Steps

The following steps may be followed when deciding whether to implement a roundabout at an intersection:

- Step 1: Consider the context. What are there regional policy constraints that must be addressed? Are there site-specific and community impact reasons why a roundabout of any particular size would not be a good choice? (Section 3.2)
- Step 2: Determine a preliminary lane configuration and roundabout category based on capacity requirements (Section 3.3). Exhibit 3-1 will be useful for making a basic decision on the required number of lanes. If Exhibit 3-1 indicates that more than one lane is required on any approach, refer to Chapters 4 and 6 for the more detailed analysis and design procedures. Otherwise, proceed with the planning procedure.
- Step 3: Identify the selection category (Section 3.4). This establishes why a roundabout may be the preferred choice and determines the need for specific information.

- Step 4: Perform the analysis appropriate to the selection category. If the selection is to be based on operational performance, use the appropriate comparisons with alternative intersections (Section 3.5).
- Step 5: Determine the space requirements. Refer to Section 3.6 and Appendix B for the right-of-way widths required to accommodate the inscribed circle diameter. Determine the space feasibility. Is there enough right-of-way to build it? This is a potential rejection point. There is no operational reason to reject a roundabout because of the need for additional right-of-way; however, right-of-way acquisition introduces administrative complications that many agencies would prefer to avoid.
- Step 6: If additional space must be acquired or alternative intersection forms are viable, an economic evaluation may be useful (Section 3.7).

The results of the steps above should be documented to some extent. The level of detail in the documentation will vary among agencies and will generally be influenced by the size and complexity of the roundabout. A roundabout selection study report may include the following elements:

Suggested contents of a roundabout selection study report.

- It may identify the selection category that specifies why a roundabout is the logical choice at this intersection;
- It may identify current or projected traffic control or safety problems at the intersection if the roundabout is proposed as a solution to these problems;
- It may propose a configuration, in terms of number of lanes on each approach;
- It may demonstrate that the proposed configuration can be implemented feasibly and that it will provide adequate capacity on all approaches; and
- It may identify all potential complicating factors, assess their relevance to the location, and identify any mitigation efforts that might be required.

Agencies that require a more complete or formal rationale may also include the following additional considerations:

- It may demonstrate institutional and community support indicating that key institutions (e.g., police, fire department, schools, etc.) and key community leaders have been consulted;
- It may give detailed performance comparisons of the roundabout with alternative control modes;
- It may include an economic analysis, indicating that a roundabout compares favorably with alternative control modes from a benefit-cost perspective; and
- It may include detailed appendices containing traffic volume data, signal, or all-way stop control (AWSC) warrant analysis, etc.

None of these elements should be construed as an absolute requirement for documentation. The above list is presented as a guide to agencies who choose to prepare a roundabout study report.

3.2 Considerations of Context

3.2.1 Decision environments

There are three somewhat different policy environments in which a decision may be made to construct a roundabout at a specific location. While the same basic analysis tools and concepts apply to all of the environments, the relative importance of the various aspects and observations may differ, as may prior constraints that are imposed at higher policy levels.

Will the roundabout be...

- **Part of a new roadway?**
- **The first in an area?**
- **A retrofit of an existing intersection?**

A new roadway system: Fewer constraints are generally imposed if the location under consideration is not a part of an existing roadway system. Right-of-way is usually easier to acquire or commit. Other intersection forms also offer viable alternatives to roundabouts. There are generally no field observations of site-specific problems that must be addressed. This situation is more likely to be faced by developers than by public agencies.

The first roundabout in an area: The first roundabout in any geographic area requires an implementing agency to perform due diligence on roundabouts regarding their operational and design aspects, community impacts, user needs, and public acceptability. On the other hand, a successfully implemented roundabout, especially one that solves a perceived problem, could be an important factor in gaining support for future roundabouts at locations that could take advantage of the potential benefits that roundabouts may offer. Some important considerations for this decision environment include:

The first roundabout in an area requires greater education and justification efforts. Single-lane roundabouts will be more easily understood initially than multilane roundabouts.

- Effort should be directed toward gaining community and institutional support for the selection of a site for the first roundabout in an area. Public acceptance for roundabouts, like any new roadway facility, require agency staff to understand the potential issues and communicate these effectively with the impacted community;
- An extensive justification effort may be necessary to gain the required support;
- A cautious and conservative approach may be appropriate; careful consideration should be given to conditions that suggest that the benefits of a roundabout might not be fully realized. Collecting data on current users of the facility can provide important insights regarding potential issues and design needs;
- A single-lane roundabout in the near-term is more easily understood by most drivers and therefore may have a higher probability of acceptance by the motoring public;
- The choice of design and analysis procedures could set a precedent for future roundabout implementation; therefore, the full range of design and analysis alternatives should be explored in consultation with other operating agencies in the region; and
- After the roundabout is constructed, evaluating its operation and the public response could provide documentation to support future installations.

Retrofit to an existing intersection in an area where roundabouts have already gained acceptance: This environment is one in which a solution to a site-specific problem is being sought. Because drivers are familiar with roundabout operation, a less intensive process may suffice. Double-lane roundabouts could be considered, and the regional design and evaluation procedures should have already been agreed upon. The basic objectives of the selection process in this case are to demonstrate the community impacts and that a roundabout will function properly during the peak period within the capacity limits imposed by the space available; and to decide whether one is the preferred alternative. If the required configuration involves additional right-of-way, a more detailed analysis will probably be necessary, using the methodology described in Chapter 4.

Many agencies that are contemplating the construction of their first roundabout are naturally reluctant to introduce complications, such as double-lane, yield-controlled junctions, which are not used elsewhere in their jurisdiction. It is also a common desire to avoid intersection designs that require additional right-of-way, because of the effort and expense involved in right-of-way acquisition. Important questions to be addressed in the planning phase are therefore:

- Will a minimally configured roundabout (i.e., single-lane entrances and circulatory roadway) provide adequate capacity and performance for all users, or will additional lanes be required on some legs or at some future time?
- Can the roundabout be constructed within the existing right-of-way, or will it be necessary to acquire additional space beyond the property lines?
- Can a single-lane roundabout be upgraded in the future to accommodate growth?

If not, a roundabout alternative may require that more rigorous analysis and design be conducted before a decision is made.

3.2.2 Site-specific conditions

Some conditions may preclude a roundabout at a specific location. Certain site-related factors may significantly influence the design and require a more detailed investigation of some aspects of the design or operation. A number of these factors (many of which are valid for any intersection type) are listed below:

Site-specific factors that may significantly influence a roundabout's design.

- Physical or geometric complications that make it impossible or uneconomical to construct a roundabout. These could include right-of-way limitations, utility conflicts, drainage problems, etc.
- Proximity of generators of significant traffic that might have difficulty negotiating the roundabout, such as high volumes of oversized trucks.
- Proximity of other traffic control devices that would require preemption, such as railroad tracks, drawbridges, etc.
- Proximity of bottlenecks that would routinely back up traffic into the roundabout, such as over-capacity signals, freeway entrance ramps, etc. The successful operation of a roundabout depends on unimpeded flow on the circulatory roadway. If traffic on the circulatory roadway comes to a halt, momentary intersection gridlock can occur. In comparison, other control types may continue to serve some movements under these circumstances.
- Problems of grades or unfavorable topography that may limit visibility or complicate construction.
- Intersections of a major arterial and a minor arterial or local road where an unacceptable delay to the major road could be created. Roundabouts delay and deflect all traffic entering the intersection and could introduce excessive delay or speed inconsistencies to flow on the major arterial.

- Heavy pedestrian or bicycle movements in conflict with high traffic volumes. (These conflicts pose a problem for all types of traffic control. There is very little experience on this topic in the U.S., mostly due to a lack of existing roundabout sites with heavy intermodal conflicts).
- Intersections located on arterial streets within a coordinated signal network. In these situations, the level of service on the arterial might be better with a signalized intersection incorporated into the system. Chapter 8 deals with system considerations for roundabouts.

The existence of one or more of these conditions does not necessarily preclude the installation of a roundabout. Roundabouts have, in fact, been built at locations that exhibit nearly all of the conditions listed above. Such factors may be resolved in several ways:

- They may be determined to be insignificant at the specific site;
- They may be resolved by operational modeling or specific design features that indicate that no significant problems will be created;
- They may be resolved through coordination with and support from other agencies, such as the local fire department; and
- In some cases, specific mitigation actions may be required.

All complicating factors should be resolved prior to the choice of a roundabout as the preferred intersection alternative.

The effect of a particular factor will often depend on the degree to which roundabouts have been implemented in the region. Some conditions would not be expected to pose problems in areas where roundabouts are an established form of control that is accepted by the public. On the other hand, some conditions, such as heavy pedestrian volumes, might suggest that the installation of a roundabout be deferred until this control mode has demonstrated regional acceptance. Most agencies have an understandable reluctance to introduce complications at their first roundabout.

3.3 Number of Entry Lanes

A basic question that needs to be answered is how many entry lanes a roundabout would require to serve the traffic demand. The capacity of a roundabout is clearly a critical parameter and one that should be checked at the outset of any feasibility study. Chapter 4 offers a detailed capacity computation procedure, mostly based on experiences in other countries. Some assumptions and approximations have been necessary in this chapter to produce a planning-level approach for deciding whether or not capacity is sufficient.

Since this is the first of several planning procedures to be suggested in this chapter, some discussion of the assumptions and approximations is appropriate. First, traffic volumes are generally represented for planning purposes in terms of Average Daily Traffic (ADT), or Average Annual Daily Traffic (AADT). Traffic operational analyses must be carried out at the design hour level. This requires an assumption of a K factor and a D factor to indicate, respectively, the proportion of the AADT assigned to the design hour, and the proportion of the two-way traffic that is assigned to the peak direction. All of the planning-level procedures offered in this chapter were based on reasonably typical assumed values for K of 0.1 and D of 0.58.

There are two site-specific parameters that must be taken into account in all computations. The first is the proportion of traffic on the major street. For roundabout planning purposes, this value was assumed to lie between 0.5 and 0.67. All analyses assumed a four-leg intersection. The proportion of left turns must also be considered, since left turns affect all traffic control modes adversely. For the purposes of this chapter, a reasonably typical range of left turns were examined. Right turns were assumed to be 10 percent in all cases. Right turns are included in approach volumes and require capacity, but are not included in the circulating volumes downstream because they exit before the next entrance.

The volume-to-capacity ratio of any roundabout leg is recommended not to exceed 0.85.

The capacity evaluation is based on values of entering and circulating traffic volumes as described in Chapter 4. The AADT that can be accommodated is conservatively estimated as a function of the proportion of left turns, for cross-street volume proportions of 50 percent and 67 percent. For acceptable roundabout operation, many sources advise that the volume-to-capacity ratio on any leg of a roundabout not exceed 0.85 (1, 2). This assumption was used in deriving the AADT maximum service volume relationship.

3.3.1 Single- and double-lane roundabouts

The resulting maximum service volumes are presented in Exhibit 3-1 for a range of left turns from 0 to 40 percent of the total volume. This range exceeds the normal expectation for left turn proportions. This procedure is offered as a simple, conservative method for estimating roundabout lane requirements. If the 24-hour volumes fall below the volumes indicated in Exhibit 3-1, a roundabout should have no operational problems at any time of the day. It is suggested that a reasonable approximation of lane requirements for a three-leg roundabout may be obtained using 75 percent of the service volumes shown on Exhibit 3-1.

If the volumes exceed the threshold suggested in Exhibit 3-1, a single-lane or double-lane roundabout may still function quite well, but a closer look at the actual turning movement volumes during the design hour is required. The procedures for such analysis are presented in Chapter 4.

3.3.2 Mini-roundabouts

Mini-roundabouts are distinguished from traditional roundabouts primarily by their smaller size and more compact geometry. They are typically designed for negotiation speeds of 25 km/h (15 mph). Inscribed circle diameters generally vary from 13 m to 25 m (45 ft to 80 ft). Mini-roundabouts are usually implemented with safety in mind, as opposed to capacity. Peak-period capacity is seldom an issue, and most mini-roundabouts operate on residential or collector streets at demand levels well below their capacity. It is important, however, to be able to assess the capacity of any proposed intersection design to ensure that the intersection would function properly if constructed.

At very small roundabouts, it is reasonable to assume that each quadrant of the circulatory roadway can accommodate only one vehicle at a time. In other words, a vehicle may not enter the circulatory roadway unless the quadrant on both sides of the approach is empty. Given a set of demand volumes for each of the 12 standard movements at a four-leg roundabout, it is possible to simulate the roundabout to estimate the maximum service volumes and delay for each approach. By making assumptions about the proportion of left turns and the proportion of cross street traffic, a general estimate of the total entry maximum service volumes of the roundabout can be made, and is provided in Exhibit 3-2. AADT maximum service volumes are represented based on an assumed K value of 0.10. Note that these volumes range from slightly more than 12,000 to slightly less than 16,000 vehicles per day. The maximum throughput is achieved with an equal proportion of vehicles on the major and minor roads, and with low proportions of left turns.

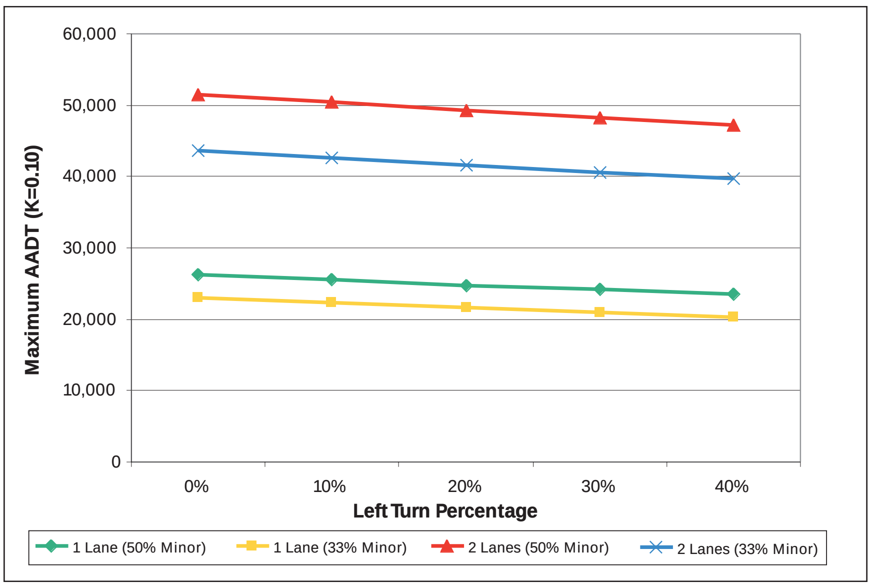

Exhibit 3-1. Maximum daily service volumes for a four-leg roundabout.

For three-leg roundabouts, use 75 percent of the maximum AADT volumes shown.

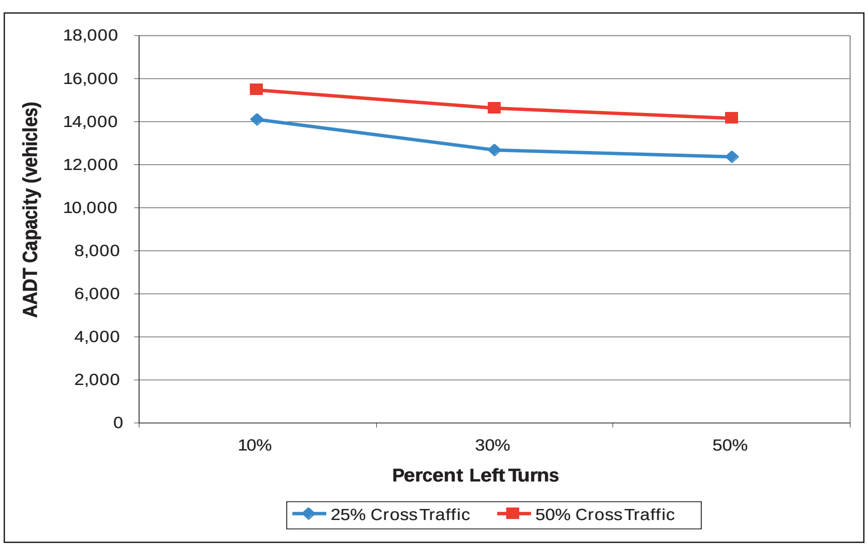

Exhibit 3-2. Planning-level maximum daily service volumes for mini-roundabouts.

3.4 Selection Categories

There are many locations at which a roundabout could be selected as the preferred traffic control mode. There are several reasons why this is so, and each reason creates a separate selection category. Each selection category, in turn, requires different information to demonstrate the desirability of a roundabout. The principal selection categories will be discussed in this section, along with their information requirements.

A wide range of roundabout policies and evaluation practices exists among operating agencies within the U.S. For example, the Florida Department of Transportation requires a formal "justification report" to document the selection of a roundabout as the most appropriate traffic control mode at any intersection on their State highway system. On the other hand, private developers may require no formal rationalization of any kind. It is interesting to note that the Maryland Department of Transportation requires consideration of a roundabout as an alternative at all intersections proposed for signalization.

It is reasonable that the decision to install a roundabout should require approximately the same level of effort as the alternative control mode. In other words, if a roundabout is proposed as an alternative to a traffic signal, then the analysis effort should be approximately the same as that required for a signal. If the alternative is stop sign control, then the requirements could be relaxed.

The following situations present an opportunity to demonstrate the desirability of installing a roundabout at a specific location.

3.4.1 Community enhancement

Roundabouts have been proposed as a part of a community enhancement project and not as a solution to capacity problems. Such projects are often located in commercial and civic districts, as a gateway treatment to convey a change of environment and to encourage traffic to slow down. Traffic volumes are typically well below the thresholds shown in Exhibit 3-1; otherwise, one of the more operationally oriented selection categories would normally be more appropriate.

The planning focus for community enhancement roundabouts should be to demonstrate that they will not create traffic problems that do not now exist.

Roundabouts proposed for community enhancement require minimal analysis as a traffic control device. The main focus of the planning procedure should be to demonstrate that they would not introduce traffic problems that do not exist currently. Particular attention should be given to any complications that would imply either operational or safety problems. The urban compact category may be the most appropriate roundabout for such applications. Exhibit 3-3 provides an example of a roundabout installed primarily for community enhancement.

3.4.2 Traffic calming

The decision to install a roundabout for traffic calming purposes should be supported by a demonstrated need for traffic calming along the intersecting roadways. Most of the roundabouts in this category will be located on local roads. Examples of conditions that might suggest a need for traffic calming include:

Conditions that traffic calming roundabouts may address.

- Documented observations of speeding, high traffic volumes, or careless driving activities;

Naples, FL

Exhibit 3-3. Example of community enhancement roundabout.

- Inadequate space for roadside activities, or a need to provide slower, safer conditions for non-automobile users; or
- New construction (road opening, traffic signal, new road, etc.) which would potentially increase the volumes of "cut-through" traffic.

Capacity should be an issue when roundabouts are installed for traffic calming purposes only because traffic volumes on local streets will usually be well below the level that would create congestion. If this is not the case, another primary selection category would probably be more suitable. The urban mini-roundabout or urban compact roundabout are most appropriate for traffic calming purposes. Exhibit 3-4 provides an example of roundabouts installed primarily for traffic calming.

3.4.3 Safety improvement

The decision to install a roundabout as a safety improvement should be based on a demonstrated safety problem of the type susceptible to correction by a roundabout. A review of crash reports and the type of accidents occurring is essential. Examples of safety problems include:

Safety issues that roundabouts may help correct.

- High rates of crashes involving conflicts that would tend to be resolved by a roundabout (right angle, head-on, left/through, U-turns, etc.);
- High crash severity that could be reduced by the slower speeds associated with roundabouts;

Exhibit 3-4. Example of traffic calming roundabouts.

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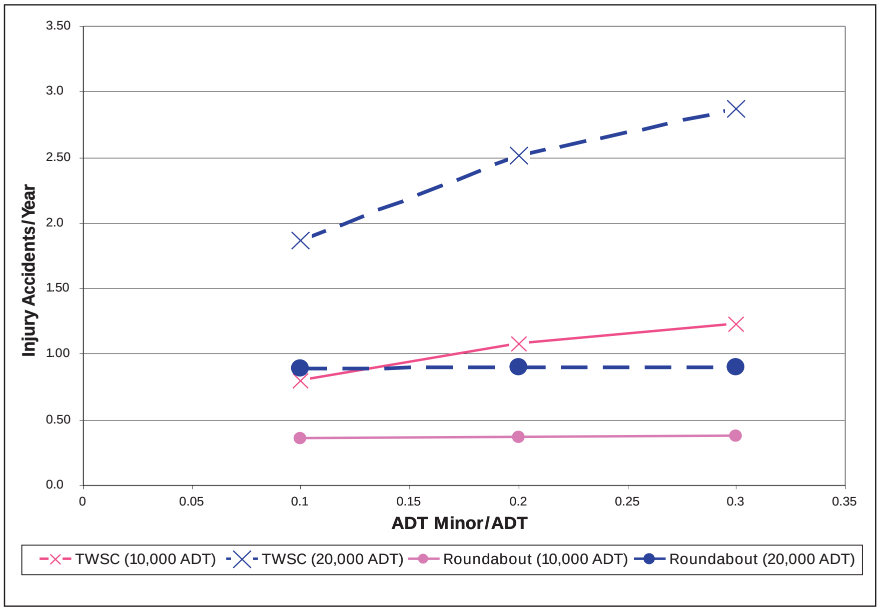
- Site visibility problems that reduce the effectiveness of stop sign control (in this case, landscaping of the roundabout needs to be carefully considered); and
- Inadequate separation of movements, especially on single-lane approaches.

Chapter 5 should be consulted for a more detailed analysis of the safety characteristics of roundabouts. There are currently a small number of roundabouts and therefore a relatively small crash record data base in the U.S. Therefore, it has not been possible to develop a national crash model for this intersection type. Roundabout crash prediction models have been developed for the United Kingdom (3). Crash models for conventional intersections in the United States are available (4, 5). Although crash data reporting may not be consistent between the U.K. and the U.S., comparison is plausible. The two sets of models have a key common measure of effectiveness in terms of injury and fatal crash frequency.

Therefore, for illustrative purposes, Exhibit 3-5 provides the results of injury crash prediction models for various ADT volumes of roundabouts versus rural TWSC intersections (6). The comparison shown is for a single-lane approach, four-leg roundabout with single-lane entries, and good geometric design. For the TWSC rural intersection model, the selected variables include rolling terrain, the main road as major collector, and a design speed of 80 km/h (50 mph). Rural roundabouts may experience approximately 66 percent fewer injury crashes than rural TWSC intersections for 10,000 entering ADT, and approximately 64 percent fewer crashes for 20,000 ADT. At urban roundabouts, the reduction will probably be smaller.

Also for illustration, Exhibit 3-6 provides the results of injury crash prediction models for various average daily traffic volumes at roundabouts versus rural and urban signalized intersections (6). The selected variables of the crash model for signalized (urban/suburban) intersections include multiphase fully-actuated signal, with a speed of 80 km/h (50 mph) on the major road. The 20,000 entering ADT is applied to single-lane roundabout approaches with four-legs. The 40,000 ADT is applied to double-lane roundabout approaches without flaring of the roundabout entries. In comparison to signalized intersections, roundabouts may experience approximately



Source: (6)

Exhibit 3-5. Comparison of predicted roundabout injury crashes with rural TWSC intersections.

Roundabouts have fewer annual injury crashes than rural two-way stop-controlled intersections, and the total number of crashes at roundabouts is relatively insensitive to minor street demand volumes.

Source: (6)

Exhibit 3-6. Comparison of predicted injury crashes for single-lane and double-lane roundabouts with rural or urban signalized intersections.

Roundabouts have fewer injury accidents per year than signalized intersections, particularly in rural areas. At volumes greater than 50,000 ADT, urban roundabout safety may be comparable to that of urban signalized intersections.

33 percent fewer injury crashes in urban and suburban areas and 56 percent fewer crashes in rural areas for 20,000 entering ADT. For 40,000 entering ADT, this reduction may only be about 15 percent in urban areas. Therefore, it is likely that roundabout safety may be comparable to signalized intersections at higher ADT (greater than 50,000).

These model comparisons are an estimation of mean crash frequency or average safety performance from a random sample of four-leg intersections from different countries and should be supplemented by engineering judgment and attention to safe design for all road users.

3.4.4 Operational improvement

A roundabout may be considered as a logical choice if its estimated performance is better than alternative control modes, usually either stop or signal control. The performance evaluation models presented in the next chapter provide a sound basis for comparison, but their application may require more effort and resources than an agency is prepared to devote in the planning stage. To simplify the selection process, the following assumptions are proposed for a planning-level comparison of control modes:

General delay and capacity comparisons between roundabouts and other forms of intersection control.

1. A roundabout will always provide a higher capacity and lower delays than AWSC operating with the same traffic volumes and right-of-way limitations.
2. A roundabout is unlikely to offer better performance in terms of lower overall delays than TWSC at intersections with minor movements (including cross street entry and major street left turns) that are not experiencing, nor predicted to experience, operational problems under TWSC.
3. A single-lane roundabout may be assumed to operate within its capacity at any intersection that does not exceed the peak-hour volume warrant for signals.
4. A roundabout that operates within its capacity will generally produce lower delays than a signalized intersection operating with the same traffic volumes and right-of-way limitations.

The above assumptions are documented in the literature (7) or explained by the analyses in Section 3.5. Collectively, they provide a good starting point for further analysis using procedures in Chapter 4. Although a roundabout may be the optimal control type from a vehicular operation standpoint, the relative performance of this control alternative for other modes should also be taken into consideration, as explained in Chapter 4.

3.4.4.1 Roundabout performance at flow thresholds for peak hour signal warrants

There are no warrants for roundabouts included in the *Manual of Uniform Traffic Control Devices* (MUTCD) (8), and it may be that roundabouts are not amenable to a warranting procedure. In other words, each roundabout should be justified on its own merits as the most appropriate intersection treatment alternative. It is, however, useful to consider the case in which the traffic volumes just meet the MUTCD warrant thresholds for traffic signals. For purposes of this discussion, the MUTCD peak hour warrant will be applied with a peak hour factor (PHF) of 0.9. Thus, the evaluation will reflect the performance in the heaviest 15 minutes of the peak hour.

Roundabout delays were compared with the corresponding values for TWSC, AWSC, and signals. A single-lane roundabout was assumed because the capacity of a single lane roundabout was adequate for all cases at the MUTCD volume warrant thresholds. SIDRA analysis software was used to estimate the delay for the various control alternatives because SIDRA was the only program readily available at the time this guide was developed that modeled all of the control alternatives (9).

The MUTCD warrant thresholds are given in terms of the heaviest minor street volume and sum of the major street volumes. Individual movement volumes may be obtained from the thresholds by assuming a directional factor, D, and left turn proportions. A "D" factor of 0.58 was applied to this example. Left turns on all approaches were assumed to be 10 to 50 percent of the total approach volume. In determining the MUTCD threshold volumes, two lanes were assumed on the major street and one lane on the minor street.

Based on these assumptions, the average delays per vehicle for signals and roundabouts are presented in Exhibit 3-7. These values represent the approach delay as perceived by the motorist. They do not include the geometric delay incurred within the roundabout. It is clear from this figure that roundabout control delays are substantially lower than signal delays, but in neither case are the delays excessive.

Similar comparisons are not presented for TWSC, because the capacity for minor street vehicles entering the major street was exceeded in all cases at the signal

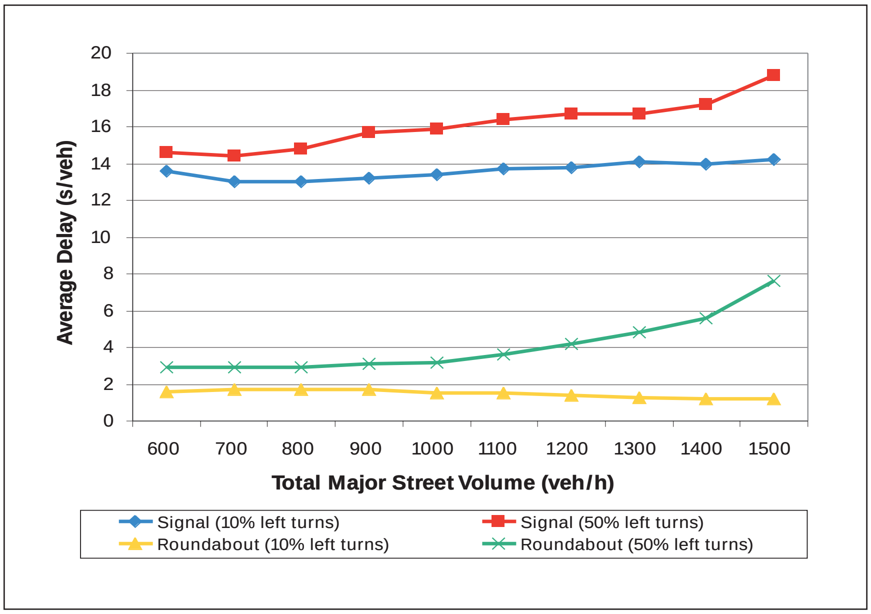


Exhibit 3-7. Average delay per vehicle at the MUTCD peak hour signal warrant threshold (excluding geometric delay).

Roundabout approach delay is relatively insensitive to total major street volume, but is sensitive to the left-turn percentage.

warrant thresholds. AWSC was found to be feasible only under a limited range of conditions: a maximum of 20 percent left turns can be accommodated when the major street volume is low and only 10 percent can be accommodated when the major street volume is high. Note that the minor street volume decreases as the major street volume increases at the signal warrant threshold.

This analysis of alternative intersection performance at the MUTCD peak hour volume signal warrant thresholds indicates that the single-lane roundabout is very competitive with all other forms of intersection control.

3.4.5 Special situations

It is important that the selection process not discourage the construction of a roundabout at any location where a roundabout would be a logical choice. Some flexibility must be built into the process by recognizing that the selection categories above are not all-inclusive. There may still be other situations that suggest that a roundabout would be a sensible control choice. Many of these situations are associated with unusual alignment or geometry where other solutions are intractable.

3.5 Comparing Operational Performance of Alternative Intersection Types

If a roundabout is being considered for operational reasons, then it may be compared with other feasible intersection control alternatives such as TWSC, AWSC, or signal control. This section provides approximate comparisons suitable for planning.

3.5.1 Two-way stop-control alternative

The majority of intersections in the U.S. operate under TWSC, and most of those intersections operate with minimal delay. The installation of a roundabout at a TWSC intersection that is operating satisfactorily will be difficult to justify on the basis of performance improvement alone, and one of the previously described selection categories is likely to be more appropriate.

Roundabouts may offer an effective solution at TWSC intersections with heavy left turns from the major street.

The two most common problems at TWSC intersections are congestion on the minor street caused by a demand that exceeds capacity, and queues that form on the major street because of inadequate capacity for left turning vehicles yielding to opposing traffic. Roundabouts may offer an effective solution to traffic problems at TWSC intersections with heavy left turns from the major route because they provide more favorable treatment to left turns than other control modes. "T" intersections are especially good candidates in this category because they tend to have higher left turning volumes.

Roundabouts work better when the proportion of minor street traffic is higher.

On the other hand, the problems experienced by low-volume cross street traffic at TWSC intersections with heavy through volumes on the major street are very difficult to solve by any traffic control measure. Roundabouts are generally not the solution to this type of problem because they create a significant impediment to the major movements. This situation is typical of a residential street intersection with a major arterial. The solution in most cases is to encourage the residential traffic to enter the arterial at a collector road with an intersection designed to accommodate higher entering volumes. The proportion of traffic on the major street is an important consideration in the comparison of a roundabout with a conventional four-leg intersection operating under TWSC. High proportions of minor street traffic tend to favor roundabouts, while low proportions favor TWSC.

An example of this may be seen in Exhibit 3-8, which shows the AADT capacity for planning purposes as a function of the proportion of traffic on the major street. The assumptions in this exhibit are the same as those that have been described previously in Section 3.3. Constant proportions of 10 percent right turns (which were ignored in roundabout analysis) and 20 percent left turns were used for all movements. As expected, the roundabout offers a much higher capacity at lower proportions of major street traffic. When the major and minor street volumes are equal, the roundabout capacity is approximately double that of the TWSC intersection. It is interesting to note that the two capacity values converge at the point where the minor street proportion becomes negligible. This effect confirms the expectation that a roundabout will have approximately the same capacity as a stop-controlled intersection when there is no cross street traffic.

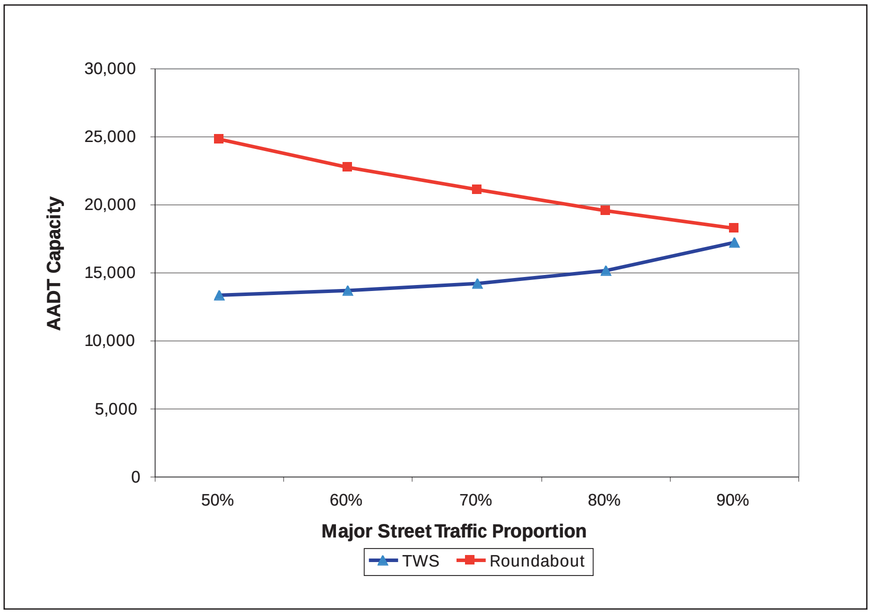


Exhibit 3-8. Comparison of TWSC and single-lane roundabout capacity.

Roundabout capacity decreases as the proportion of minor street entering traffic decreases. Roundabouts and TWSC intersections have about the same capacity when the minor street proportion is less than 10 percent.

3.5.2 All-way stop-control alternative

When cross street traffic volumes are heavy enough to meet the MUTCD warrants for AWSC control, roundabouts become an especially attractive solution because of their higher capacities and lower delays. The selection of a roundabout as an alternative to AWSC should emphasize cost and safety considerations, because roundabouts always offer better performance for vehicles than AWSC, given the same traffic conditions. Roundabouts that are proposed as alternatives to stop control would typically have single-lane approaches.

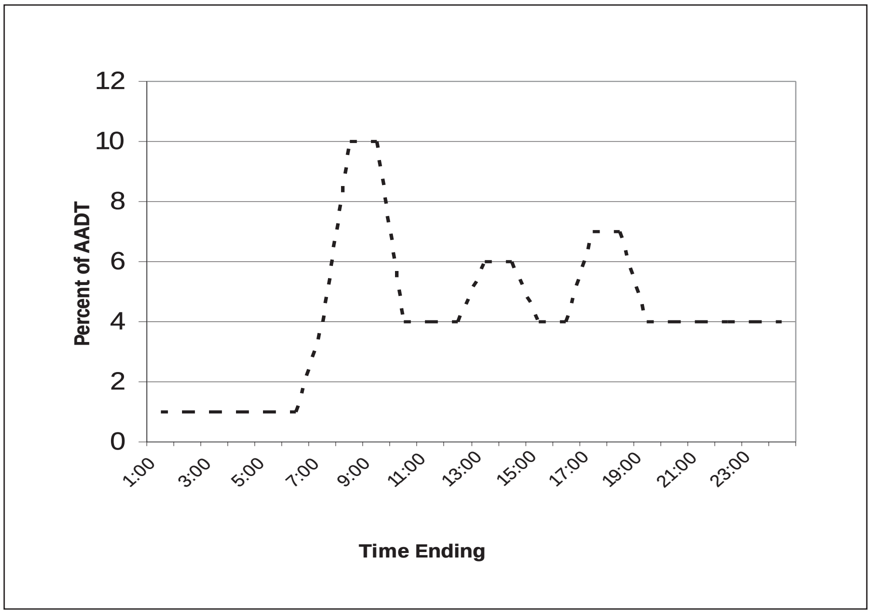
A substantial part of the benefit of a roundabout compared to an all-way stop intersection is obtained during the off-peak periods, because the restrictive stop control applies for the entire day. The MUTCD does not permit stop control on a part-time basis. The extent of the benefit will depend on the amount of traffic at the intersection and on the proportion of left turns. Left turns degrade the operation of all traffic control modes, but they have a smaller effect on roundabouts than on stop signs or signals.

A substantial part of the delay-reduction benefit of roundabouts, compared to AWSC intersections, comes during off-peak periods.

The planning level analysis that began earlier in this chapter may be extended to estimate the benefits of a roundabout compared to AWSC. Retaining the previous assumptions about the directional and temporal distribution factors for traffic volumes (i.e., K=0.1, D=0.58), it is possible to analyze both control modes throughout an entire 24-hour day. Only one additional set of assumptions is required. It is necessary to construct an assumed hourly distribution of traffic throughout the day that conforms to these two factors.

A reasonably typical sample distribution for this purpose is illustrated in Exhibit 3-9, which would generally represent inbound traffic to employment centers, because of the larger peak in the AM period, accompanied by smaller peaks in the noontime and PM periods. Daytime off-peak periods have 4 percent of the AADT per hour, and late-night off-peak periods (midnight to 6 AM) have 1 percent.

Exhibit 3-9. Sample hourly distribution of traffic.



The outbound direction may be added as a mirror image of the inbound direction, keeping the volumes the same as the inbound during the off-peak periods and applying the D factor of 0.58 during the AM and PM peaks. This distribution was used in the estimation of the benefits of a roundabout compared to the AWSC mode. It was also used later for comparison with traffic signal operations. For purposes of estimating annual delay savings, a total of 250 days per year is assumed. This provides a conservative estimate by eliminating weekends and holidays.

The comparisons were performed using traffic operations models that are described in Chapter 4 of this guide. The SIDRA model was used to analyze both the roundabout and AWSC operation, because SIDRA was the only model readily available at the time this guide was developed that treated both of these types of control. SIDRA provides an option to either include or omit the geometric delay experienced within the intersection. The geometric delay was included for purposes of estimating annual benefits. It was excluded in Section 3.4.4.1 that dealt with driver-perceived approach delay.

The results of this comparison are presented in Exhibit 3-10 and Exhibit 3-11 in terms of potential annual savings in delay of a single-lane roundabout over an AWSC intersection with one lane on all approaches, as a function of the proportion of left turning traffic for single-lane approaches for volume distributions of 50 percent and 65 percent on the major street, respectively. Each exhibit has lines representing 10 percent, 25 percent, and 33 percent left turn proportions.

Note that the potential annual benefit is in the range of 5,000 to 50,000 vehicle-hours per year. The benefit increases substantially with increasing AADT and left turn proportions. The comparison terminates in each case when the capacity of the AWSC operation is exceeded. No comparisons were made beyond 18,000 AADT, because AWSC operation is not practical beyond that level.

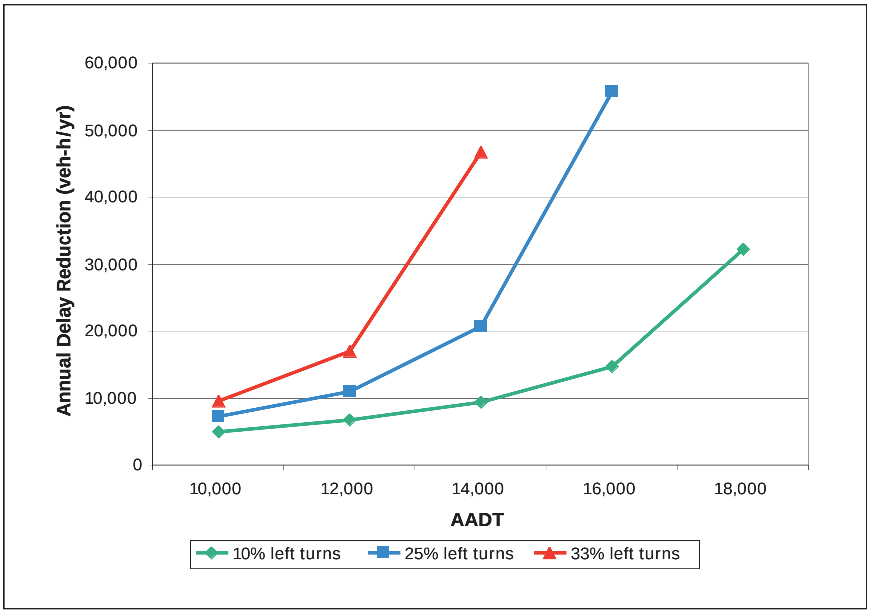


Exhibit 3-10. Annual savings in delay of single-lane roundabout versus AWSC, 50 percent of volume on the major street.

The delay-reduction benefit of roundabouts, compared to AWSC, increases as left-turn volumes, major street proportion, and AADT increase.

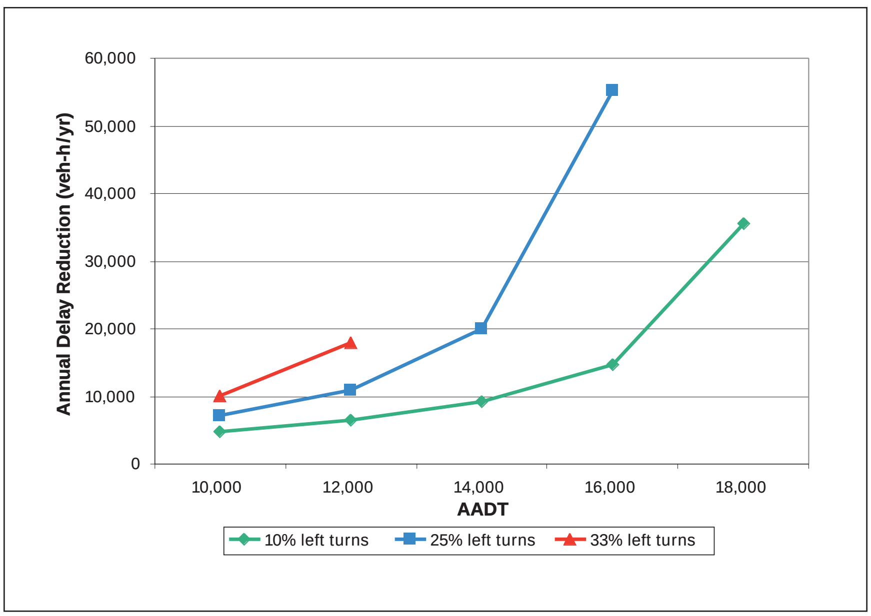


Exhibit 3-11. Annual savings in delay of single-lane roundabout versus AWSC, 65 percent of volume on the major street.

3.5.3 Signal control alternative

When traffic volumes are heavy enough to warrant signalization, the selection process becomes somewhat more rigorous. The usual basis for selection here is that a roundabout will provide better operational performance than a signal in terms of stops, delay, fuel consumption, and pollution emissions. For planning purposes, this may generally be assumed to be the case provided that the roundabout is operating within its capacity. The task then becomes to assess whether any roundabout configuration can be made to work satisfactorily. If not, then a signal or grade separation are remaining alternatives. As in the case of stop control, intersections with heavy left turns are especially good roundabout candidates.

The graphical approximation presented earlier for capacity estimation should be useful at this stage. The results should be considered purely as a planning level estimate, and it must be recognized that this estimate will probably change during the design phase. Users of this guide should also consult the most recent version of the *Highway Capacity Manual* (HCM) (10) as more U.S. data and consensus on modeling U.S. roundabout performance evolves.

As in the case of AWSC operations, some of the most important benefits of a roundabout compared to a traffic signal will accrue during the off-peak periods. The comparison of delay savings discussed previously has therefore been extended to deal with traffic signals as well as stop signs. The same temporal distribution of traffic volumes used for the roundabout-AWSC comparison was assumed.

The signal timing design was prepared for each of the conditions to accommodate traffic in the heaviest peak period. The traffic actuated controller was allowed to respond to fluctuations in demand during the rest of the day using its own logic. This strategy is consistent with common traffic engineering practice. All approaches were considered to be isolated and free of the influence of coordinated systems. Left turn protection was provided for the whole day for all approaches with a volume cross-product (i.e., the product of the left turn and opposing traffic volumes) of 60,000 or greater during the peak period. When left turn protection was provided, the left turns were also allowed to proceed on the solid green indication (i.e., protected-plus-permitted operation).

The results of this comparison are presented in Exhibit 3-12 for 50 percent major street traffic and Exhibit 3-13 for 65 percent major street traffic. Both cases include AADT values up to 34,000 vehicles per day. Single-lane approaches were used for both signals and roundabouts with AADTs below 25,000 vehicles per day. Two-lane approaches were assumed beyond that point. All signalized approaches were assumed to have left turn bays.

Benefits may continue to accrue beyond the 34,000 AADT level but the design parameters for both the signal and the roundabout are much more difficult to generalize for planning level analyses. When AADTs exceed 34,000 vehicles per day, performance evaluation should be carried out using the more detailed procedures presented in Chapter 4 of this guide.

The selection of a roundabout as an alternative to signal control will be much simpler if a single-lane roundabout is estimated to have adequate capacity. If, on the other hand, it is determined that one or more legs will require more than one entry lane, some preliminary design work beyond the normal planning level will generally be required to develop the roundabout configuration and determine the space requirements.

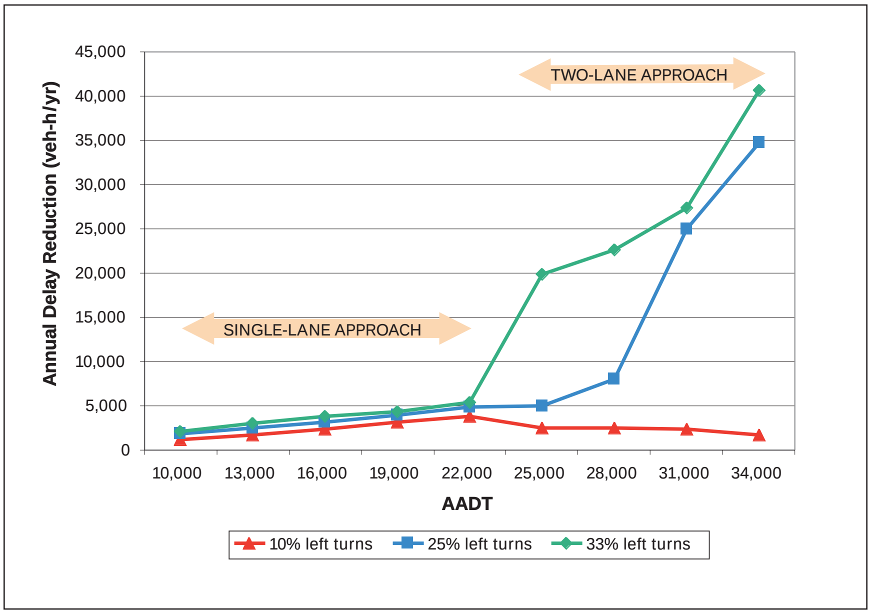


Exhibit 3-12. Delay savings for roundabout vs. signal, 50 percent volume on major street.

When volumes are evenly split between major and minor approaches, the delay savings of roundabouts versus signals are especially notable on two-lane approaches with high left turn proportions.

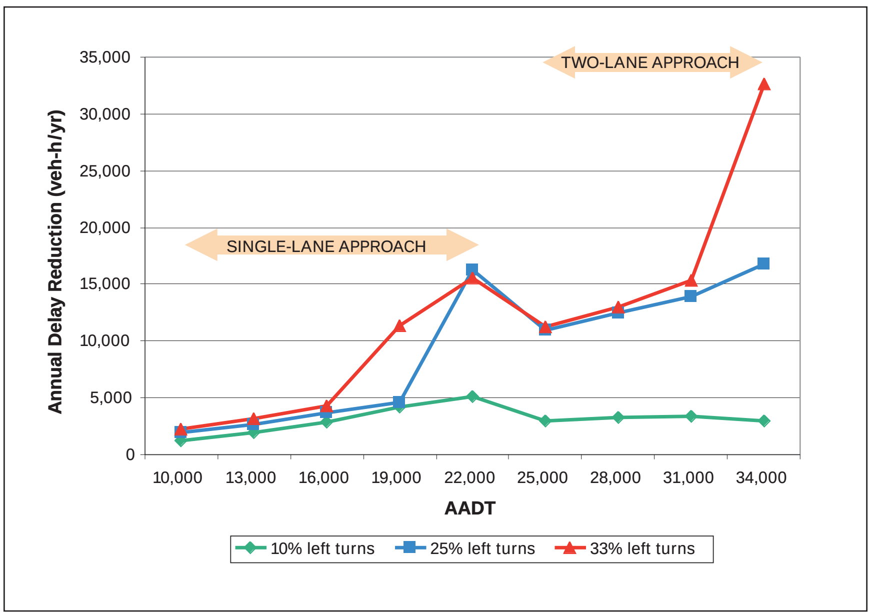


Exhibit 3-13. Delay savings for roundabout vs. signal, 65 percent volume on major street.

When the major street approaches dominate, roundabout delay is lower than signal delay, particularly at the upper volume limit for single-lane approaches and when there is a high proportion of left turns.

3.6 Space Requirements

Roundabouts that are designed to accommodate vehicles larger than passenger cars or small trucks typically require more space than conventional intersections. However, this may be more than offset by the space saved compared with turning lane requirements at alternative intersection forms. The key indicator of the required space is the inscribed circle diameter. A detailed design is required to determine the space requirements at a specific site, especially if more than one lane is needed to accommodate the entering and circulating traffic. This is, however, another case in which the use of assumptions and approximations can produce

The design templates in Appendix B may be used to determine initial space requirements for the appropriate roundabout category.

preliminary values that are adequate for planning purposes. For initial space requirements, the design templates in Appendix B for the most appropriate of the six roundabout categories for the specific site may be consulted.

One important question is whether or not the proposed roundabout will fit within the existing property lines, or whether additional right-of-way will be required. Four examples have been created to demonstrate the spatial effects of comparable intersection types, and the assumptions are summarized in Exhibit 3-14. Note that there are many combinations of turning volumes that would affect the actual lane configurations and design storage lengths. Therefore, these examples should not be used out of context.

Exhibit 3-14. Assumptions for spatial comparison of roundabouts and comparable conventional intersections.

	Roundabout Type		Conventional Intersection	
Category	Main Street Approach Lanes	Side Street Approach Lanes	Main Street Approach Lanes	Side Street Approach Lanes
Urban compact	1	1	1	1
Urban single-lane	1	1	1 + LT pocket	1
Urban double-lane	2	1	2 + LT pocket	1 + LT pocket
Urban double-lane with flaring	1 flared to 2	1	2 + LT pocket	1 + LT pocket

Note: LT = left turn

Although roundabouts typically require more area at the junction compared to conventional intersections, they may not need as much area on the approaches.

As can be seen in Exhibit 3-15 through Exhibit 3-18, roundabouts typically require more area at the junction than conventional intersections. However, as capacity needs increase the size of the roundabout and comparable conventional (signalized) intersection, the increase in space requirements are increasingly offset by a reduction in space requirements on the approaches. This is because the widening or flaring required for a roundabout can be accomplished in a shorter distance than is typically required to develop left turn lanes and transition tapers at conventional intersections.

As can be seen in Exhibit 3-18, flared roundabouts offer the most potential for reducing spatial requirements on the approaches as compared to conventional intersections. This effect of providing capacity at the intersections while reducing lane requirements between intersections, known as "wide nodes and narrow roads," is discussed further in Chapter 8.

3.7 Economic Evaluation

Economic evaluation is an important part of any public works planning process. For roundabout applications, economic evaluation becomes important when compar-

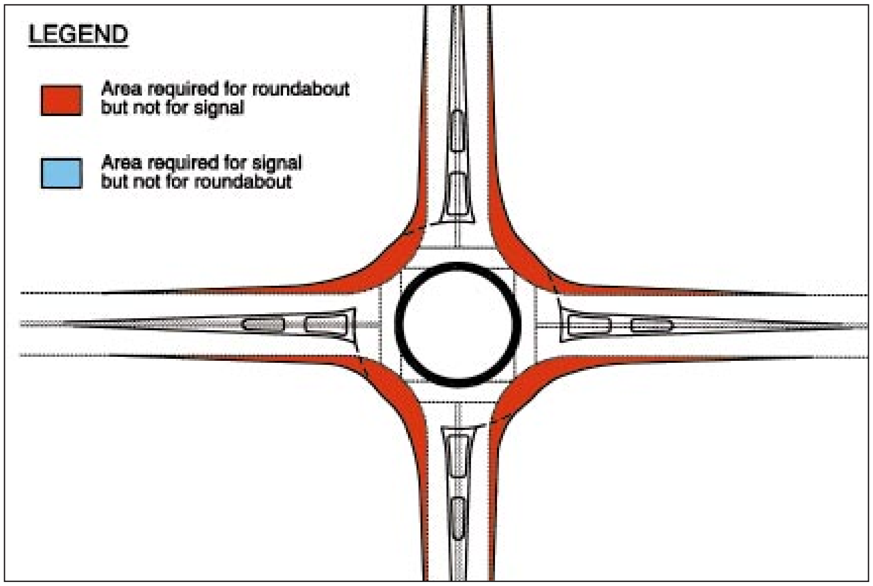


Exhibit 3-15. Area comparison: Urban compact roundabout vs. comparable signalized intersection.

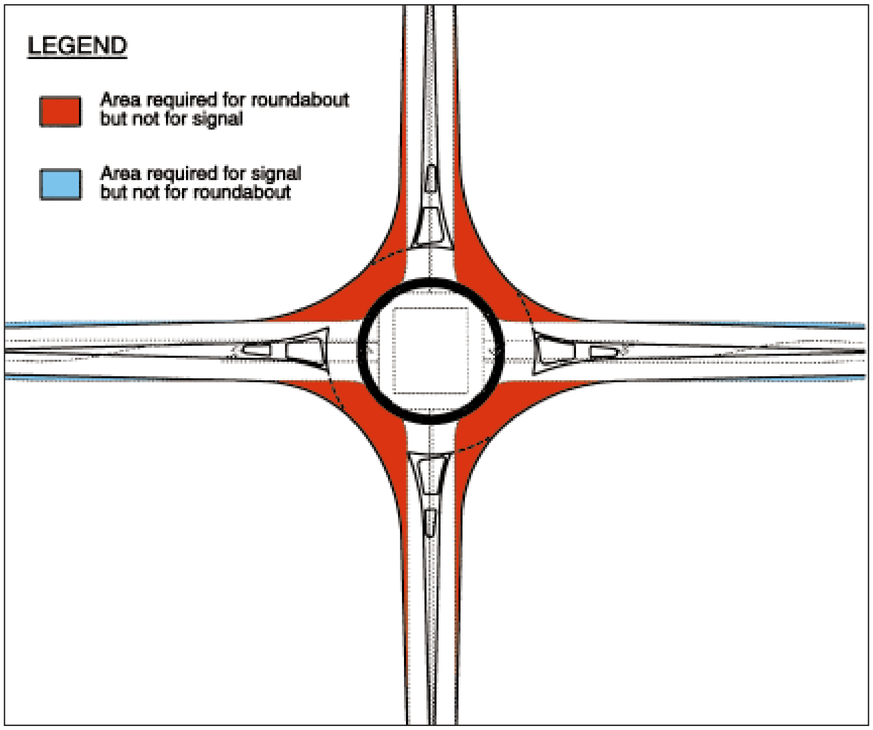


Exhibit 3-16. Area comparison: Urban single-lane roundabout vs. comparable signalized intersection.

Exhibit 3-17. Area comparison: Urban double-lane roundabout vs. comparable signalized intersection.

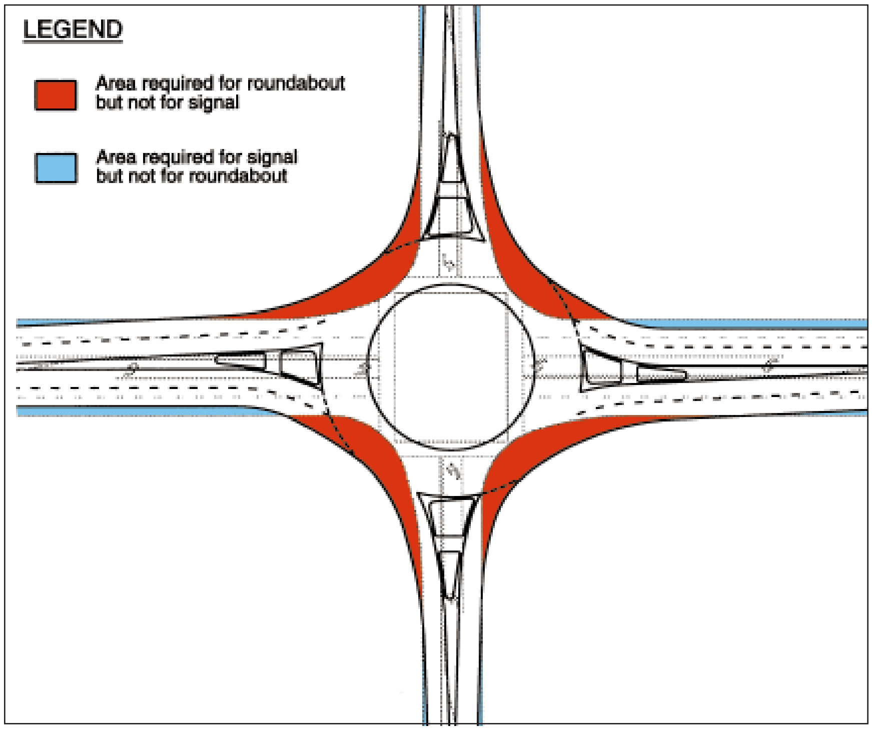
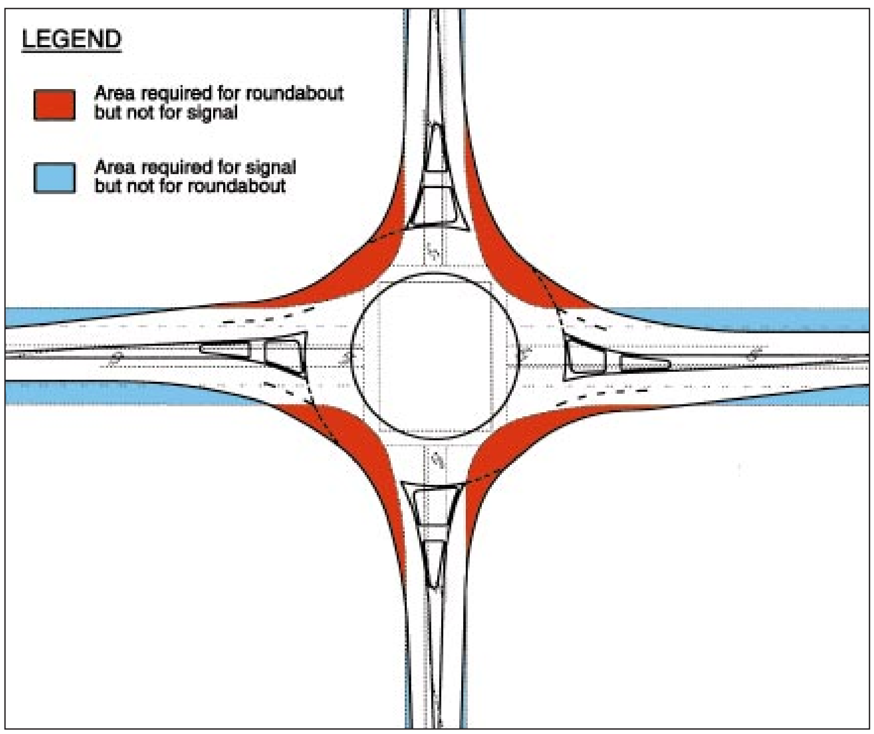


Exhibit 3-18. Area comparison: Urban flared roundabout vs. comparable signalized intersection.

Urban flared roundabouts in particular illustrate the "wide nodes, narrow roads" concept discussed further in Chapter 8.



ing roundabouts against other forms of intersections and traffic control, such as comparing a roundabout with a signalized intersection.

The most appropriate method for evaluating public works projects of this type is usually the benefit-cost analysis method. The following sections discuss this method as it typically applies to roundabout evaluation, although it can be generalized for most transportation projects.

3.7.1 Methodology

The benefit-cost method is elaborated on in detail in a number of standard references, including the ITE *Transportation Planning Handbook* (11) and various American Association of State Highway and Transportation Officials (AASHTO) publications (12, 13). The basic premise of this method of evaluation is to compare the incremental benefit between two alternatives to the incremental costs between the same alternatives. Assuming Alternatives A and B, the equation for calculating the incremental benefit-cost ratio of Alternative B relative to Alternative A is given in Equation 3-1.

$$B/C_{B\,A} = \frac{Benefits_B - Benefits_A}{Costs_B - Costs_A} \qquad (3\text{-}1)$$

Benefit-cost analysis typically takes two forms. For assessing the viability of a number of alternatives, each alternative is compared individually with a no-build alternative. If the analysis for Alternative A relative to the no-build alternative indicates a benefit-cost ratio exceeding 1.0, Alternative A has benefits that exceed its costs and is thus a viable project.

For ranking alternatives, the incremental benefit-cost ratio analysis is used to compare the relative benefits and costs between alternatives. Projects should not be ranked based on their benefit-cost ratio relative to the no-build alternative. After eliminating any alternatives that are not viable as compared to the no-build alternative, alternatives are compared in a pair-wise fashion to establish the priority between projects.

Rank alternatives based on their incremental benefit-cost ratio, not on their ratio relative to the no-build alternative.

Since many of the input parameters may be estimated, a rigorous analysis should consider varying the parameter values of key assumptions to verify that the recommended alternative is robust, even under slightly varying assumptions, and under what circumstances it may no longer be preferred.

3.7.2 Estimating benefits

Benefits for a public works project are generally comprised of three elements: safety benefits, operational benefits, and environmental benefits. Each benefit is typically quantified on an annualized basis and so is readily usable in a benefit-cost analysis. The following sections discuss these in more detail.

Benefits consist of:
- **Safety benefits**
- **Operational benefits**
- **Environmental benefits**

3.7.2.1 Safety benefits

Safety benefits are defined as the assumed savings to the public due to a reduction in crashes within the project area. The general procedure for determining safety benefits is as follows:

- Quantify the existing safety history in the study area in terms of a crash rate for each level of severity (fatal, injury, property damage). This rate, expressed in terms of crashes per million entering vehicles, is computed by dividing the number of crashes of a given severity that occurred during the "before" period by the number of vehicles that entered the intersection during the same period. This results in a "before" crash rate for each level of severity.
- Estimate the change in crashes of each level of severity that can be reasonably expected due to the proposed improvements. As documented elsewhere in this guide, roundabouts tend to have proportionately greater reductions in fatal and injury crashes than property damage crashes.
- Determine a new expected crash rate (an "after" crash rate) by multiplying the "before" crash rates by the expected reductions. It is best to use local data to determine appropriate crash reduction factors due to geometric or traffic control changes, as well as the assumed costs of various severity levels of crashes.
- Estimate the number of "after" crashes of each level of severity for the life of the project by multiplying the "after" crash rate by the expected number of entering vehicles over the life of the project.
- Estimate a safety benefit by multiplying the expected number of "after" crashes of each level of severity by the average cost of each crash and then annualizing the result. The values in Exhibit 3-19 can provide a starting point, although local data should be used where available.

Exhibit 3-19. Estimated costs for crashes of varying levels of severity.

Crash Severity	Economic Cost (1997 dollars)
Death (per death)	$980,000
Injury (per injury)	$34,100
Property Damage Only (per crash)	$6,400

Source: National Safety Council (14)

3.7.2.2 Operational benefits

Quantify operational benefits in terms of vehicle-hours of delay.

The operational benefits of a project may be quantified in terms of the overall reduction in person-hours of delay to the public. Delay has a cost to the public in terms of lost productivity, and thus a value of time can typically be assigned to changes in estimated delay to quantify benefits associated with delay reduction.

The calculation of annual person-hours of delay can be performed with varying levels of detail, depending on the availability of data. For example, the vehicle-hours of delay may be computed as follows. The results should be converted to person-hours of delay using appropriate vehicle-occupancy factors (including transit), then adding pedestrian delay if significant.

- Estimate the delay per vehicle for each hour of the day. If turning movements are available for multiple hours, this estimate can be computed directly. If only the peak hour is available, the delay for an off-peak hour can be approximated by proportioning the peak hour turning movements by total entering vehicles.
- Determine the daily vehicle-hours of delay by multiplying the estimated delay per vehicle for a given hour by the total entering vehicles during that hour and then aggregating the results over the entire day. If data is available, these calculations can be separated by day of week or by weekday, Saturday, and Sunday.
- Determine annual vehicle-hours of delay by multiplying the daily vehicle-hours of delay by 365. If separate values have been calculated by day of week, first determine the weekday vehicle-hours of delay and then multiply by 52.1 (365 divided by 7). It may be appropriate to use fewer than 365 days per year because the operational benefits will not usually apply equally on all days.

3.7.2.3 Environmental benefits

The environmental benefits of a project are most readily quantified in terms of reduced fuel consumption and improved air quality. Of these, reductions in fuel consumption and the benefits associated with those reductions are typically the simplest to determine.

One way to determine fuel consumption is to use the same procedure for estimating delay, as described previously. Fuel consumption is an output of several of the models in use today, although the user is cautioned to ensure that the model is appropriately calibrated for current U.S. conditions. Alternatively, one can estimate fuel consumption by using the estimate of annual vehicle-hours of delay and then multiplying that by an assumed fuel consumption rate during idling, expressed as liters per hour (gallons per hour) of idling. The resulting estimate can then be converted to a cost by assuming an average cost of fuel, expressed in dollars per liter (dollars per gallon).

3.7.3 Estimation of costs

Costs for a public works project are generally comprised of two elements: capitalized construction costs and operations and maintenance (O&M) costs. Although O&M costs are typically determined on an annualized basis, construction costs are typically a near-term activity that must be annualized. The following sections discuss these in more detail.

3.7.3.1 Construction costs

Construction costs for each alternative should be calculated using normal preliminary engineering cost estimating techniques. These costs should include the costs of any necessary earthwork, paving, bridges and retaining walls, signing and striping, illumination, and signalization.

To convert construction costs into an annualized value for use in the benefit-cost analysis, a *capital recovery factor* (CRF) should be used, shown in Equation 3-2. This converts a present value cost into an annualized cost over a period of *n* years using an assumed discount rate of *i* percent.

$$CRF = \frac{i(1+i)^n}{i(1+i)^n - 1} \qquad (3\text{-}2)$$

where: *i* = discount rate
n = number of periods (years)

3.7.3.2 Operation and maintenance (O&M) costs

Roundabout O&M costs are typically slightly higher than signalized intersections for:
- **Illumination**
- **Signing**
- **Pavement marking**
- **Landscaping**

Operation and maintenance costs vary significantly between roundabouts and other forms of intersection control beyond the basic elements. Common elements include signing and pavement marking maintenance and power for illumination, if provided.

Roundabouts typically have a slightly higher illumination power and maintenance costs compared to signalized or sign-controlled intersections due to a larger number of illumination poles. Roundabouts have slightly higher signing and pavement marking maintenance costs due to a higher number of signs and pavement markings. Roundabouts also introduce additional cost associated with the maintenance of any landscaping in and around the roundabout.

Signalized intersections also have O&M costs for:
- **Signal power**
- **Bulb replacement**
- **Detection maintenance**

Signalized intersections have considerable additional cost associated with power for the traffic signal and maintenance costs such as bulb replacement, detection maintenance, etc. Power costs vary considerably from region to region and over time and should be verified locally. For general purposes, an annual cost of $3,000 for providing power to a signalized intersection is a reasonable approximation.

3.8 References

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