3-72

Synthesis on Channelized Right Turns at Intersections on Urban and Suburban Arterials

NCHRP Project 3-72
MRI Project 110286

Final Synthesis

August 2006

Prepared for

National Cooperative Highway Research Program
Transportation Research Board
National Research Council

by

Ingrid B. Potts, Douglas W. Harwood, and Darren J. Torbic
Midwest Research Institute

Sonia A. Hennum, Chris B. Tiesler, John D. Zegeer, and John F. Ringert
Kittelson and Associates

David L. Harkey
Consultant

Janet M. Barlow
Accessible Design for the Blind

ACKNOWLEDGMENT OF SPONSORSHIP

This work was sponsored by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council.

DISCLAIMER

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SUMMARY

This synthesis presents a review of current literature and state and local highway agency policies and practices related to channelized right turns. The synthesis documents current knowledge and practice concerning the advantages and disadvantages and the safety and operational tradeoffs of specific design practices for channelized right turns. The research included an extensive review of literature and a survey of practice reported by highway agencies in 40 states and 35 cities and counties. The survey of highway practice focused on current design practices for channelized right turns and operational and safety experience with existing sites.

Channelized right turns are defined as turning roadways at intersections that provide for free-flow or nearly free-flow right-turn movements. Channelization can be provided in a variety of forms including painted pavement areas and curbed islands. Channelized right turns have become increasingly common in urban areas over the last 20 years, enhancing intersection capacity and operations. In fact, results of the highway agency survey indicate that 85 percent of state and local highway agencies use channelized right turns.

The AASHTO *Policy on Geometric Design of Highways and Streets*, commonly known as the *Green Book*, provides guidance on the design of channelized right turns under the topic of turning roadways. The policy describes the design controls and criteria for turning roadways and recommends values for the design elements of the horizontal and vertical alignment and the cross section of turning roadways. This synthesis presents a discussion of a number of geometric design issues as they relate to channelized right turns.

Consideration of pedestrian needs, and particularly the needs of pedestrians with vision impairments, has become a key issue in the use of channelized right turns. Conflicts with

pedestrians may be likely at right-turn roadways because the driver's attention may be focused on the cross-street traffic. Furthermore, pedestrians with vision impairments may have particular difficulty crossing the right-turn roadway because it is not as easy to audibly detect approaching traffic as at a conventional intersection. Despite these potential problems, channelized right turns also provide advantages for pedestrians. The presence of a channelized right turn, while making it necessary for pedestrians to cross two roadways, often reduces the pedestrian crossing distance of the cross street. Furthermore, the channelizing island, particularly when bounded by raised curbs, serves as a refuge area for pedestrians and improves safety and accessibility by allowing pedestrians to cross the street in two stages.

In many ways, it may not be the design of the channelized roadway, but the type of traffic control at an intersection with a channelized right turn, that most directly affects the safety of travel through the intersection by pedestrians and bicyclists. Traffic control devices at channelized right turns can range from simple pavement markings and signing to accessible pedestrian signals or pedestrian-actuated warning devices. This synthesis addresses general traffic control issues and traffic control solutions for accommodating pedestrians and bicyclists.

The primary traffic operational reasons for providing channelized right turns are to increase vehicular capacity at an intersection and to reduce delay to drivers by allowing them to turn at higher speeds and reduce unnecessary stops. Channelized right turns appear to provide a net reduction in motor vehicle delay at intersections where they are installed, although no existing data and no established methodology are available to directly compare the operational performance of urban intersections with and without channelized right turns. Furthermore, no data are available on the operational effects of installing pedestrian-activated signals along right-turn roadways. A traffic operational evaluation of channelized right turns, with and without pedestrian signals on the right-turn roadway, is needed to quantify the differences between alternative designs.

The safety effects of channelized right turns on motor vehicles, pedestrians, and bicyclists are largely unknown. It is generally accepted that channelized right turns improve safety for motor vehicles at intersections where they are used, but there is only limited quantitative data to demonstrate this. No studies have been found concerning pedestrian safety at channelized right turns that have used crash data to document the pedestrian safety implications of channelized right turns. There also appears to be an inherent risk to bicyclists at channelized right turns because motor vehicles entering the channelized right-turn roadway must weave across the path of bicycles traveling straight through the intersection, but no studies based upon crash history are available to support this presumption. However, this same type of conflict between through bicyclists and right-turn vehicles is present at conventional intersections as well.

This synthesis summarizes the advantages and disadvantages of channelized right turns. While these advantages and disadvantages reflect the current knowledge and experience of highway agencies concerning channelized right turns, there is very little quantitative data on their performance. There are many unresolved issues concerning channelized right turns that indicate a need for further research.

CHAPTER 1.

INTRODUCTION

BACKGROUND

Channelized right-turn lanes are turning roadways at intersections that provide for free-flow or nearly free-flow right-turn movements. Channelization can be provided in a variety of forms including painted pavement areas and curbed islands. Figure 1 illustrates an intersection with channelized right-turn lanes. While the figure shows channelized right turns in all quadrants of the intersection, channelized right turns may be appropriate in some quadrants, but not in others, depending on intersection geometry and traffic demands.

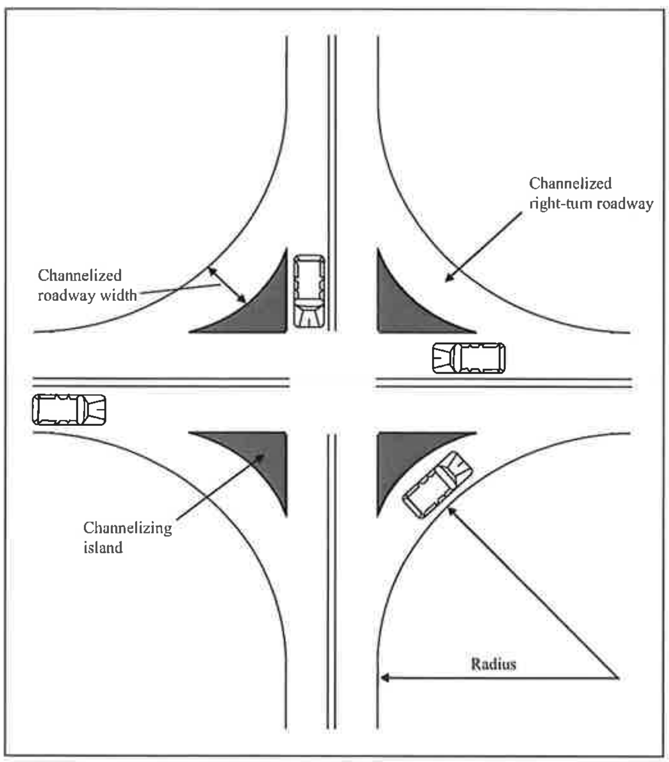


Figure 1. Typical intersection with channelized right turns.

The primary reasons for providing a channelized right turn are (*1, 2, 3*):

- To increase vehicular capacity at intersections
- To reduce delay to drivers by allowing them to turn at higher speeds
- To reduce unnecessary stops
- To clearly define the appropriate path for right-turn maneuvers at skewed intersections or at intersections with high right-turn volumes
- To improve safety by separating the points at which crossing conflicts and right-turn merge conflicts occur
- To permit the use of large curb return radii to accommodate turning vehicles, including large trucks, without unnecessarily increasing the intersection pavement area and the pedestrian crossing distance

Channelized right turns have become increasingly common in urban areas over the last 20 years, enhancing intersection capacity and operations. It is also likely that provision of channelized right turns reduces vehicle emissions by minimizing unnecessary stops.

A key concern with channelized right turns is the extent of conflicts between vehicles and pedestrians that occur at the point where pedestrians cross the right-turn roadway. Conflicts with pedestrians may be likely at right-turn roadways because the driver's attention may be focused on the cross-street traffic; the placement of pedestrian crosswalks or pedestrian signals on channelized turning roadways may violate driver expectancy. For most pedestrians, crossing the right-turn roadway is a relatively easy task because such roadways are not very wide and because traffic is approaching from a single direction. However, pedestrians with vision impairments may have difficulty detecting approaching traffic in the channelized right-turn roadway because of the difficulty discriminating the sound of traffic on the right-turn roadway from the traffic on the major street and the possibility of major street traffic masking the sounds of quieter vehicles in the channelized right-turn roadway.

Despite these potential problems, channelized right turns also provide advantages for pedestrians. The provision of a channelized right turn often reduces the pedestrian crossing distance at major roadways, whose width may be reduced because right-turn maneuvers are served by the separate turning roadway. The presence of the channelized right turn makes it necessary for pedestrians to cross two roadways, but each is narrower than the single crossing might be if no channelized right-turn were provided. Furthermore, the channelizing island, particularly when bounded by raised curbs, serves as a refuge area for pedestrians and improves safety and accessibility by allowing pedestrians to cross the street in two stages.

OBJECTIVES AND SCOPE

The objective of this synthesis is to document current knowledge and practice concerning the use of channelized right turns. The synthesis addresses the advantages and disadvantages and the safety and operational tradeoffs of specific design practices for channelized right turns on urban and suburban arterials. Effects of channelized right turns on the pedestrian, bicycle, and vehicle modes of travel are presented. In particular, consideration of pedestrians who are visually impaired is included. The preparation of this synthesis included critical review of relevant literature and a survey to determine the current practices of state and local highway agencies.

This synthesis has been developed as part of research for NCHRP Project 3-72, *Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes*. Separate syntheses have been prepared to address lane widths and right-turn deceleration lanes on urban and suburban arterials. Further research on those two issues is being conducted in Phase II of the research.

ORGANIZATION OF THIS SYNTHESIS

This synthesis is organized as follows. Chapter Two addresses the geometric design of channelized right turns, based on highway agency policies and practices. Chapter Three addresses the traffic control used at channelized right turns to accommodate vehicles, pedestrians, and bicycles. Chapter Four summarizes current knowledge concerning traffic operations at channelized right turns, and Chapter Five summarizes current knowledge concerning traffic safety at channelized right turns. Chapter Six presents a summary of the advantages and disadvantages of channelized right turns. Appendix A presents the questionnaire used in the highway agency survey, while Appendix B summarizes the survey results concerning channelized right turns.

CHAPTER 2.

GEOMETRIC DESIGN

The highway agency survey reported in Appendix B of this synthesis indicates that 87 percent of state and local highway agencies use channelized right turns; even casual observation indicates that channelized right turns are a relatively common geometric feature at intersections on urban and suburban arterials.

Figure 2 illustrates the basic geometric alternatives available to highway agencies for handling right-turn maneuvers at intersections (*4*). Alternative A includes two configurations for conventional intersection approaches without right-turn deceleration lanes. Alternative B is a conventional intersection approach with an exclusive right-turn deceleration lane. Alternatives C, D, and E represent various types of channelized right turns, focusing primarily on the treatment of the upstream or entrance end of the channelized right-turn roadway, where it departs from the through roadway. Figure 3 illustrates the geometric and traffic control options for the downstream or exit end of the channelized right-turn roadway, where it joins the cross street (*4*). Most combinations of the upstream-end treatments shown in Figure 2 and the downstream-end treatments shown in Figure 3 are feasible.

The AASHTO *Policy on Geometric Design of Highways and Streets* (*1, 2*), commonly known as the *Green Book*, provides guidance on the design of channelized right turns under the topic of turning roadways. The policy describes the design controls and criteria for turning roadways and recommends values for the design elements of the horizontal and vertical alignment and the cross section of turning roadways. Although the *Green Book* is the primary reference for roadway design, channelized right turns are also addressed in the AASHTO *Guide* *for Planning, Design, and Operation of Pedestrian Facilities* (*5*). Published literature also addresses design issues for channelized right turns, including design speed, horizontal alignment, and speed-change lanes.

This section presents a discussion of the following geometric design issues as they relate to channelized right-turn lanes:

- Warrants
- Design principles
- Island size and design
- Design speed of turning roadways
- Radius and superelevation of turning roadways
- Width of turning roadways
- Angle of entry to cross street
- Deceleration and acceleration lanes

Each of these issues is addressed below.

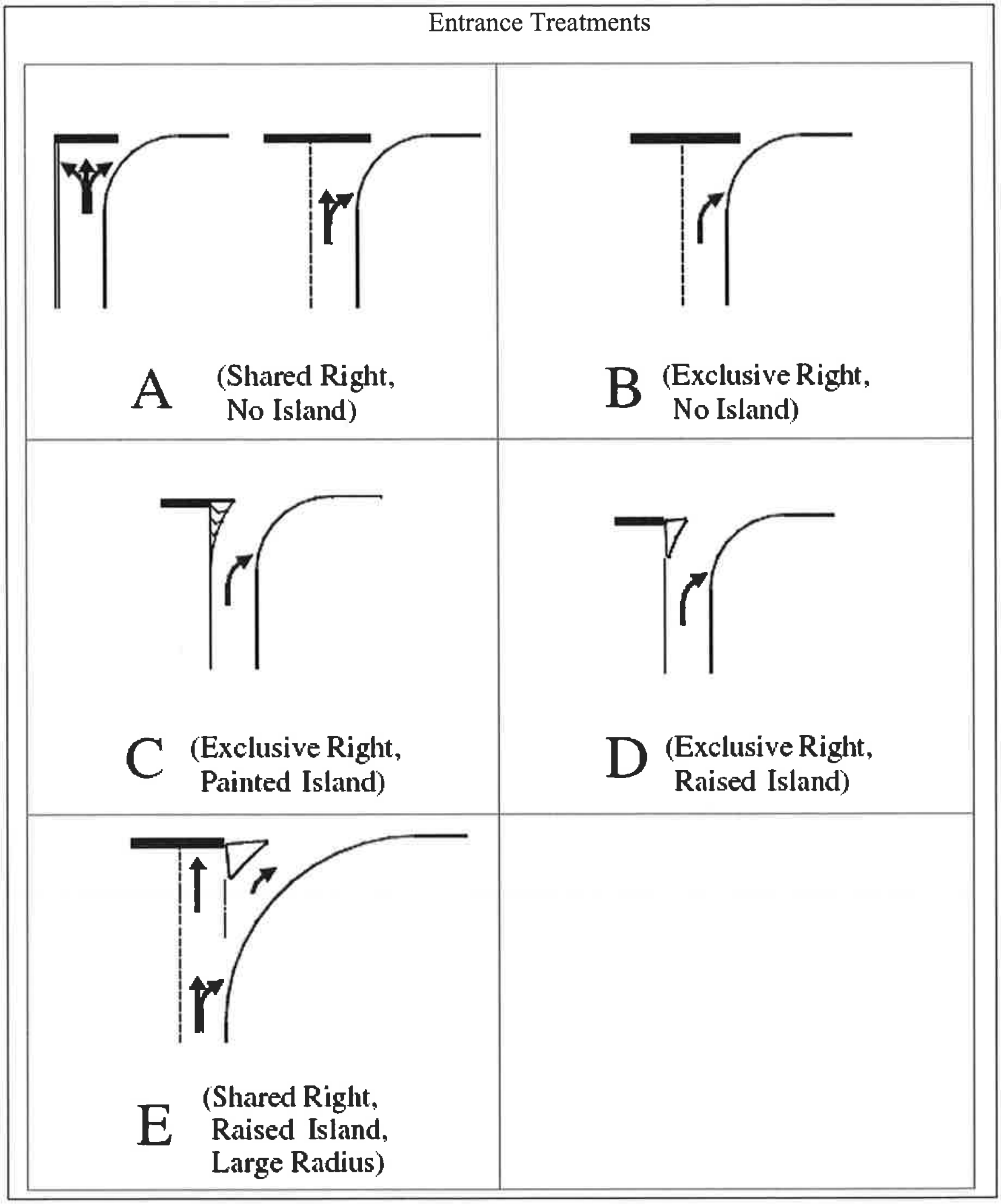


Figure 2. Right-turn treatments for intersections including treatments for the upstream or entrance end of channelized right-turn roadways (4).

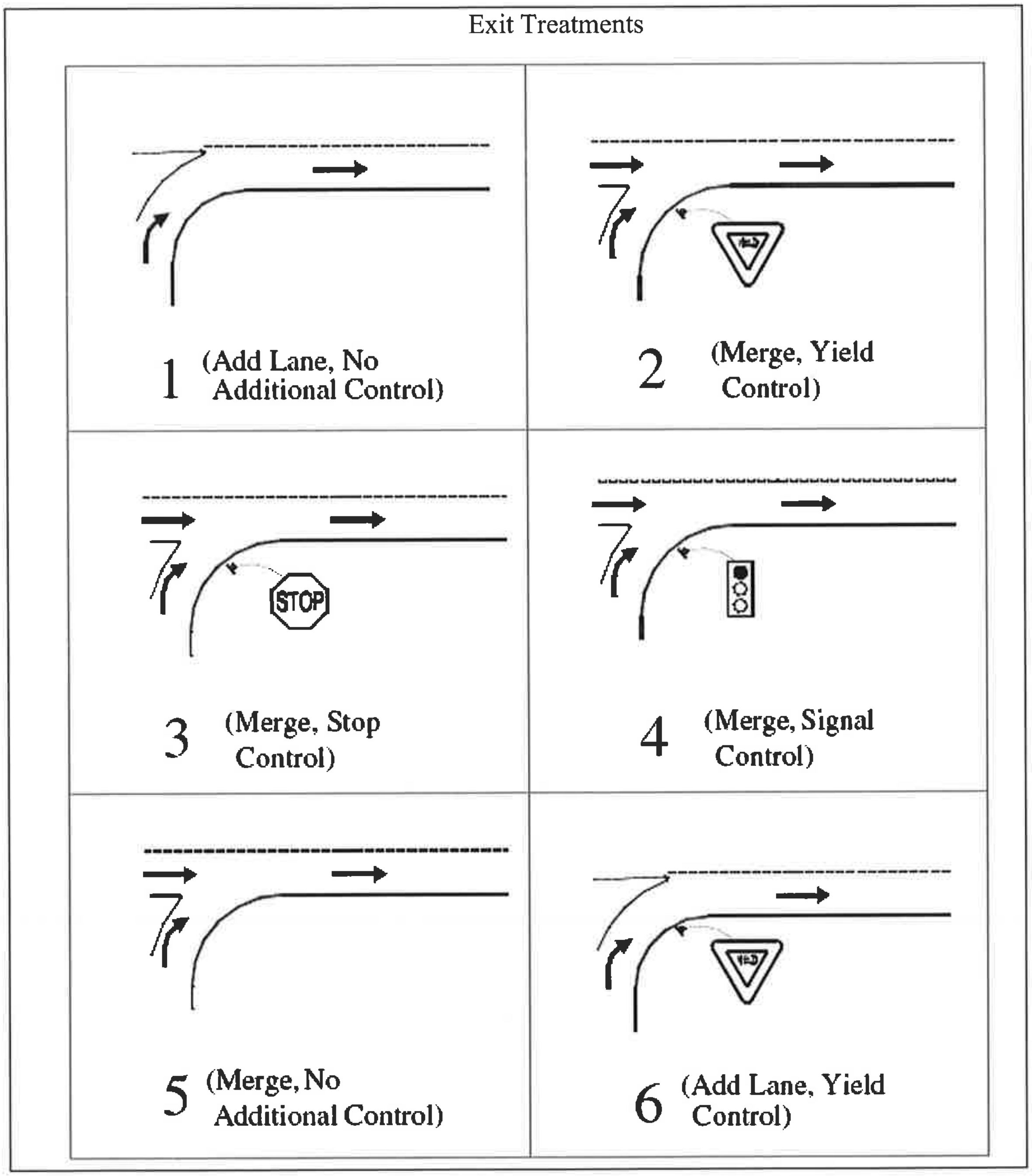


Figure 3. Geometric and traffic control treatments for the downstream or exit end of channelized right-turn roadways (4).

WARRANTS

The *Green Book* notes some of the general conditions that should be considered in determining the need for turning roadways but does not include specific warrants for their use. The *Green Book* suggests that channelized right turns may be appropriate at intersections with large paved areas, such as those with large corner radii or those with oblique angle crossings, because such intersections permit and encourage uncontrolled vehicle movements, involve long pedestrian crossings, and have unused pavement areas.

NCHRP Report 279, *Intersection Channelization Design Guide* (*3*), addresses channelized right turns under the topic of turning roadways. While specific warrants for the use of turning roadways are not provided, Neuman recommends using channelized right turns for the following purposes:

- To clearly define the appropriate path for right-turn movements at skewed intersections, or at intersections with high right-turn volumes,
- To facilitate high-speed right-turn movements from high-speed roadways,
- To separate right-turn merge conflicts from the crossing conflicts within the intersection,
- To promote safe merging for right-turn movements operating under yield control or no control,
- To facilitate high-priority traffic movements (e.g., intersections with route turns), and
- To provide safe refuge for pedestrians and other non-motor vehicle users.

The *Traffic Engineering Handbook* (*6*) states that channelization is warranted to facilitate high-priority traffic movements and traffic control schemes and to remove decelerating, stopped, or slow vehicles from a through traffic stream.

While there do not appear to be any quantitative warrants for channelized right turns at intersections in urban and suburban areas, McCoy and Bonneson (*7*) developed volume warrants for channelized right-turn lanes at unsignalized intersections on rural two-lane highways. The warrant was based on a traffic operational cost-benefit analysis that determined the right-turn volumes required to justify the construction and maintenance of channelized right-turn lanes at such locations. The volume warrant developed in this research indicates that a minimum design-year right-turn AADT between 440 and 825 veh/day, depending on the percentage of trucks, is required to warrant a channelized right-turn lane at unsignalized intersections on rural two-lane highways. A more complete discussion of this study is presented in Chapter Four of this synthesis.

DESIGN PRINCIPLES

The *Intersection Channelization Design Guide* (*3*) states that channelization and intersection design are closely tied to the requirements for vehicles undergoing substantial speed changes, as well as to the need for other drivers to react to these speed changes. Drivers expect and, to a degree, anticipate certain geometric and operational situations at intersections. The channelization and traffic control used at an intersection should, as a minimum, avoid violating driver expectations, and should desirably reinforce these expectations.

General design-related principles related to design to accommodate right turns at intersections presented in the guide include (*3*):

- Intersections should accommodate decelerating, slow, or stopped vehicles outside higher-speed through traffic lanes.
- Right-turn lanes reduce the potential for rear-end conflicts between through vehicles and right-turn vehicles, in advance of crossing conflicts at unsignalized intersections.
- Provision of a right-turn lane eliminates unnecessary delays to right-turning vehicles from drivers waiting to make the more difficult left turn (T-intersections).
- Improved level of service at signalized intersections can result from addition of a separate right-turn lane, or from conversion of a through lane to a right-turn lane.
- Design of corner radii involves more than consideration of turning and tracking requirements for right-turning vehicles. Additional factors include (*3*):
  - presence of pedestrians and bicyclists

- other intersection geometry such as grades, curvature, and traffic islands
- desired traffic control
- available right-of-way

Specific principles in the guide that relate to the design of channelized right turns include (*3*):

- Safe merging of traffic streams is accomplished by small angles of merge and acceleration tapers, both of which reduce conflict severity.
- Large corner radii enable higher-speed turns, producing smaller speed differentials with following vehicles and thus less severe rear-end conflicts.
- Channelization should promote desirable vehicle speeds wherever possible.
- Undesirable or wrong-way movement should be discouraged or prohibited through design of the channelization.
- Safe refuge from motor vehicles for pedestrians should be provided, where appropriate.
- Small corner radii, which promote low-speed right turns, are appropriate where such turns regularly conflict with pedestrians. At other locations, capacity considerations may dictate the use of larger radii, which enable higher-speed, higher-volume turns.
- Right-turn movements intended to operate as free movements (i.e., no traffic control) or under yield control should be designed with flat angle merging areas. In a flat angle merge, the merging vehicles are as close to parallel with each other as possible.
- Where it is intended that vehicles stop before completing the turn, the channelization should promote a stop at right angles to the crossing facility.

The *Green Book* (*1, 2*) also provides a number of design controls that should be considered when designing channelized intersections, including type of design vehicle, cross sections of the intersecting roads, projected traffic volumes in relation to capacity, number of pedestrians, speed of vehicles, location of bus stops, and type and location of traffic control devices.

ISLAND SIZE AND DESIGN

A channelized right turn consists of a right-turning roadway at an intersection, separated from the through travel lanes of both adjoining legs of the intersection by a channelizing island. At right-angle intersections, as shown in Figure 1, such channelizing islands are roughly triangular in shape, although the sides of the island may be curved, where appropriate, to match the alignment of the adjacent roadways.

The AASHTO *Green Book* (*1, 2*) states that an island is a defined area between traffic lanes used for control of vehicle movements. Islands also provide an area for pedestrian refuge and traffic control devices. The *Green Book* states that islands are included in intersection designs for one or more of the following purposes:

- Separation of conflicts
- Control of angle of conflict
- Reduction in excessive pavement areas
- Regulation of traffic and indication of proper use of intersection
- Arrangements to favor a predominant turning movement
- Protection of pedestrians

- Protection and storage of turning and crossing vehicles
- Location of traffic control devices

Islands serve three primary functions: (a) channelization—to control and direct traffic movement, usually turning; (b) division—to divide opposing or same direction traffic streams; and (c) refuge—to provide refuge for pedestrians. Most islands combine two or all of these functions. Islands for channelized right turns typically serve all three functions.

The *Green Book* states that the minimum island size should be 5 m^2 (50 ft^2) for urban intersections, with an island size of 9 m^2 (100 ft^2) being preferable. Accordingly, corner triangular islands should not be less than about 3.5 m (12 ft), and preferably 4.5 m (15 ft), on a side after rounding of corners.

The edges of channelizing islands may be defined by raised curbs or may consist of painted pavement or turf that is flush with the pavement. Most channelizing islands in urban areas are defined by raised curbs. Curbed islands are considered most favorable for pedestrians because curbs most clearly define the boundary between the traveled way, intended for vehicle use, and the island, intended for pedestrian refuge. Where a pedestrian crosswalk leads to a channelizing island, the island must either have curb ramps or have a cut-through walkway to accommodate pedestrians in wheelchairs. Truncated dome detectable warnings are required at the base of the ramp, where it joins the street, to indicate the location of the edge of the street to pedestrians who are visually impaired or blind.

Figure 4, based on *Green Book* Exhibit 9-37, illustrates the details of corner island designs for turning roadways.

DESIGN SPEED OF TURNING ROADWAYS

Selection of an appropriate design speed for a channelized right-turn roadway should take into consideration the pedestrian, bicycle, and vehicle modes of travel. However, the selection of a design speed is a design decision for which the needs of pedestrians, bicyclists, and vehicles may be in conflict. On one hand, it is important to provide a turning roadway design that is consistent with the speed characteristics of the turning vehicles; the reduction of delay to turning vehicles is a key reason for providing a channelized right turn. On the other hand, where pedestrians and bicycles may be present, low speeds for turning vehicles are desirable.

The *Green Book* does not address the needs of pedestrians and bicyclists in its discussion of design speed. It simply states that a desirable design speed for a turning roadway is the average running speed of the traffic on the highway approaching the turn. It does not suggest minimum design speed values, but states that the design speed of the turning roadway may be equal to, or possibly up to 30 km/h (20 mph) less than, the through roadway design speed.

RADIUS AND SUPERELEVATION OF TURNING ROADWAYS

A principal control for the design of turning roadways is the alignment of the traveled way edge, which is defined by the radius of the turning roadway. The radius of a turning roadway, in combination with the turning roadway width, ensures that a turning maneuver by a specified design vehicle can be accommodated. Large turning radii enable higher-speed turns, producing smaller-speed differentials with following vehicles and thus less severe rear-end conflicts. Design criteria for the radii of channelized right-turn roadways are a function of turning speeds, truck considerations, pedestrian crossing distances, and resulting island sizes.

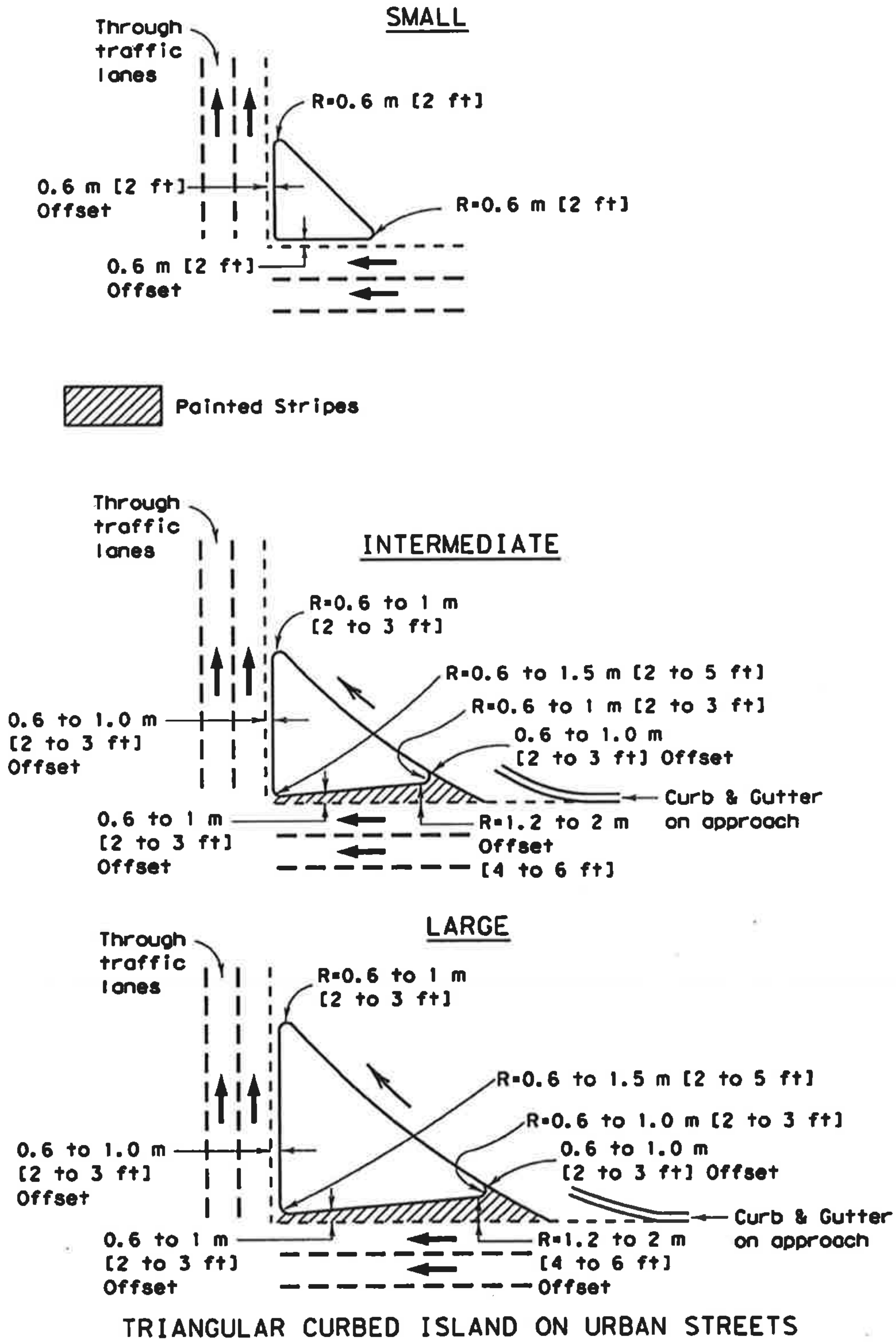


Figure 4. Details of corner island designs for turning roadways at urban locations (1, 2).

Such criteria are established in current design policy, but the needs of pedestrians and trucks are in tension in setting such criteria. For example, large turning radii better accommodate large trucks negotiating through right-turn maneuvers, but larger turning radii also create longer crossing distances for pedestrians. Channelized right turns provide one method for accommodating larger turning radii without widening the major-street pedestrian crossings and without increasing the intersection pavement area.

The AASHTO *Green Book* (*1, 2*) provides design guidance on minimum radii and superelevation of turning roadways. Table 1 presents the minimum radii for intersection curves, based on *Green Book* Exhibit 3-43 (*1*). The 2005 *Green Book* (*2*) reflects the latest research on superelevation and side friction factors, as presented in NCHRP Report 439 (*8*), and presents minimum radii for various combinations of superelevation and design speeds for each of five values of maximum superelevation rate (see Exhibits 3-25 to 3-29). The minimum radii should be used for design preferably on the inner edge of the traveled way rather than on the middle of the vehicle path or the centerline of the traveled way. Figure 5, based on *Green Book* Exhibit 9-41, illustrates minimum turning roadway designs for design vehicles with a range of turning radii.

The *Green Book* recommends that as much superelevation as practical, up to the appropriate maximum value, be provided for all turning roadways with minimum radii. However, it cautions that a number of factors—such as wide pavement areas, the need to meet the grade of adjacent property, surface drainage considerations, and frequency of cross streets and driveways—may make superelevation impractical in urban areas. Where large trucks will be using an intersection, less superelevation may be appropriate. In addition, where pedestrian crosswalks are present, forthcoming regulations may limit the grade of the pedestrian route (*9*).

According to the *Intersection Channelization Design Guide* (*3*), turning roadways require superelevation to assist drivers in completing the turn with relative comfort at the design speed of the turn. The guide states that superelevation may also be important in providing drainage at urban intersections with curb and gutter and that design for superelevation should consider grades of approach and departure roadways, desired maximum superelevation, and reasonable rates of change of superelevation.

WIDTH OF TURNING ROADWAYS

Another principal control for the design of turning roadways is the turning roadway width. This design feature, together with radius of turning roadways, ensures that a turning maneuver by a specified design vehicle can be accommodated. Design criteria for the width of channelized right-turn roadways are a function of turning speeds, truck considerations, pedestrian crossing distances, and resulting island sizes. Such criteria are established in current design policy, but the needs of pedestrians and trucks are in tension in setting such criteria. For example, wider channelized roadways better accommodate large trucks, but they also create longer crossing distances for pedestrians.

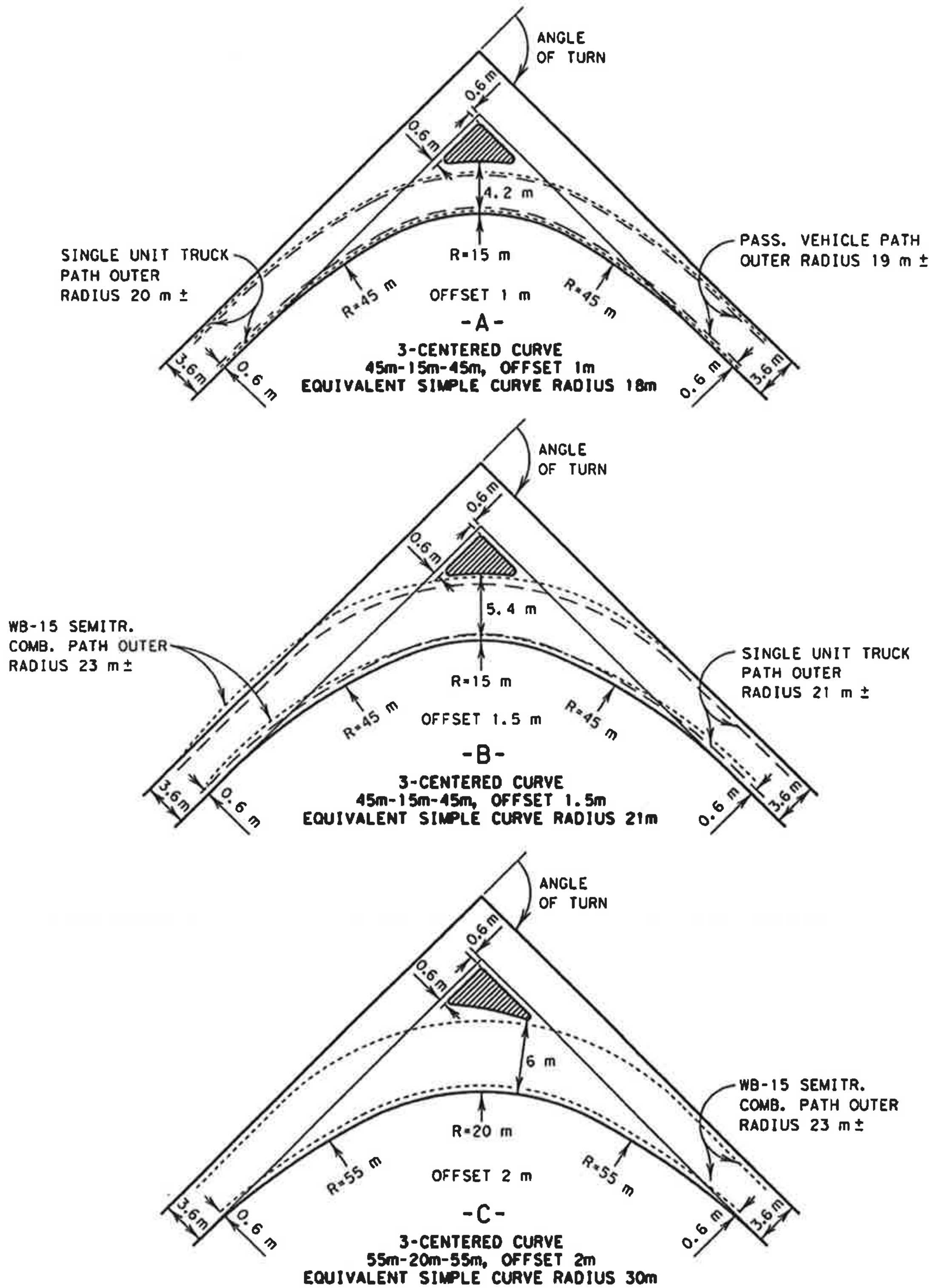


Figure 5. Minimum turning roadway designs with corner islands at urban locations (1, 2).

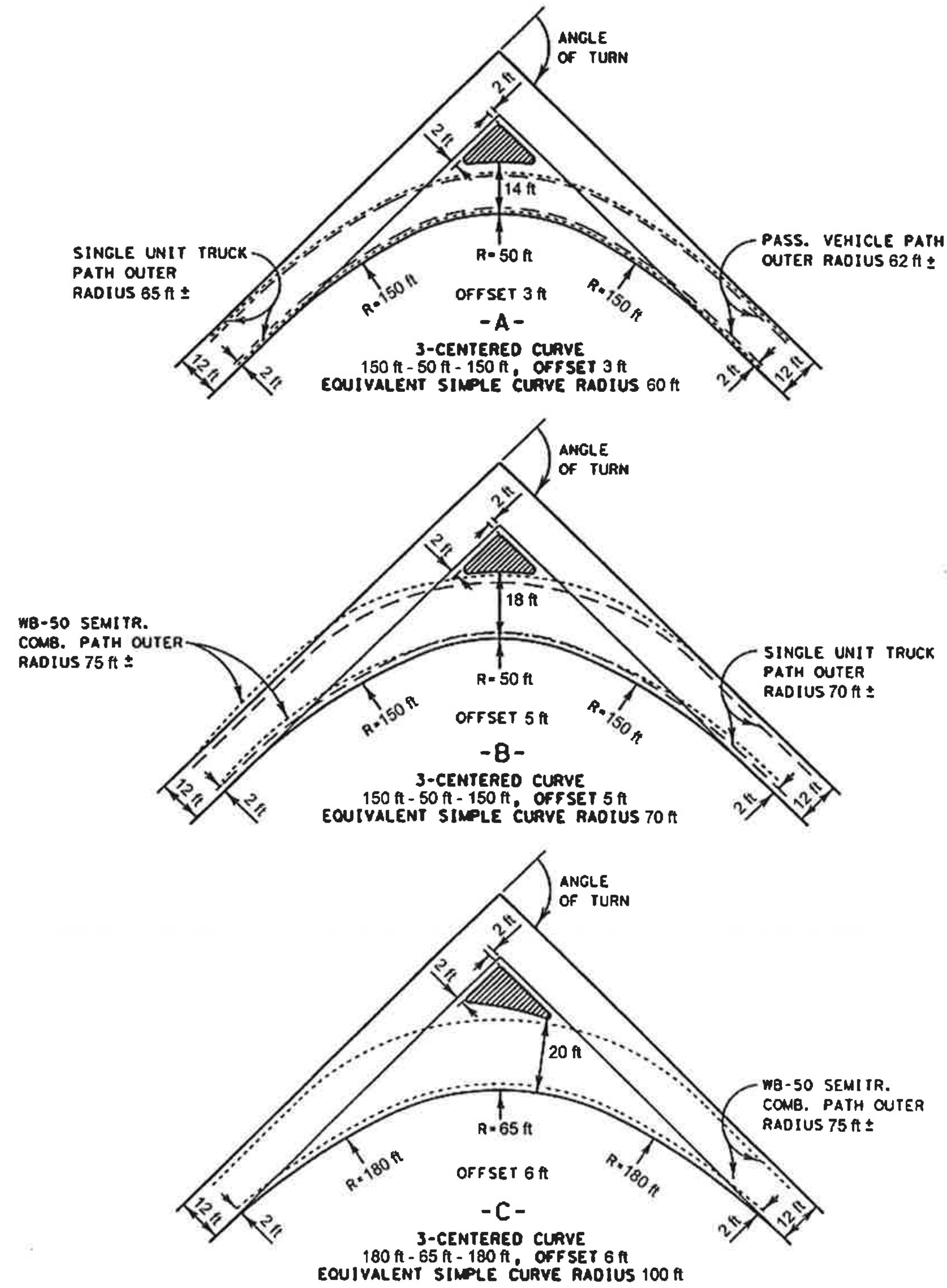


Figure 5. Minimum Turning Roadway Designs With Corner Islands at Urban Locations (1, 2) (Continued)

The *Green Book* provides design guidance on the selection of an appropriate turning roadway width. It states that the widths of turning roadways are governed by the types of vehicles to be accommodated, the radius of curvature, and the expected speed. Selection of an appropriate design vehicle should be based on the size and frequency of vehicle types using or expected to use the facility. The policy provides more specific guidance and states that a turning roadway should be wide enough to permit the right and left wheel tracks of a selected vehicle to be within the edges of the traveled way by about 0.6 m (2 ft) on each side. Generally, the turning roadway width should not be less than 4.2 m (14 ft). When the turning roadway is designed for a semitrailer combination, a much wider roadway is needed. To discourage passenger vehicles from using this wider roadway as two lanes, the roadway may be reduced in size by marking out part of the roadway with pavement markings.

Table 1, based on *Green Book* Exhibit 3-51, shows design widths of pavements for turning roadways at intersections. Figure 5, based on *Green Book* Exhibit 9-41, and presented above, shows roadway widths for minimum turning roadway designs for specific design vehicles and turning radii. Minimum dimensions for oblique-angle turns are presented in Table 2, based on *Green Book* Exhibit 9-42.

The *Intersection Channelization Design Guide* (*3*) also addresses the width of turning roadways. It states that turning roadway widths should be able to accommodate any vehicle stalls, or other incidents, within the roadway because the presence of a raised channelizing island limits the ability of vehicles to bypass stalled or parked vehicles on the roadway.

ANGLE OF ENTRY TO CROSS STREET

The alignment of the channelized right-turn roadway and the angle between the channelized right-turn roadway and the cross street at the location where traffic from the right-turn roadway enters the cross street can be designed in two different ways, depending on the presence of pedestrians.

The *Intersection Channelization Design Guide* (*3*) recommends that channelized right-turn roadways intended to operate as free movements (i.e. no traffic control) or under yield control should be designed with flat-angle merging areas; that is, where merging vehicles are as close to parallel with each other as possible. This recommendation is based on the principle that safe merging of traffic streams is accomplished by small angles of merge and acceleration tapers, both of which reduce conflict severity.

By contrast, the *Intersection Channelization Design Guide* (*3*) recommends that, where it is intended that vehicles stop before completing the turn, the channelization should promote a stop at right angles to the cross street. The presence of pedestrians crossing the right-turn roadway at its intersection with the cross street is one reason why stop-sign control might be considered on the right-turn roadway at the entry to the cross street. Where pedestrians are present, the *Pedestrian Facility User's Guide* (*10*) recommends that the right-turn roadway be designed to force motorists to enter the cross street at a much sharper angle than the typical channelized right-turn design, as illustrated in Figure 6, but at an angle less than the right angle recommended for use with stop control.

TABLE 1. Design Widths of Pavements for Turning Roadways *(1, 2)*

Metric

Radius on inner edge of pavement R (m)	Pavement width (m) Case I One-lane, one-way operation—with provision for passing a stalled vehicle			Case II One-lane, one-way operation—with provision for passing a stalled vehicle			Case III Two-lane operation—either one-way or two-way		
	Design traffic conditions								
	A	B	C	A	B	C	A	B	C
15	5.4	5.5	7.0	6.0	7.8	9.2	9.4	11.0	13.6
25	4.8	5.0	5.8	5.6	6.9	7.9	8.6	9.7	11.1
30	4.5	4.9	5.5	5.5	6.7	7.6	8.4	9.4	10.6
50	4.2	4.6	5.0	5.3	6.3	7.0	7.9	8.8	9.5
75	3.9	4.5	4.8	5.2	6.1	6.7	7.7	8.5	8.9
100	3.9	4.5	4.8	5.2	5.9	6.5	7.6	8.3	8.7
125	3.9	4.5	4.8	5.1	5.9	6.4	7.6	8.2	8.5
150	3.6	4.5	4.5	5.1	5.8	6.4	7.5	8.2	8.4
Tangent	3.6	4.2	4.2	5.0	5.5	6.1	7.3	7.9	7.9
Width modification regarding edge treatment									
No stabilized shoulder	None			None			None		
Sloping curb	None			None			None		
Vertical curb:									
one side	Add 0.3 m			None			Add 0.3 m		
two sides	Add 0.6 m			Add 0.3 m			Add 0.6 m		
Stabilized shoulder, one or both sides	Lane width for conditions B & C on tangent may be reduced to 3.6 m where shoulder is 1.2 m or wider			Deduct shoulder width; minimum width as under Case I			Deduct 0.6 where shoulder is 1.2 m or wider		

Note: A = predominantly P vehicles, but some consideration for SU trucks.
B = sufficient SU vehicles to govern design, but some consideration for semitrailer combination trucks.
C = sufficient bus and combination-trucks to govern design.

US Customary

Radius on inner edge of pavement R (ft)	Pavement width (ft) Case I One-lane, one-way operation—no provision for passing a stalled vehicle			Case II One-lane, one-way operation—with provision for passing a stalled vehicle			Case III Two-lane operation—either one-way or two-way		
	Design traffic conditions								
	A	B	C	A	B	C	A	B	C
50	18	18	23	20	26	30	31	36	45
75	16	17	20	19	23	27	29	33	38
100	15	16	18	18	22	25	28	31	35
150	14	15	17	18	21	23	26	29	32
200	13	15	16	17	20	22	26	28	30
300	13	15	15	17	20	22	25	28	29
400	13	15	15	17	19	21	25	27	28
500	12	15	15	17	19	21	25	27	28
Tangent	12	14	14	17	18	20	24	26	26
Width modification regarding edge treatment									
No stabilized shoulder	None			None			None		
Sloping curb	None			None			None		
Vertical curb:									
one side	Add 1 ft			None			Add 1 ft		
two sides	Add 2 ft			Add 1 ft			Add 2 ft		
Stabilized shoulder, one or both sides	Lane width for conditions B & C on tangent may be reduced to 12 ft where shoulder is 4 ft or wider			Deduct shoulder width; minimum pavement width as under Case I			Deduct 2 ft where shoulder is 4 ft or wider		

Note: A = predominantly P vehicles, but some consideration for SU trucks.
B = sufficient SU vehicles to govern design, but some consideration for semitrailer combination trucks.
C = sufficient bus and combination-trucks to govern design.

TABLE 2. Typical Designs for Turning Roadways *(1, 2)*

Metric						US Customary					
Angle of turn (degrees)	Design classification	Three-centered compound curve: Radii (m)	Three-centered compound curve: Offset (m)	Width of lane (m)	Approx. island size (m^2)	Angle of turn (degrees)	Design classification	Three-centered compound curve: Radii (ft)	Three-centered compound curve: Offset (ft)	Width of lane (ft)	Approx. island size (ft^2)
75	A	45-23-45	1.0	4.2	5.5	75	A	150-75-150	3.5	14	60
	B	45-23-45	1.5	5.4	5.0		B	150-75-150	5.0	18	50
	C	55-28-55	1.0	6.0	5.0		C	180-90-180	3.5	20	50
90[a]	A	45-15-45	1.0	4.2	5.0	90[a]	A	150-50-150	3.0	14	50
	B	45-15-45	1.5	5.4	7.5		B	150-50-150	5.0	18	80
	C	55-20-55	2.0	6.0	11.5		C	180-65-180	6.0	20	125
105	A	36-12-36	0.6	4.5	6.5	105	A	120-40-120	2.0	15	70
	B	30-11-30	1.5	6.6	5.0		B	100-35-100	5.0	22	50
	C	55-14-55	2.4	9.0	5.5		C	180-45-180	8.0	30	60
120	A	30-9-30	0.8	4.8	11.0	120	A	100-30-100	2.5	16	120
	B	30-9-30	1.5	7.2	8.5		B	100-30-100	5.0	24	90
	C	55-12-55	2.5	10.2	20.0		C	180-40-180	8.5	34	220
135	A	30-9-30	0.8	4.8	43.0	135	A	100-30-100	2.5	16	460
	B	30-9-30	1.5	7.8	35.0		B	100-30-100	5.0	26	370
	C	48-11-48	2.7	10.5	60.0		C	160-35-160	9.0	35	640
150	A	30-9-30	0.8	4.8	130.0	150	A	100-30-100	2.5	16	1400
	B	30-9-30	2.0	9.0	110.0		B	100-30-100	6.0	30	1170
	C	48-11-48	2.1	11.4	160.0		C	160-35-160	7.1	38	1720

[a] Illustrated in Exhibit 9-41.

Notes: Asymmetric three-centered compound curve and straight tapers with a simple curve can also be used without significantly altering the width of roadway or corner island size. Painted island delineation is recommended for islands less than 7 m^2 [75 ft^2] in size.

Design classification:

A—Primarily passenger vehicles; permits occasional design single-unit truck to turn with restricted clearances.
B—Provides adequately for SU; permits occasional WB-15 [WB-50] to turn with slight encroachment on adjacent traffic lanes.
C—Provides fully for WB-15 [WB-50].

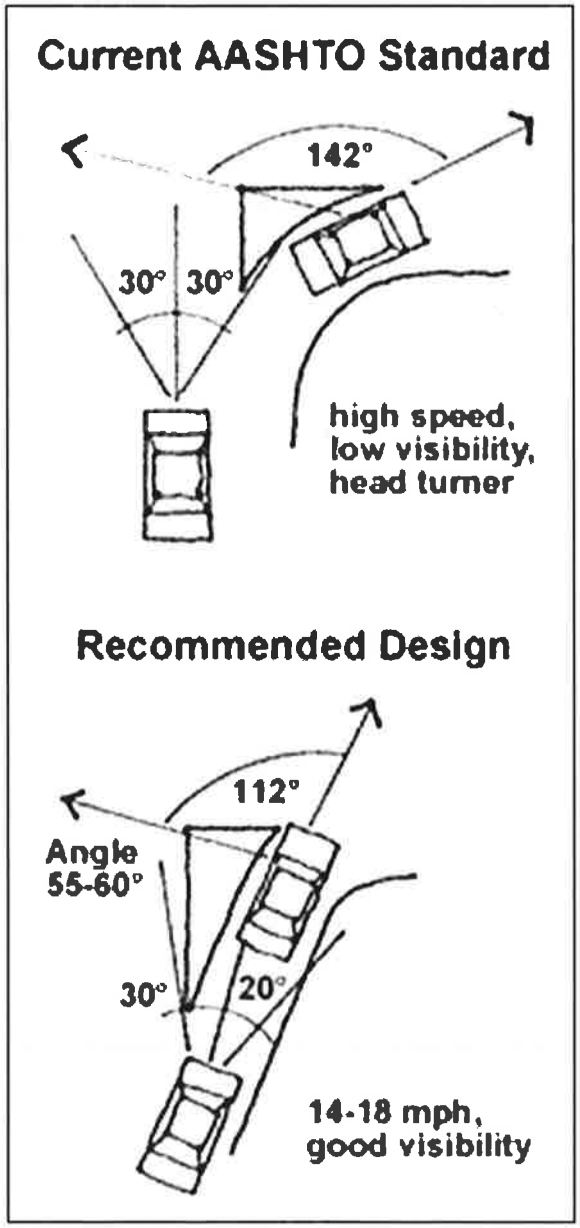


Figure 6. Current and recommended design of entry angle for channelized right-turn lane (10).

The guide indicates that the use of a sharper angle of entry has several positive effects with respect to pedestrian safety. First, the sharper angle slows both the speed of approach into the turn and the exit speed. Second, the crosswalk can be placed further upstream at a location where the pedestrian is more visible and the motorist can more easily separate the tasks of watching for pedestrians and watching for cross-street traffic gaps, as previously discussed.

Finally, in placing the crosswalk further upstream, it may reduce the crossing distance for the pedestrian, as the crosswalk may be located on a short tangent section rather than in the radius portion of the lane where the paved surface may be wider. This guidance in the *Pedestrian Facilities User's Guide* does not appear to be related directly to the traffic control at the entry to the cross street, as guidance in the *Intersection Channelization Design Guide* does, and does not appear to be based on any formal human factors studies. There is a need for more definitive information on the relationships between the traffic control at entry to the cross street, the angle of entry to the cross street, and the location of any pedestrian crosswalk that may be present.

DECELERATION AND ACCELERATION LANES

Drivers making a right-turn maneuver at an intersection are usually required to reduce speed before turning. Similarly, drivers entering a roadway from a turning roadway accelerate until the desired speed is reached. Large deceleration or acceleration that takes place directly on the through traveled way may disrupt the flow of through traffic and increase the potential for conflicts with through vehicles. To minimize deceleration and acceleration in the through travel lanes, speed-change lanes, both for deceleration and for acceleration, may be provided by highway agencies.

Figure 7 shows the typical use of deceleration and acceleration lanes in conjunction with channelized right turns. Deceleration lanes in conjunction with channelized right turns are also illustrated by Alternatives C and D in Figure 2. Acceleration lanes in conjunction with channelized right turns are also illustrated by Alternatives 1 and 6 in Figure 3.

There are no generally established criteria concerning where deceleration and acceleration lanes should be provided in conjunction with channelized right-turn roadways. The *Green Book* (*1, 2*) does not give definitive warrants for the use of speed-change lanes, but identifies several factors that should be considered when deciding whether to implement speed-change lanes: vehicle speeds, traffic volumes, percentage of trucks, capacity, type of highway, service provided, and the arrangement and frequency of intersections. AASHTO policy also provides the following guidance on the use of speed-change lanes:

- Speed-change lanes are warranted on high-speed and on high-volume highways where a change in speed is necessary for vehicles entering or leaving the through-traffic lanes.
- All drivers do not use speed-change lanes in the same manner; some use little of the available facility. As a whole, however, these lanes are used sufficiently to improve highway operation.

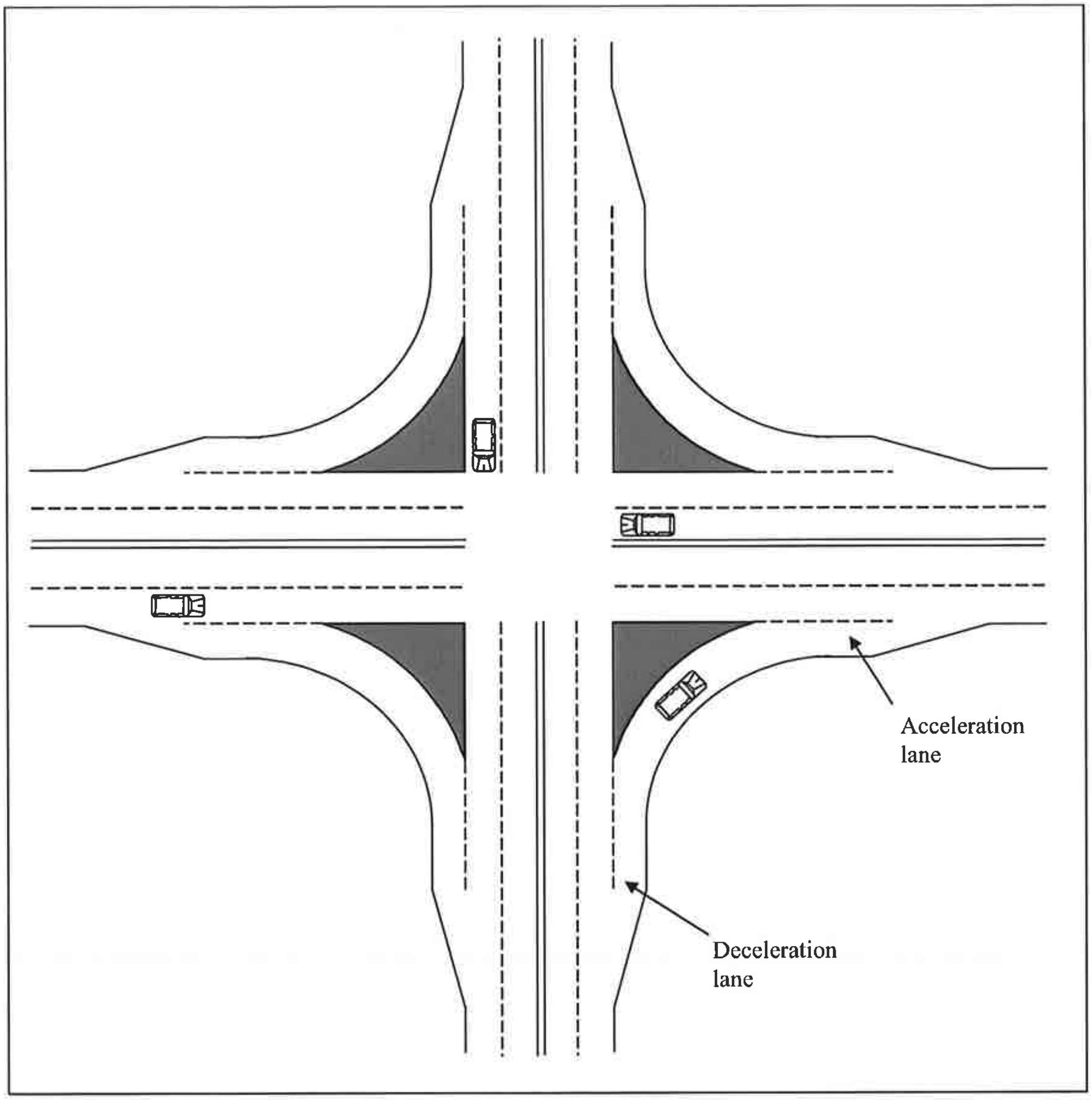


Figure 7. Channelized right turns with deceleration and acceleration lanes.

- Use of speed-change lanes varies with volume, the majority of drivers using them at high volumes.
- The directional type of speed-change lane consisting of a long taper fits the behavior of most drivers and does not require maneuvering on a reverse-curve path.
- Deceleration lanes on the approaches to intersections that also function as storage lanes for turning traffic are particularly advantageous, and experience with them generally has been favorable.

Deceleration Lanes

Right-turn deceleration lanes provide one or more of the following functions (*3*):

- A means of safe deceleration outside the high-speed through lanes for right-turning traffic.
- A storage area for right-turning vehicles to assist in optimization of traffic signal phasing.
- A means of separating right-turning vehicles from other traffic at stop-controlled intersection approaches.

The addition of a deceleration lane at the approach to a channelized right turn provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway. In response to the survey reported in Appendix B, 89 percent of the state highway agencies and 70 percent of the local agencies that use channelized right turns indicated that they have used deceleration lanes in advance of those channelized right turns for at least some locations.

Acceleration Lanes

Acceleration lanes provide an opportunity for vehicles to complete the right-turn maneuver unimpeded and then accelerate parallel to the cross-street traffic prior to merging. They may also allow motorists to focus on the crosswalk area prior to having to address the task of looking for a gap to merge into traffic. In response to the survey reported in Appendix B, 77 percent of the state highway agencies and 43 percent of the local agencies that use channelized right turns indicated that they have used acceleration lanes downstream of those channelized right turns for at least some locations.

CHAPTER 3.

TRAFFIC CONTROL

Traffic control devices at channelized right turns are intended to promote safe and efficient movement through the intersection and along the right-turn roadway for motor vehicle, pedestrian, and bicycle modes of travel. Traffic control devices promote safe and efficient movement by:

- Assigning right of way to particular movements or modes
- Providing positive guidance along intended paths
- Designating portions of the roadway for preferential or exclusive use by particular modes
- Warning of potential conflicts or locations where conflicts may occur

Traffic control devices can range from simple pavement markings and signing to accessible pedestrian signals and advanced signal control systems. This section focuses on general traffic control issues, such as standard placements of signs along channelized right-turn roadways and the type of control along the roadway, and on traffic control solutions for accommodating pedestrians and bicyclists. In many ways, it may not be the design of the channelized roadway, but the type of traffic control at an intersection with a channelized right turn, that most directly affects the safe navigation of the intersection by pedestrians and bicyclists.

TRAFFIC CONTROL DEVICES FOR MOTOR VEHICLES

The following discussion focuses on traffic control devices that address conflicts between motor vehicles. Traffic control devices that address conflicts between motor vehicles and pedestrians or bicycles are addressed in the subsequent sections of this chapter.

Channelized right turns are used at signalized intersections (i.e., where traffic at the main junction between the intersecting streets is controlled by traffic signals) and at unsignalized intersections, typically two-way stop-controlled intersections (i.e., locations at which traffic on the minor road is controlled by stop signs, but there is no traffic control on the major road).

Traffic on a channelized right-turn roadway generally proceeds independently of the signals or stop signs for through traffic on the intersecting streets. Laws concerning motorist obedience to traffic control devices generally apply to traffic control devices which motorists are facing, and motorists on a channelized right-turn roadway are not generally considered to be facing the signals or stop signs at the main intersection. Thus, any traffic control for motorists on a right-turn roadway must be provided by traffic control devices intended specifically for motorists on that roadway.

The primary traffic control decision for a channelized right-turn roadway concerns the type of traffic control device to be provided at the downstream end of the right-turn roadway, where it enters the cross street. The geometric and traffic control alternatives, including no control, yield control, stop control, and signal control, with and without acceleration lanes, are illustrated in Figure 3 in Chapter Two of this synthesis. There are no data specific to channelized right-turn roadways to indicate differences in operational or safety performance between these traffic control choices. The design principles presented in Chapter Two indicate that the type of traffic control used at the cross street influences the desirable angle of intersection between the right-turn roadway and the cross street.

The survey results presented in Appendix B of this synthesis indicate that only 14 percent of state highway agencies and 17 percent of local highway agencies have formal policies concerning traffic control devices for channelized right-turn roadways. Other agencies rely on the *Manual on Uniform Traffic Control Devices* (MUTCD) (*11*) for guidance concerning the proper application of yield signs, stop signs, and signals; such guidance deals with the general application of these devices, but is not specific to channelized right turns.

The MUTCD provides general guidance on the standard location of typical signs along a channelized intersection when the main intersection is stop controlled, as illustrated in Figure 8. In the figure, the main intersection is controlled by a stop sign and the channelized roadway is controlled by a yield sign. The yield sign is placed 3.7 m (12 ft) from the edge of the roadway, but no specific guidance is provided on how far in advance of the cross street the sign should be placed. The MUTCD states only that signs should be located on the right side of the roadway where they are easily recognized and understood by road users and, in urban areas where crosswalks are present (i.e., at the intersection between the right-turn roadway and the cross street), the yield signs should be placed within 1.2 m (4 ft) in advance of the crosswalk.

The MUTCD does not present a drawing analogous to Figure 8 for channelized right turns at *signalized* intersections, but the general considerations for traffic control on the channelized right-turn roadway are similar to the considerations for unsignalized intersections. Where the main intersection is signalized and the channelized right-turn roadway operates with no control, yield control, or stop control, the main signal can operate more efficiently because the right-turning traffic does not pass through the signal and does not need to be accounted for in the signal timing. Explicit signalization of a channelized right-turn roadway may also occur (*4*). Often, this signal control is not simply concurrent with the adjacent through movement green cycle, but provides some additional right-turn "green time." If signalization of the channelized right-turn roadway proves impractical, the highway agency may choose to provide a conventional intersection instead, which would eliminate the traffic operational benefits of the right-turn roadway. However, the effects of such tradeoffs have not yet been sufficiently quantified to serve as a basis for policy decisions.

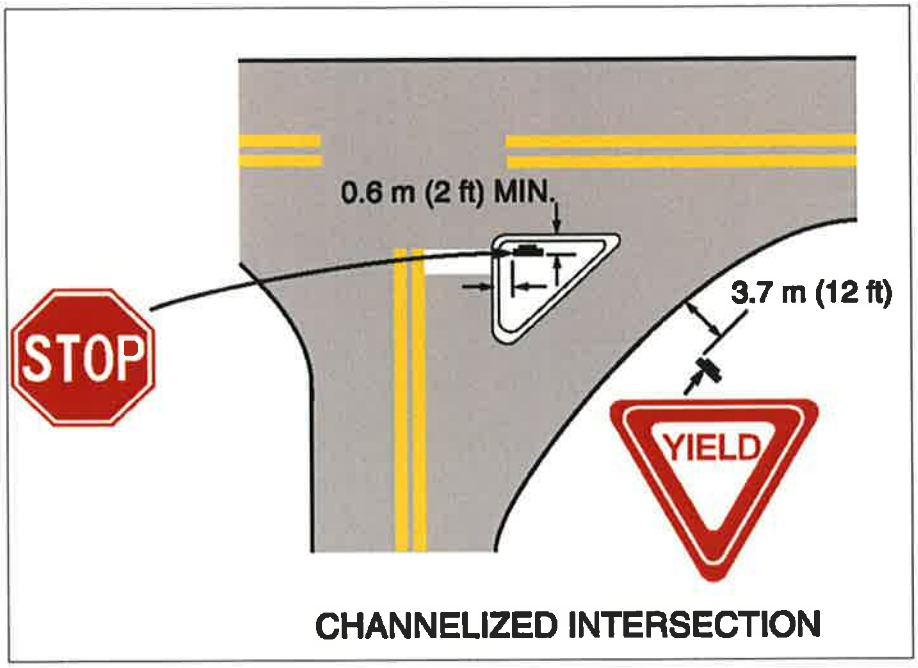


Figure 8. Typical locations for signs at channelized right turns (11).

The MUTCD also addresses the general characteristics of islands as traffic control devices. For traffic control purposes, an island is defined as the area between traffic lanes for control of vehicular movement or for pedestrian refuge. An island may be designated by pavement markings, channelizing devices, curbs, pavement edges, or other devices. The end of the island that is first approached by traffic should be preceded by a gradually diverging marking on the roadway surface, to guide vehicles into desired paths of travel along the edge of the island. Raised or curbed islands provide more restrictive channelization for right-turn roadways than flush islands. Geometric design of islands is discussed in Chapter Two of this synthesis.

TRAFFIC CONTROL FOR PEDESTRIAN CROSSINGS

Appropriate traffic control for pedestrians crossing channelized right-turn roadways is an important emerging issue. In preparation of this synthesis, no research was found on the appropriate crossing treatments for pedestrians, in general, and research is just beginning on crossing treatments for pedestrians who are blind or have vision impairments.

The factors that might make crossing at an intersection difficult for pedestrians who are blind or have vision impairments include: increasingly quiet cars, right turns on red (which masks the beginning of the through phase), continuous right-turn movements, complex signal operations, complex intersection geometry, roundabouts, and wide streets. Of these factors, continuous right-turn movements and complex intersection geometry are the greatest concern at channelized right turns. Right turns on red and wider streets are potential problems for pedestrians at major intersections that may be ameliorated by channelized right turns. Increasingly quiet cars and complex signal operations may present challenges to pedestrians who are blind or have vision impairments at any type of intersection. Roundabouts are an intersection type with continuous traffic flow that differ greatly in geometrics from channelized right turns, but present similar challenges to pedestrians who are blind or have vision impairments.

Crosswalks

The MUTCD (*11*) specifies markings for pedestrian crosswalks and these markings are applicable to crosswalks on channelized right-turn roadways. However, there is not universal agreement on where the pedestrian crosswalk should be placed on a channelized right-turn roadway. A crosswalk could potentially be placed at any location along a channelized right-turn roadway; Figure 9 shows six alternatives for such crosswalks. It is obviously desirable to place the crosswalk at whatever location would maximize safety, presumably the location where pedestrians who are crossing or about to cross the right-turn roadway are most visible to motorists and where motorists are most likely to yield to pedestrians, but there are no research findings to verify which of the potential crosswalk locations shown in the figure is most desirable.

Crosswalks that are parallel to and constitute an extension of the sidewalk may provide the best alignment information for pedestrians who are blind or visually impaired because they allow the pedestrian to continue along a straight travel path. Also, the sounds of traffic moving

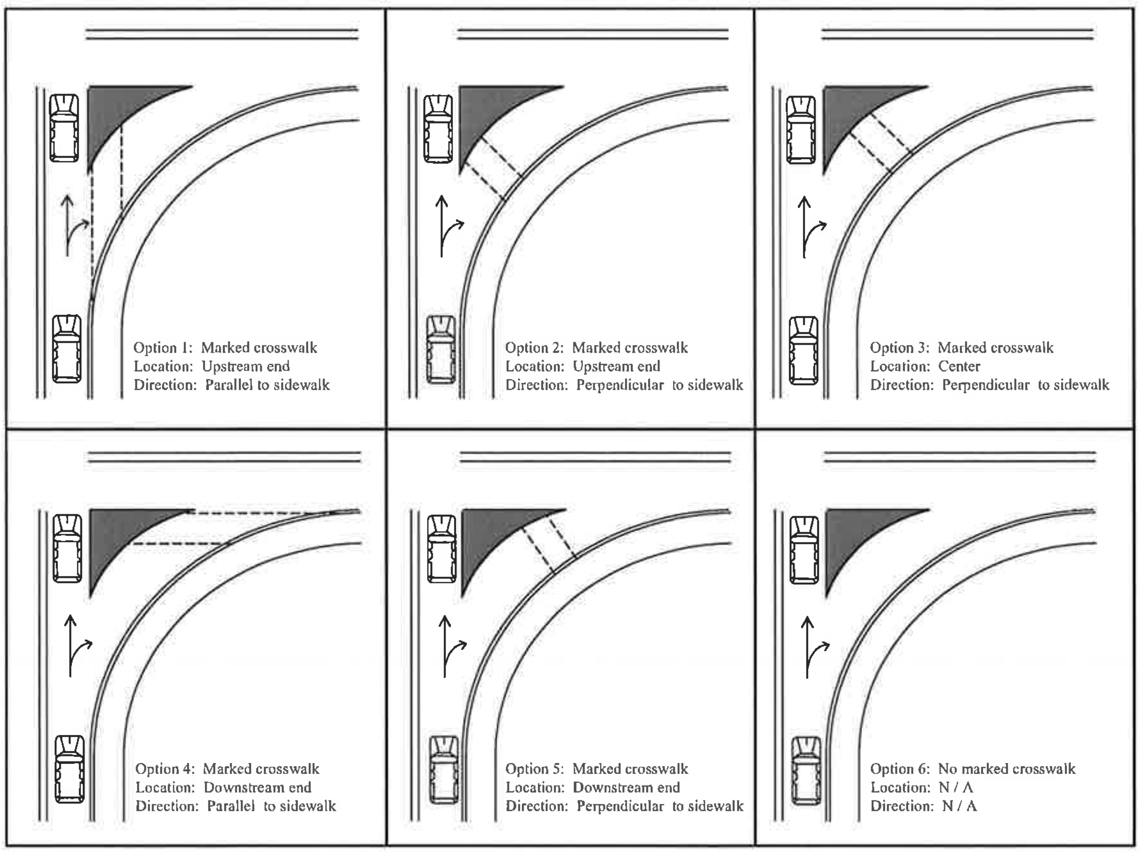


Figure 9. Alternative crosswalk locations.

parallel to the pedestrian's line of travel can often be used for establishing and maintaining alignment for crossing. Although not specifically illustrated in Figure 9, an additional factor to be considered in locating the crosswalk is the ability to construct appropriate curb ramps to provide access for wheelchair users. While the alignment of parallel crosswalks may be preferred by pedestrians who are blind or visually impaired, it is difficult to build wheelchair ramps in these locations without shifting grades at the gutter that cause problems in traversing the ramps for wheelchair users. For that reason, the perpendicular crosswalk alignments would be preferred for wheelchair users, along with maintaining the crosswalk at a level grade, with a cross slope of less than 2 percent.

Table 3 summarizes highway agency practices concerning the placement of crosswalks for channelized right-turn roadways. The most common highway agency practice is to place the crosswalk near the center of the right-turn roadway (i.e., not immediately adjacent to either of the intersecting streets). The table indicates that 77 percent of state highway agencies and 67 percent of local highway agencies that use channelized right turns have placed pedestrian crosswalks in this center position.

TABLE 3. Locations Where Highway Agencies Place Pedestrian Crosswalks at Channelized Right-Turn Roadways

	Number (percentage) of agencies					
Location	State agencies		Local agencies		Total	
At the upstream end	8	(22.9)	7	(23.3)	15	(23.1)
In the middle	27	(77.1)	20	(66.7)	47	(72.3)
At the downstream end	9	(25.7)	12	(40.0)	21	(32.3)

NOTES: 1. Columns total to more than 100 percent because of multiple responses.
2. Percentages are of those highway agencies that have used channelized right-turn roadways.

In contrast, the FHWA *Highway Design Handbook for Older Drivers and Pedestrians* (*12*) recommends that any pedestrian crosswalk be placed at the upstream end of the channelized right-turn roadway. The handbook's rationale for this recommendation is as follows:

> "If a crosswalk is within the channelized area, it should be located as close as possible to the approach leg to maximize the visibility of pedestrians before drivers are focused on scanning for gaps in traffic on the intersecting roadway."

One of the primary goals of this recommendation is to separate the tasks of the driver such that the task of approaching the crosswalk area where pedestrians may be present is completely separated from the task of preparing to enter the cross street. The *Pedestrian Facility Users' Guide* (*10*) also discusses the existence of this problem for intersections with "older designs." Approximately 23 percent of the highway agencies that have used channelized right turns indicated in response to the survey that they have placed crosswalks at the upstream end of the right-turn roadway. However, there is no specific research to verify that application of the principle discussed above results in safer designs.

In contrast to the handbook recommendation, pedestrians who are blind or have vision impairments may prefer to cross at the downstream end of the right-turn roadway, although no research has been found that addresses this issue. A downstream location places these pedestrians closer to and parallel to the cross-street traffic (see Figure 9, Option 4), which can then be used as an audible guide for crossing the right-turn roadway. Pedestrians who are blind or have vision impairments may cross with the parallel surge of heavy traffic flow beside them, which will reduce the likelihood that a car in the right-turn roadway will attempt to take a gap and enter the traffic stream. In other words, pedestrians who are blind or have vision impairments use the sound of traffic moving parallel to their line of travel to gain some assurance that vehicles in the right-turn roadway are unlikely to proceed. (This approach does not work where there is a separate acceleration lane at the exit of the right-turn roadway because drivers do not have to stop and wait for an appropriate gap in traffic.) This strategy, which is taught by some orientation and mobility specialists, may place the pedestrians outside of the marked crosswalk and result in pedestrians having to deviate from their desired direction of travel. Given that pedestrians are crossing at a point that may not be in the crosswalk, and are at the point where the driver is searching to the left for a gap, pedestrians approaching from the right may be particularly vulnerable. Pedestrians with low-vision may tap a waiting car with their cane or hand before crossing in front of it, to get the attention of the driver and make the driver aware that they are about to cross in front of the vehicle. This strategy suggests that a crosswalk location at the downstream end of the right-turn roadway might be preferred. The survey results presented in Appendix B indicate that approximately 32 percent of highway agencies that use channelized right turns have placed the crosswalk at the downstream end of the right-turn roadway.

Table 4 summarizes the advantages and disadvantages of the six alternative crosswalk locations. The magnitude of these advantages and disadvantages is strongly influenced by the length of the right-turn roadway. On a shorter right-turn roadway, the various crosswalk locations and their advantages and disadvantages may hardly differ; on a longer right-turn roadway, the various crosswalk locations may have advantages and disadvantages that are quite distinct, as shown in the table. There is no specific research that provides a firm basis for choosing between these potential crosswalk locations and, as indicated above, the preferred location may differ for specific types of pedestrians.

Alternative Traffic Control Approaches for Pedestrian Crossings

Crosswalks are the primary traffic control device for indicating the presence of a pedestrian crossing. To reduce vehicle-pedestrian conflicts, the proper location of a crosswalk within a channelized right-turn lane to improve pedestrian visibility is important but, as discussed above, there is no general agreement about what location is best. To some extent, this may be a site-specific decision depending on the length of the right-turn roadway, the type of traffic control at the entry to the cross street, and the available sight distance. It should also be noted that if nothing else is done beyond marking crosswalks, pedestrians will not experience increased safety (*13*). Drivers do not always yield the right of way to pedestrians simply because they are in a crosswalk. This is evident from the fact that 41 percent of pedestrian crashes in

TABLE 4. Advantages and Disadvantages of Crosswalk Alternatives at Channelized Right Turns

Crosswalk location and direction	Advantages	Disadvantages
Option 1: Marked crosswalk Location: Upstream end Direction: Parallel to sidewalk	• Serves as the pedestrian right-of-way across the channelized right-turn roadway • Provides a direct path to the refuge island for pedestrians walking along sidewalk paralleling the approach street • Since the crosswalk is located at the upstream end, drivers can more easily separate the tasks of watching for pedestrians and watching for cross-street traffic gaps	• Creates a longer crossing distance • Pedestrians walking along the cross street must deviate from their desired direction of travel • Pedestrians cross channelized right-turn roadway adjacent to approach street traffic • Where a deceleration lane is not provided, motorists may have to stop in the through traffic lane when encountering pedestrians in the crosswalk • Difficult to provide pedestrian signals, where needed • Difficult to construct curb ramps
Option 2: Marked crosswalk Location: Upstream end Direction: Perpendicular to sidewalk	• Serves as the pedestrian right-of-way across the channelized right-turn roadway • Provides a shorter crossing distance • Since the crosswalk is located at the upstream end, drivers can more easily separate the tasks of watching for pedestrians and watching for cross-street traffic gaps	• Pedestrians walking along either the approach or cross street must deviate from their desired direction of travel • Pedestrians walking along the approach street must deviate slightly from their desired direction of travel • Pedestrians cross channelized right-turn roadway nearly adjacent to approach street traffic • Where a deceleration lane is not provided, motorists may have to stop in the through traffic lane when encountering pedestrians in the crosswalk • Difficult to provide pedestrian signals, where needed

Table 4. Advantages and Disadvantages of Crosswalk Alternatives at Channelized Right Turns (Continued)

Crosswalk location and direction	Advantages	Disadvantages
Option 3: Marked crosswalk Location: Center Direction: Perpendicular to sidewalk	• Serves as the pedestrian right-of-way across the channelized right-turn roadway • Provides a shorter crossing distance • Since the crosswalk is located in the center, drivers can more easily separate the tasks of watching for pedestrians and watching for cross-street traffic gaps • Pedestrians do not cross channelized right-turn roadway immediately adjacent to traffic on either the approach or cross streets • When drivers encounter pedestrians in the crosswalk, some storage space is provided outside of the through traffic lane	• Pedestrians walking along either the approach or cross street must deviate from their desired direction of travel • Pedestrian signals, if provided, may not be expected by drivers
Option 4: Marked crosswalk Location: Downstream end Direction: Parallel to sidewalk	• Serves as the pedestrian right-of-way across the channelized right-turn roadway • Provides a direct path to the refuge island for pedestrians walking along sidewalk paralleling the cross street • Pedestrians with vision impairments are closer to and parallel to the cross-street traffic, which can be used as an audible guide for crossing the right-turn roadway • When drivers encounter pedestrians in the crosswalk, more storage space is provided outside of the through traffic lane.	• Creates a longer crossing distance • Pedestrians walking along the approach street must deviate from their desired direction of travel • Pedestrians cross channelized right-turn roadway adjacent to cross street traffic • Since the crosswalk is located at the downstream end, drivers encounter crosswalk as they scan for gaps in motor vehicle traffic on the cross street. • Difficult to construct curb ramps • Pedestrian signals, if provided, may not be expected by drivers

Table 4. Advantages and Disadvantages of Crosswalk Alternatives at Channelized Right Turns (Continued)

Crosswalk location and direction	Advantages	Disadvantages
Option 5: Marked crosswalk Location: Downstream end Direction: Perpendicular to sidewalk	• Serves as the pedestrian right-of-way across the channelized right-turn roadway • Provides a shorter crossing distance • When drivers encounter pedestrians in the crosswalk, more storage space is provided outside of the through traffic lane.	• Pedestrians walking along the approach street must deviate from their desired direction of travel • Pedestrians walking along the cross street must deviate slightly from their desired direction of travel • Pedestrians cross channelized right turn nearly adjacent to cross street traffic • Since the crosswalk is located at the downstream end, drivers encounter crosswalk as they scan for gaps in motor vehicle traffic on the cross street. • Pedestrian signals, if provided, may not be expected by drivers
Option 6: No marked crosswalk Location: N / A Direction: N / A		• Pedestrians are not provided the right-of-way when crossing the right-turn roadway • No markings are provided to warn drivers as to where pedestrians are expected to cross • Pedestrian signals should not be provided without crosswalks

marked crosswalks at uncontrolled locations are due to "motorist failure to yield" and that vehicle turn and merge crashes, which are generally the fault of the driver, account for 19 percent of pedestrian crashes in marked crosswalks at uncontrolled locations.

Other traffic control approaches that have been considered for use at pedestrian crossings on channelized right-turn roadways to enhance crossing safety for pedestrians, in general, and for pedestrians who are blind or have vision impairments include:

- Use of high-visibility crosswalk markings (to improve conspicuity of pavement markings to motorists)
- Addition of fluorescent yellow-green signs both at the crosswalk and in advance of the crossing location (to supplement the high-visibility markings)
- Use of a real-time warning device to indicate to the motorist when a pedestrian is present in the area (may be activated via passive detection technologies such as microwave or infrared or via traditional methods such as push buttons)
- Use of dynamic message signs (for real-time or static warning messages to motorists)
- Installation of traditional traffic signals with pedestrian signal heads (for warning or full stop control)

None of these traffic control approaches has proven effectiveness for pedestrian crossings on channelized right-turn roadways. Even pedestrian signals, which can be considered proven technology at other locations, may not operate efficiently or safety on channelized right-turn roadways, as discussed below.

Just as there is no definitive information on the best location for pedestrian crosswalks, there is also no definitive information on where pedestrian signals should be placed for the safest and most efficient operation. Most current guidance envisions the pedestrian crosswalk at the center of the channelized right-turn roadway. However, there appear to be significant disadvantages associated with each potential pedestrian crosswalk and signal placement—upstream end, center, or downstream end of the channelized right-turn roadway. There is concern that pedestrian signals located on the channelized right-turn roadway may be unexpected by drivers; may not be in the driver's field of view sufficiently in advance to stop safely; and, when a green indication is displayed, may suggest to right-turning motorists that it is safe to enter the cross street when there is actually conflicting cross traffic present. The extent to which these concerns are present may be a function of the radius and length of the channelized right-turn roadway.

For pedestrians with vision impairments, the presence of a channelized right-turn roadway makes the intersection more complex in terms of knowing where to cross, knowing when to cross, knowing the direction to walk during the crossing, and knowing when they have reached the other side of the street. These difficulties and the desire to make all intersections accessible have prompted a proposed guideline by the U.S. Access Board, in their *Draft Guidelines for Accessible Public Rights-of-Way* (*9*), that reads as follows:

> "**1105.7 Turn Lanes at Intersections.** Where pedestrian crosswalks are provided at right or left turn slip lanes, a pedestrian activated traffic signal complying with **1106** shall be provided for each segment of the pedestrian crosswalk, including at the channelizing island."

This guideline is only a proposal at present, but if adopted in the future as a final rule, the guideline would be a legal requirement. The staff of the U.S. Access Board has clarified that, while the text of the guideline refers specifically to pedestrian activated traffic signals, implementation of pedestrian-activated warning devices other than conventional traffic signals could satisfy the guideline, if the devices provided equivalent access to users with disabilities.

Signal systems with conventional pedestrian signals provide red, yellow, and green signal indicators to motor vehicle traffic and WALK (symbolized by a WALKING PERSON) and DON'T WALK (symbolized by a UPRAISED HAND) signal indicators to pedestrians. An accessible pedestrian signal (APS) is a device that communicates pedestrian signal information in a nonvisual format such as audible tones, verbal messages, and/or vibrating surfaces (*11*). APSs are now available in the United States that include a pushbutton locator tone to help pedestrians with vision impairments locate the crosswalk and let them know that a pushbutton is there to activate the pedestrian signal. Devices are available with speech pushbutton information and walk messages that can provide additional information about the intersection signalization or geometry. In these newer devices, a quiet audible walk indication is provided during the walk interval. A quiet signal is essential in installations at channelized right-turn lanes, where the pedestrian phase may not be at the same time as the crossing from the island across the main part of the intersection, so the pedestrian does not become confused by hearing the wrong audible indication. These signals also respond to ambient traffic sound, decreasing in volume when the traffic volume is low and increasing when volume is heavy and noisy.

With crosswalk warning devices such as signs with beacons that flash when activated by a pedestrian, additional information is needed by pedestrians with vision impairments. Some

APS devices have been installed with a message that "the crosswalk warning devices are flashing" to give pedestrians with vision impairments the information typically available to sighted pedestrians at crosswalk warning devices.

The advantages to pedestrians with vision impairments and to pedestrians, in general, of providing pedestrian-actuated signals on channelized right-turn roadways are also largely unproven, and the proposed criteria do not include any guidelines related to traffic or pedestrian volumes. In particular, the benefits of requiring pedestrian signalization for channelized right turns, even where there is no signal for crossing the main roadway, as proposed by the Access Board, are unclear.

The lack of information on the effectiveness of alternative traffic control approaches for pedestrian crossings on channelized right-turn roadways for pedestrians, in general, and for pedestrians with vision impairments, is a major impediment to improving the safety of pedestrian crossings at channelized right-turn roadways.

Current Highway Agency Practices

In the survey reported in Appendix B of this synthesis, highway agencies were asked whether they install pedestrian-actuated signals at channelized right-turn roadways on urban and suburban arterials. The responses are summarized below:

- Of the highway agencies that use channelized right-turn roadways, only 6 percent of state highway agencies and 17 percent of local highway agencies install pedestrian-actuated signals at *all* channelized right-turn roadways.

- The majority of highway agencies using channelized right-turn roadways (83 percent of state highway agencies and 60 percent of local highway agencies) install pedestrian-actuated signals at *selected* locations only.
- Of the highway agencies that use channelized right-turn roadways, approximately 11 percent of state highway agencies and 23 percent of local highway agencies do not use pedestrian-actuated signals.

Highway agencies were also asked whether they have developed or used any strategies specifically intended to assist visually impaired pedestrians in crossing channelized right-turn roadways without pedestrian signals. Of the highway agencies that use channelized right-turn roadways, 23 percent of state highway agencies and 10 percent of local highway agencies have either developed or used such strategies. The general types of strategies used by the responding agencies to assist visually impaired pedestrians in crossing channelized right-turn roadways are summarized in Table 5. One highway agency that does not currently use accessible pedestrian signals at channelized right turns is considering their use. One highway agency reportedly installed audible signals at one intersection, but was requested by an organization representing pedestrians with vision impairments to deactivate the sound.

While textured curb ramps are listed by highway agencies as a strategy used to assist pedestrians with visual impairments, research has indicated that various textures are not detectable or usable by pedestrians who are blind or visually impaired. The only texture that is recognized to provide adequate detectability, both underfoot and under cane, is the truncated dome detectable warning surface required by ADA. However, neither strategy assists pedestrians with determining the appropriate time to cross channelized right-turn roadways

TABLE 5. General Strategies Used by Highway Agencies to Assist Pedestrians With Vision Impairments

General strategy	State agencies	Local agencies	Total
Curb ramps with truncated domes	5	1	6
Textured curb ramps	4	1	5
Audible signals	1	0	1

In the survey, highway agencies were asked about pedestrian considerations in determining the radius or width of channelized right-turn roadways. Of the highway agencies that use channelized right-turn roadways, 23 percent of state highway agencies and 40 percent of local highway agencies indicated that they consider pedestrian issues in determining the radius and/or width of a channelized right-turn roadway. Table 6 presents a list of specific pedestrian-related issues considered by highway agencies in determining the radius or width of a channelized right-turn roadway. One highway agency indicated that they do not use channelized right turns, and another is trying to minimize their use, because of pedestrian concerns.

TABLE 6. Pedestrian Issues Considered in Determining the Radius or Width of Channelized Right-Turn Roadway

Pedestrian issue	Number of agencies		
	State agencies	Local agencies	Total
Pedestrian crossing distance/time minimized	3	1	4
Vehicle speeds minimized	1	3	4
Provision of pedestrian refuge location	2		2
Improved sight distance of opposing traffic		1	1
Pedestrian volumes		1	1
General consideration of pedestrians	4	1	5

Highway agencies were also asked if they have encountered any safety problems related to pedestrians crossing at channelized right-turn roadways on urban and suburban arterials. Of the highway agencies that use channelized right-turn roadways, approximately 23 percent of state highway agencies and 17 percent of local highway agencies have encountered pedestrian-related safety problems at channelized right-turn roadways. Highway agencies reported the following safety concerns related to pedestrians crossing at channelized right turns:

- General concern about pedestrian safety at channelized right-turn roadways (5 agencies)
- Higher vehicle speeds put pedestrians at risk (3 agencies)
- Visually impaired pedestrians may expect approaching traffic to stop (1 agency)
- Truck-trailer off tracking onto sidewalk jeopardizes pedestrian safety (1 agency)
- Drivers may not yield to pedestrians (1 agency)
- Larger radii may make pedestrians less visible to drivers (1 agency)
- There is some confusion regarding the most appropriate crossing location (1 agency)
- There is greater exposure to pedestrians (1 agency)
- Small islands and snow on islands are not conducive to pedestrian use (1 agency)

Only one highway agency reported a safety problem at a specific location. One location with an unsignalized right-turn roadway and no pedestrian signal has a sight distance problem that will probably be addressed by providing a signal.

Highway agencies were asked to identify innovative traffic control devices they have implemented at channelized right-turn roadways. Table 7 summarizes use of innovative traffic control devices by highway agencies. Between 35 and 50 percent of highway agencies have used high-visibility crosswalk markings and florescent yellow-green signs, but fewer than 10 percent of agencies have tried other innovative devices.

TABLE 7. Innovative Traffic Control Devices at Channelized Right-Turn Roadways

Traffic control device	Number (percentage) of agencies		
	State agencies	Local agencies	Total
High-visibility crosswalk markings	13 (37.1)	13 (43.3)	26 (41.3)
Fluorescent yellow-green signs	16 (45.7)	15 (50.0)	31 (49.2)
Real-time warning devices	2 (5.7)	3 (10.0)	5 (7.9)
Other dynamic message signs	2 (5.7)	2 (6.7)	4 (6.3)
Other	1 (2.9)	0 (0.0)	1 (1.6)

Notes: 1. Columns total to more than 100 percent because of multiple responses.
2. Percentages are of those highway agencies that have used channelized right-turn roadways.

TRAFFIC CONTROL FOR BICYCLISTS

The treatment of marked bicycle lanes at intersections with channelized right turns is the primary issue related to traffic control and bicyclists. It should be noted that very few bicycle design guidelines or bicycle research specifically address the design of bicycle lanes at intersections with channelized right turns. In most cases, the design guidelines and/or research that are synthesized address the design of bicycle lanes at intersections with right-turn lanes or the design of bicycle lanes through interchange areas that have free flowing right-turn movements. In response to the survey reported in Appendix B, several highway agencies cited the AASHTO *Guide for the Development of Bicycle Facilities* as their guide on striping bicycle lanes at channelized right turns.

Delineation treatments of bicycle lanes at channelized right turns should account for three situations:

- Motor vehicles entering the channelized right turn must weave across bicycle traffic to execute the right-turn maneuver
- Bicyclists utilize the channelized right-turn lane to execute a right-turn maneuver

- Motor vehicles from the channelized right-turn lane merge with motor vehicle and bicycle traffic on the cross street

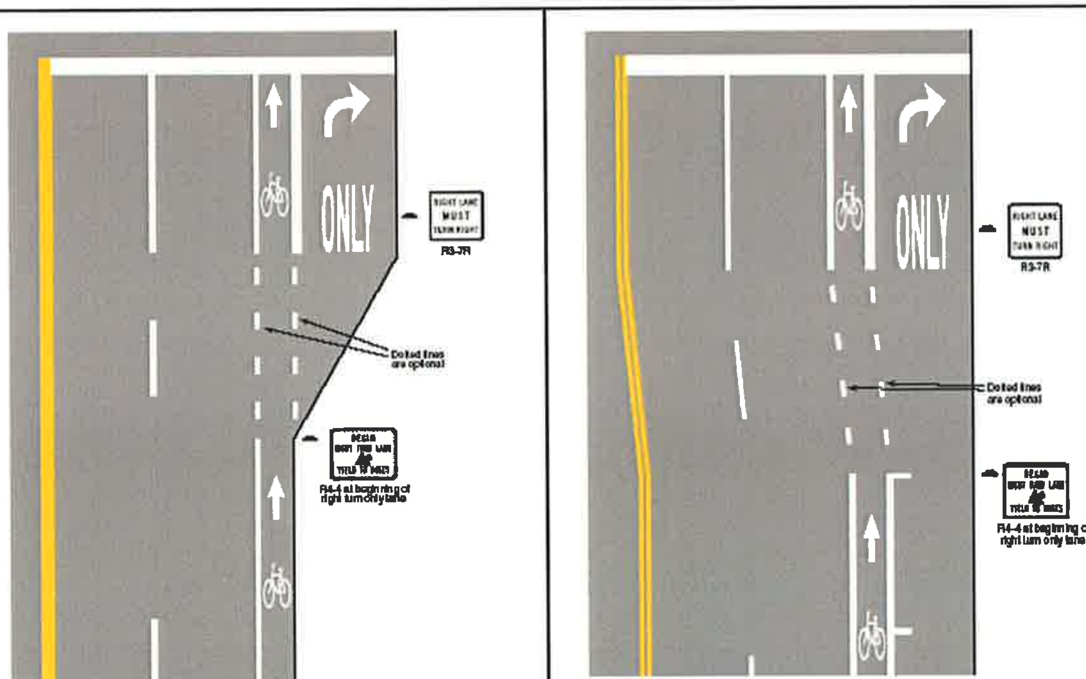
Treatments of bicycle lanes that address these three situations are addressed below.

Bicyclist Traveling Straight Through the Intersection

The MUTCD (*11*) provides guidance for marking bicycle lanes at intersections with right-turn lanes. Figure 10 illustrates an intersection with a right-turn lane and an intersection with a parking lane and a right-turn lane. In both examples, the pavement markings for the bicycle lane are solid on the approach to the intersection. Where the right-turn lane begins, the pavement markings for the bicycle lane are dashed for an unspecified length, and then the pavement markings delineating the bicycle lane are solid again near the intersection proper. In addition to recommending dashed pavement markings across the right-turn lane, the MUTCD indicates that where motor vehicles entering an exclusive right-turn lane must weave across bicycle traffic in a bicycle lane, the BEGIN RIGHT TURN LANE YIELD TO BIKES (Figure 11) sign may be used to inform both the driver and the bicyclist of this weaving area. These striping and signing configurations are intended to encourage the motorists and bicyclists to cross paths in advance of intersections in a merging fashion (*14*) and encourage bicyclists to follow the rules of the road (i.e., through vehicles including bicyclists proceed to the left of right-turning vehicles) (*15*). These bicycle lane treatments are preferable to striping configurations that force motorists and bicyclists to cross in the immediate vicinity of the intersection. The primary advantages of having through bicyclists and right-turning motor vehicles cross prior to the intersection include:

- This conflict occurs away from the intersection and other conflicts

- The difference in travel speeds enables the motorist to pass a bicyclist rather than ride side-by-side



Typical bicycle lane treatment
At a right turn only lane

Typical bicycle lane treatment
At a parking lane into right turn only lane

Figure 10. Typical intersection pavement markings (11).

Figure 11. Begin right-turn lane yield to bikes sign (11).

The AASHTO *Guide for the Development of Bicycle Facilities* (*14*) presents several optional treatments for pavement markings where a bicycle lane approaches an intersection with a right-turn lane. Figure 12 presents four of the treatments. Treatments "a" and "b" in Figure 12 are exactly the same as treatments recommended in the MUTCD (see Figure 10). AASHTO indicates, though, that the dashed lines in cases "a" and "b" are optional and presents a third type of treatment where the dashed lines are removed completely (case "c" in Figure 12). It is in this area, where the pavement markings for the bicycle lane are absent, that bicycle and motor vehicle traffic are to cross paths. It should be noted, though, that in each case (a, b, and c) solid pavement markings delineating the path of the bicycle lane are recommended at the intersection proper, assuming sufficient width is available. For case "d," where a right-turn lane and a shared through-and-right lane are present, the solid pavement markings delineating the bicycle lane are discontinued where the right-turn lane begins, and no pavement markings are provided at the intersection proper to delineate space for the bicycle lane. In response to the survey reported in Appendix B, several highway agencies cited this from the AASHTO *Guide for the Development of Bicycle Facilities* and have incorporated it into their own agency guidelines.

The AASHTO *Guide for the Development of Bicycle Facilities* (*14*) also indicates that the design of bicycle lanes should include appropriate signing at intersections to warn of conflicts, and the approach shoulder width should be provided through the intersection, where feasible, to accommodate right-turning bicyclists or bicyclists who prefer to use crosswalks to negotiate the intersection.

The practice of providing dashed pavement markings or discontinuing the bicycle lane completely in advance of the intersection is common among many state highway agencies, including Florida (*16*), Oregon (*15*), and Washington (*17*). The rationale for such treatment is that it encourages the motorists and bicyclists to cross paths in advance of intersections in a merging fashion. The remainder of this section provides examples of treatments that vary to some degree from the treatments described in the MUTCD (*11*) or the AASHTO *Guide for the Development of Bicycle Facilities* (*14*).

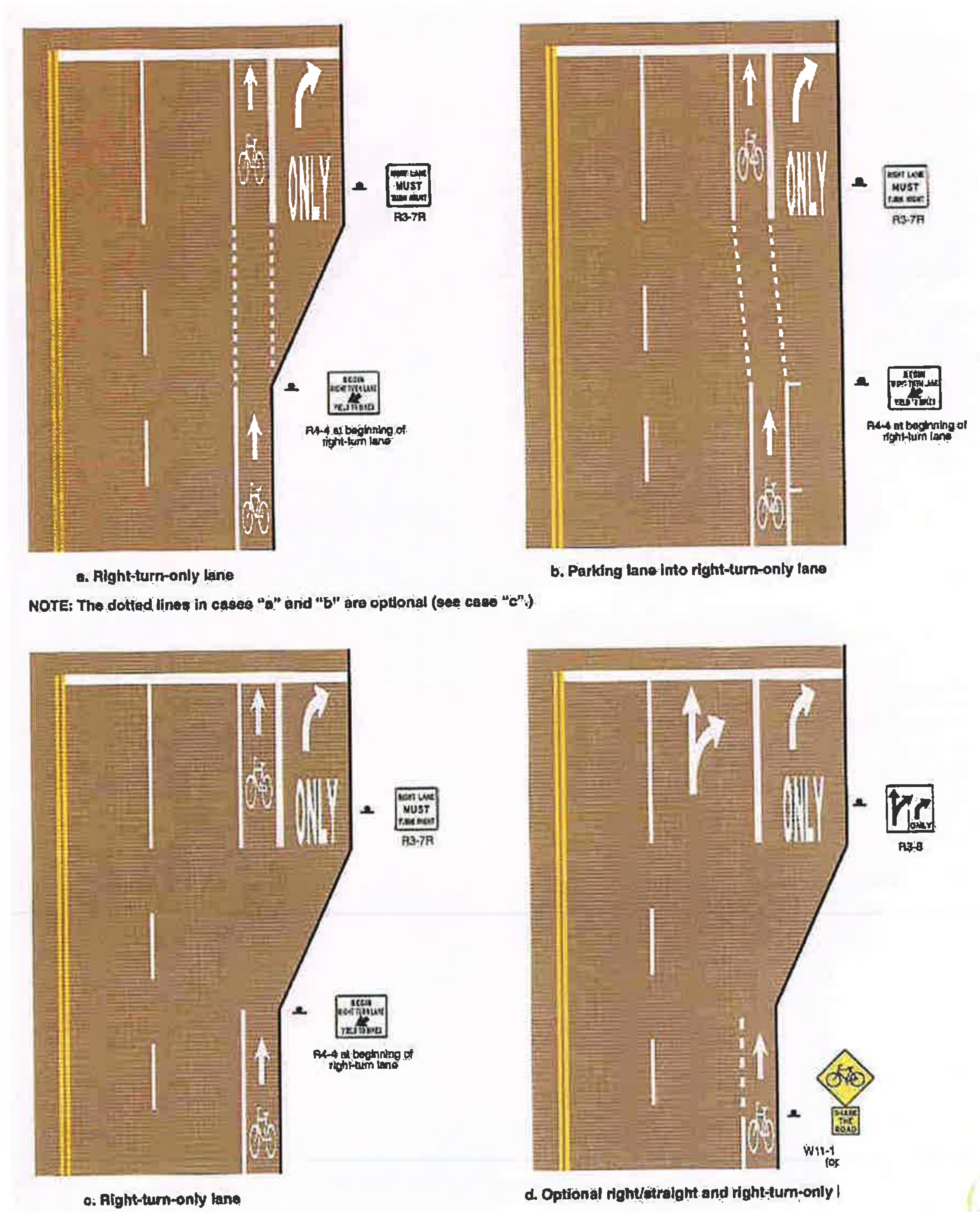


Figure 12. Bicycle lanes approaching right-turn-only lanes (14).

The City of Chicago Department of Transportation has developed signing for a bicycle lane at an intersection where the bicycle lane continues to the stop bar to the left of the right-turn only lane (see Figure 13) (*18*). This sign conveys to both motorists and bicyclists the proper channelization through the intersection.

Figure 13. Standard signing for bicycle lane at intersection (18).

Washington State DOT's bicycle design guidelines include an optional treatment for marking bicycle lanes near interchange ramp areas. This treatment is considered relevant in that both channelized right turns and interchange entrance ramps provide free-flowing right-turn movements for motor vehicles, and, when bicyclists are traveling straight through on the major roadway, both modes must cross paths. In this option, the bicycle lane continues along the right side of the exiting roadway (i.e., channelized right turn), and then bicyclists cross at a designated location along the channelized right-turn roadway to return to the bicycle lane (see Figure 14). This treatment may be preferable to bicyclists who prefer to use crosswalks to negotiate intersections.

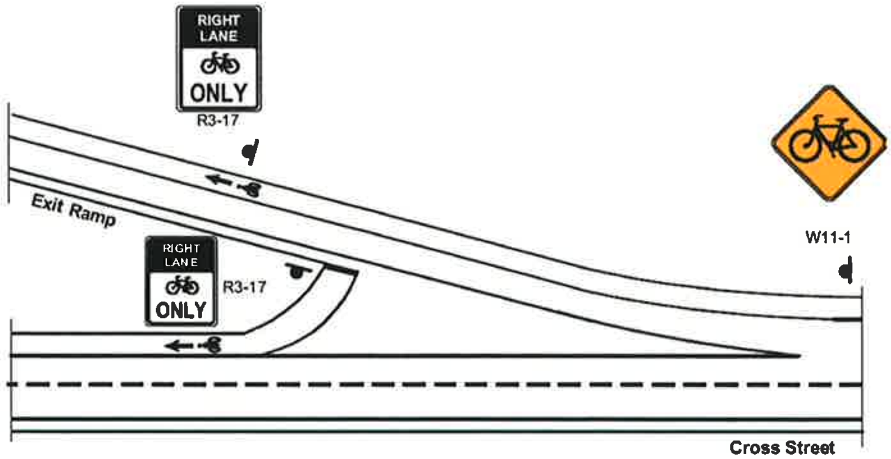


Figure 14. Bicycle crossing of interchange ramp (17).

Bicyclists Turning Right at the Intersection

To accommodate bicyclists turning right at intersections with channelized right turns, the bicycle lane should either continue along the right side of the channelized roadway or, as indicated in the AASHTO *Guide for the Development of Bicycle Facilities* (*14*), the approach shoulder width should be provided through the intersection, where feasible, to accommodate right-turning bicyclists.

Motor Vehicle Traffic from Channelized Right-Turn Roadway Merges with Bicyclists on Cross Road

Very few resources specifically address the treatment of bicycle lanes where motor vehicle traffic from a channelized right-turn roadway merges with bicyclists on the cross road. Figure 15 shows a treatment where solid pavement markings delineate the left side of the bicycle lane beginning at the crosswalk near the intersection proper and continue unbroken along the cross road. This treatment does not show pavement markings delineating the right side of the bicycle lane because at the midblock locations the curb basically delineates the right edge of the bicycle lane, and more specifically where the conflicts occur between merging motor vehicle and bicycle traffic, no pavement markings, solid or dashed, are shown. Alternatively, Figure 16 shows a treatment where all bicycle lane markings are discontinued in the area where the conflicts occur between merging motor vehicle and bicycle traffic would occur.

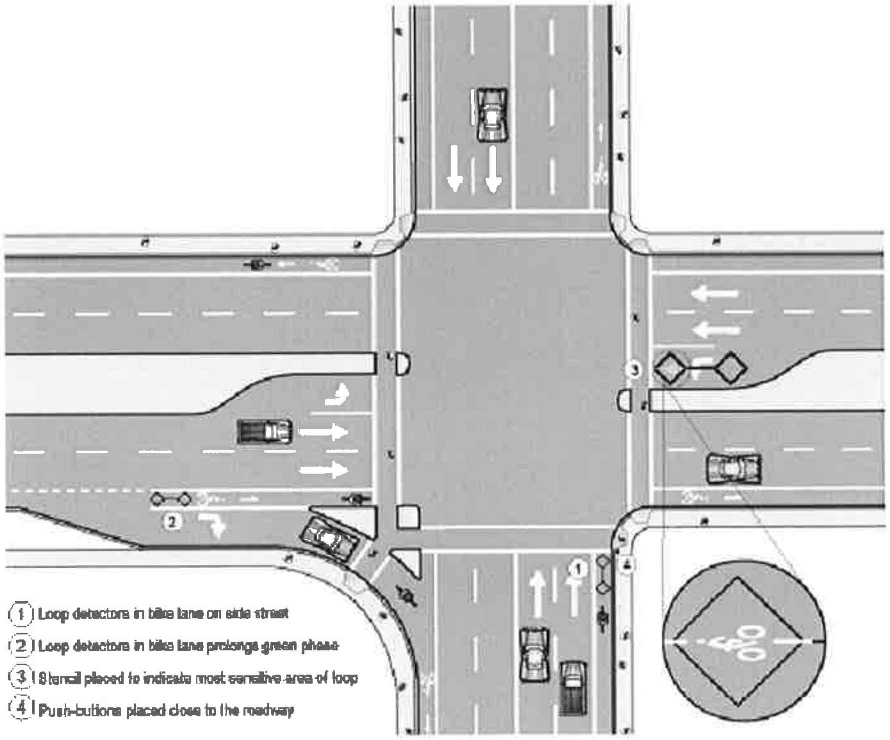


Figure 15. Bicycle lane treatment in merging area—option 1 (15).

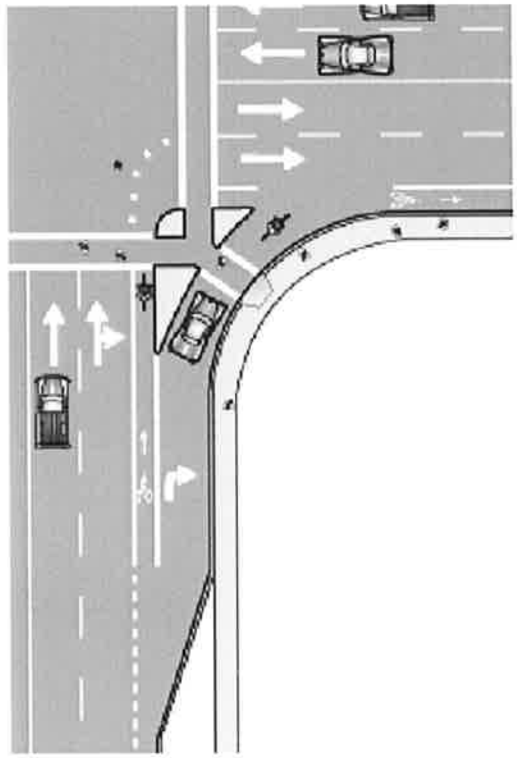


Figure 16. Bicycle lane treatment in merging area—option 2 (15).

The AASHTO *Guide for the Development of Bicycle Facilities* (*11*) presents two treatments (Figure 17) related to the design of bicycle lanes through interchange areas that are relevant to channelized right turns in that traffic from interchange exit ramps and channelized right-turn roadways is free flowing and merges with traffic on the cross street. Option 1 redirects the bicycle lane towards the channelized roadway, intersecting at a 90-degree angle. Bicyclists are to yield to the motor vehicle traffic on the channelized roadway before crossing. Option 2, in principle, is the same as the treatment shown in Figure 16 with the only difference being that a bicycle lane is also provided along the channelized roadway (i.e., the exit ramp).

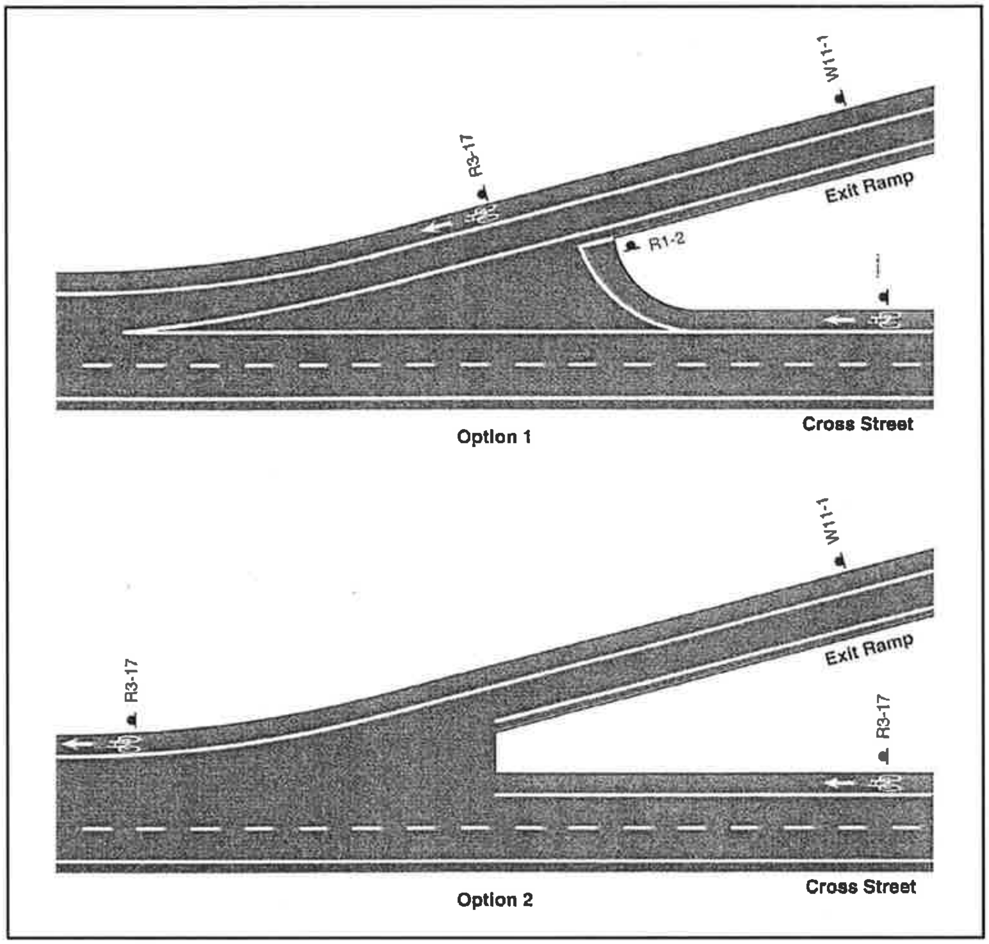


Figure 17. Bicycle lanes crossing interchange exit ramps (14).

CHAPTER 4.

TRAFFIC OPERATIONS

The primary traffic operational reasons for providing channelized right turns are to increase vehicular capacity at intersections and to reduce delay to drivers by allowing them to turn at higher speeds and reduce unnecessary stops. On signalized intersection approaches where no channelized right turn is present, traffic control for right-turn movements can be in the form of conventional signalization (where right turns take place during circular green signal phases), exclusive right-turn signal phases, and in right-turn-on-red maneuvers made after stopping for the circular red signal display and yielding to any other vehicles, pedestrians, or bicycles that are legally within the intersection. On unsignalized intersection approaches where no channelized right turn is present, drivers may turn right after complying with any stop sign that may be present and after yielding to any other vehicles, pedestrians, or bicycles that are legally within the intersection. Channelized right-turn roadways may have no control or may be controlled by stop signs, yield signs, or signals.

On a signalized intersection approach with a channelized right-turn roadway, the main signal can operate more efficiently than at a conventional intersection because the right-turning traffic does not pass through the signal and does not need to be accounted for in the signal timing. Similarly, on an unsignalized intersection approach with a channelized right turn, the delay to through and left-turning vehicles caused by slowing or stopping of right-turn vehicles is minimized.

The following discussion reviews the operational effects of right-turn maneuvers on conventional intersection approaches and on intersection approaches with channelized right turns.

OPERATIONAL EFFECTS OF RIGHT TURNS AT CONVENTIONAL INTERSECTIONS

The presence of right-turn movements at intersections and driveways can have adverse effects on roadway capacity. Due to small turning radii or pedestrian conflicts, right-turning vehicles typically slow down to a speed that is considerably lower than the speed of through vehicles to complete their turning maneuver. Therefore, unless properly accommodated, right-turn movements can result in delays to through traffic, rear-end crashes, and other traffic conflicts.

A 1970 study by Stover et al. (*19*) indicated that the delay experienced by through traffic due to right turns can range from a few seconds to more that 20 seconds per right-turning vehicle depending on the speed and volume of traffic. An important reason for considering right-turn treatments, therefore, is to improve the efficiency of traffic operations by removing decelerating right-turning vehicles from the through lanes.

The effects of right turns on traffic operations at conventional intersections are addressed in the *Highway Capacity Manual* (HCM) (*20*). The HCM provides methodology for analyzing capacity of signalized intersections and considers a wide variety of prevailing conditions, traffic composition, geometric characteristics, and traffic control. This methodology also examines performance measures and provides adjustment factors to address known or projected conditions.

The HCM indicates that, in general, a right-turn lane at a signalized intersection should be considered when the right-turn volume and adjacent through lane volume each exceed 300 veh/h. However, the HCM emphasizes that this is only a general guideline and should not be used in place of applicable state and local standards, guidelines, policies, or practice.

Table 8 provides a summary of the HCM adjustment factors for saturation flow rate with regard to geometric characteristics for right-turn lanes.

TABLE 8. Right-Turn Adjustment Factors for Saturation Flow Rate (*20*)

Factor	Formula	Definition of variables	Notes
Single Right-Turn Lanes	Exclusive Lane: $f_{RT} = 0.85$ Shared Lane: $f_{RT} = 1.0\text{-}(0.15)P_{RT}$ Single Lane: $f_{RT} = 1.0\text{-}(0.135)P_{RT}$	P_{RT} = proportion of RTs in lane group	$f_{RT} \geq 0.050$

The right-turn adjustment factors are intended to reflect the effect of geometry. A separate pedestrian and bicycle blockage factor (presented in Table 9) is used to reflect the volume of pedestrians and bicycles using a conflicting crosswalk.

TABLE 9. Vehicular Adjustment Factors for Saturation Flow Rate (*20*)

Factor	Formula	Definition of variables	Notes
Pedestrian-bicycle blockage	RT adjustment: $f_{Rpb} = 1.0\text{-}P_{RT}(1\text{-}A_{pbT})\ (1\text{-}P_{RTA})$	P_{RT} = proportion of RTs in lane group A_{pbT} = permitted phase adjustment P_{RTA} = proportion of RT protected green over total RT green	

The right-turn adjustment factor depends on a number of variables, including whether the right turn is made from an exclusive or shared lane and the proportion of right-turning vehicles in the shared lanes (see Table 8).

When right turn on red (RTOR) is permitted, the right-turn volume for analysis can be reduced by the volume of right-turning vehicles moving on the red phase. This reduction is done on the basis of hourly volumes before the conversion to flow rates. The HCM identifies seven factors that influence the number of vehicles able to turn right on a red phase:

- Approach lane allocation (shared or exclusive right-turn lane)
- Demand for right-turn movements
- Sight distance at the intersection approach
- Degree of saturation of the conflicting through movement
- Arrival patterns over the signal cycle
- Left-turn signal phasing on the conflicting street
- Conflicts with pedestrians

For an existing intersection, it is appropriate to consider the volume of RTORs that actually occur and this volume should be determined by field observation. For both the shared lane and the exclusive right-turn lane conditions, the volume of RTORs may be subtracted from the right-turn volume before analysis of lane group capacity or level of service (LOS).

If the analysis deals with future conditions or if the RTOR volume is not known from the field data, it is necessary to estimate the number of RTOR vehicles. In the absence of field data, it is usually preferable to utilize the right-turn volumes directly without a reduction for RTOR except when an exclusive right-turn movement runs concurrent with a protected left-turn phase from the cross street. In this case, the total right-turn volume for analysis can be reduced by the number of shadowed left turners. Free-flowing right turns that are not under signal control should be removed entirely from the analysis.

The procedure to determine the right-turn pedestrian-bicycle adjustment factor, f_{Rpb}, consists of four steps. The first step is to determine the average pedestrian occupancy, which accounts for only pedestrian effect. The next step is to determine the relevant conflict zone occupancy, which accounts for both pedestrian and bicycle effects. Relevant conflict zone occupancy takes into account whether other traffic is also in conflict (i.e., adjacent bicycle flow for the case of right turns). Third, the proportion of green time in which the conflict zone is occupied is determined as a function of the relevant occupancy and the number of receiving lanes for the turning vehicles.

The proportion of right turns using the protected portion of a protected-plus-permitted phase is needed. This proportion should be determined by field observation, but a gross estimate can be made from the signal timing assuming that the proportion of right-turning vehicles using the protected phase is approximately equal to the proportion of the turning phase that is protected. If $P_{RTA} = 0.0$ (i.e., if the right turn is completely protected from conflicting pedestrians), a pedestrian volume of zero should be used. The equation for this adjustment is presented in Table 9.

Finally, the saturation flow adjustment factor is calculated from the final occupancy on the basis of the turning movement protection status and the percent of turning traffic in the lane group.

The HCM does not make note of any adjustments for variances with regard to effect on saturation flow rates in right-turn radii.

Effect of Curb Radius on Traffic Operations

The FHWA *High Volume Intersection Guide* (*21*) currently under development describes that corner radii facilitate the turning of a vehicle and influence the operation of an intersection. The provision of a channelized right turn reduces impedance between lower-speed right-turning vehicles and higher-speed through or left-turning vehicles. The FHWA report reiterates the HCM finding that separating right-turn movements from through movements can reduce the green time required for a through lane.

A wide curb radius typically results in high-speed turning movements that could lead to potential safety issues related to pedestrian crossings. Existing guidelines recommend decreasing the turning radius through reconstruction to reduce turning speeds, shorten pedestrian crossing distance, and improve sight distance between a turning driver and pedestrians in the crosswalk. Studies have found that a reduction in the curb radius will reduce the speed of right-turn movements and, potentially, the capacity of the movement. However, in situations where a right-turn lane is present, the curb radius reduction should not impact the through movements.

A 1986 study by Zegeer (*22*) found that at surveyed locations consisting of curb radii between 10 and 30 ft, the average saturation flow headway for right-turning vehicles was 19 percent longer than through-vehicle headways at comparable locations. Agent and Crabtree (*23*) investigated the effect of turning radius on the beginning lost time of right-turning vehicles. Beginning lost time represents the additional time it takes for drivers stopped in a queue, when a signal changes from red to green, to proceed through the intersection. Drivers that arrive at an intersection when the signal is already green, and are not required to slow down, would experience no beginning lost time. The additional time comes from reacting to the signal change and accelerating the vehicle. The analysis conducted by Agent and Crabtree controlled urban location, city size, grade, and speed limit. Only right-turning passenger cars were included. This research found that if turning radii of between 25 and 44 ft were provided, saturation flow rates were 8 percent higher than that for smaller radii. Lost time was smaller at locations with a short turning radius. This was due to the fact that short turning radii do not affect the first three vehicles in the queue (which are already in a stopped condition) nearly as much as they affect latter vehicles (which have to slow to negotiate the turn). Table 10 illustrates the effect of turning radius on beginning lost time at signalized intersections.

TABLE 10. Effect of Turning Radius on Beginning Lost Time (*22*)

Turning radius (ft)	Average headway (seconds)				Beginning lost time (seconds)
	1 Vehicle	2 Vehicles	3 Vehicles	> 3 Vehicles	
< 25	3.21	3.01	2.74	2.74	0.74
25 to 44	3.34	2.86	2.56	2.40	1.56
≥ 45	Insufficient Data Available				

A further study by Agent and Crabtree (*24*) determined the effect of turning radius for right-turning vehicles on saturation flow. The research was limited to non-CBD locations in cities with populations of 20,000 or more, lane widths of 10 to 15 ft, grades from –3 to +3 percent, and speed limits of 35 to 45 mph. Excluded from the summary were locations with heavy pedestrian activity or with parking on the approach within 200 ft of the stop bar. The initial summary was limited to right-turning passenger cars. Locations having turning radii less than 25 ft had saturation flows approximately 8 percent lower than location having turning radii in the 25- to 44-ft range. Increasing the right-turning radius above 44 ft increased the saturation flow by approximately 2 percent.

Table 11 illustrates the effect of turning radius on saturation flows.

TABLE 11. Effect of Turning Radius on Saturation Flow of Right-Turning Passenger Cars (*23*)

Radius (ft)	Total headways	Average headway (sec)	Saturation flow (VPHG)
Less than 25	321	2.66	1,354
25 to 44	973	2.46	1,465
45 or more	180	2.40	1,500

From the results of the data analyses, Agent and Crabtree (*23*) identified factors that significantly influence saturation flow. One of the key factors identified was the correction factor for turning radius, C_r, which is calculated as:

$$C_r = 1.00 + F_r\left(\frac{P}{100}\right)$$

where: P = percentage of traffic affected by radius (affected vehicles are those that turn right or that turn left from one one-way street to another)

F_r = adjustment for turning radius. Equation given is for effect on right-turning vehicles. For left turns from one one-way street to another, switch the terms "right-turning" and "left-turning" in the equation.

–0.60 for turning radius of 0 to 10 ft

–0.40 for turning radius of 11 to 20 ft

–0.20 for turning radius of 21 to 30 ft

0.00 for turning radius of 31 to 40 ft

0.20 for turning radius of 41 to 50 ft

0.40 for turning radius greater than 50 ft

$$F_r = \left(\frac{\%\ \text{through}\ \&\ \text{left-turning vehicles}}{100}\right) + F_{rd}\left(\frac{\%\ \text{right-turning vehicles}}{100}\right)$$

where: F_{rd} = 0.93 for turning radius less than 25 ft

= 1.00 for turning radius of 25 to 44 ft

= 1.03 for turning radius of 45 or more ft

Agent found that the saturation flow is affected by the amount of "friction" between adjacent lanes, with friction depending on relative speeds and vehicle maneuvers. The single through-only lane has the highest friction, since it is adjacent to turning lanes, opposing traffic, or the roadway edge. Friction is reduced by going to multiple through-only lanes. The lowest friction is for the middle of three through-only lanes (*23*).

Right-Turn-On-Red

By the late 1970s, in responses to a federal mandate intended to reduce energy consumption, most states had adopted laws permitting right-turn movements at signalized intersections after a full stop, unless such movements were specifically prohibited by signing. In general, RTOR was implemented to maximize the efficiency of an intersection by allowing non-conflicted right turns to occur outside of their designated green time. The HCM identifies seven factors that influence optimal use of RTOR movements. These factors have been listed earlier in this chapter. These factors help to understand how RTOR functions and what type of right-turn treatment should be considered.

A 1999 study by Dixon et al. (*4*) summarizes how Cobb County Georgia (in greater Atlanta area) handles right-turn movements. The aim of the study was to identify trends in the safety performance of various right-turn treatment strategies based on observed field operation conditions. The report outlined four focus areas that need to be evaluated when considering design of right-turn movements at signalized intersections:

- Suitability of the intersection for a RTOR movement
- Right-turn configuration (shared, exclusive lane)

- Presence of traffic islands
- Cross street lane merge characteristics and supplemental traffic control devices

When a right-turn movement at a signalized intersection is shadowed by a protected left turn on the cross street, right-turn-on-red can be completed successfully without any concern for gaps in cross street traffic. However, right-turns-on-red are often impeded if the right-turn movements must occur from a lane that is shared with through and/or left-turning traffic. In addition, narrow or sharp geometry may also be counterproductive to a right-turn-on-red movement. Lin (*25*) concluded that a small increase in the approach width of an intersection would drastically raise the rate of RTOR use. In general, right-turn-on-red drivers are required to come to a complete stop before proceeding, resulting in some delay.

Tarawneh and McCoy (*26*) studied the effects of intersection geometrics on drivers making a right turn on red. One hundred drivers, with ages ranging from 25 to over 75 years of age, were evaluated on their performance at the following three types of right-turn geometrics:

- Channelized right-turn lane with an acceleration lane on the cross street
- Channelized right-turn lane without an acceleration lane on the cross street
- Unchannelized right-turn lane without an acceleration lane on the cross street

Results of the study found that 43 percent of drivers made a right turn on red without coming to a complete stop at the channelized right-turn roadway with an acceleration lane, compared to 28 percent at the channelized right-turn roadway without an acceleration lane and 9 percent at the unchannelized location. The authors concluded that channelization increases the probability that drivers will not come to a complete stop on a right turn on red. However, the results of this study are difficult to understand because, when a channelized right turn is provided at a signalized intersection, traffic using the channelized right-turn roadway is not normally controlled by the signal, so right-turn maneuvers would not normally be controlled by the signal and would not normally be considered RTOR maneuvers, regardless of the signal display.

OPERATIONAL EFFECTS OF CHANNELIZED RIGHT TURNS

The operational effects of channelized right turns have been quantified only for intersections on rural two-lane highways. McCoy and Bonneson (*7*) found that channelized right turns at rural intersections reduced travel times for right-turning vehicles, as shown in Table 12, which resulted in delay cost savings to motorists. McCoy and Bonneson also quantified the effect of channelized right turns at rural intersections on vehicle running costs. Channelized right turns decreased the magnitude, and therefore the cost, of speed-change cycles by reducing the number of stops by right-turning vehicles. This benefit was partially offset because vehicle operating costs on a curved roadway, like a channelized right-turn roadway, are higher than on a tangent roadway. Despite the latter effect, there was a net reduction in vehicle operating costs due to the channelized right turn. The reduction in vehicle operating costs comes primarily from reduced fuel usage, which implies there should be a reduction in vehicle emissions as well. Figure 18 presents the operational warrant for the application of channelized right turns, or free right turns (FRT) as McCoy and Bonneson termed them, at rural intersections.

TABLE 12. Travel Time Savings Provided by FRT Lanes (*7*)

Design speed (km/hr)	Radius[a] (m)	Acceleration rate (m/s^2)	Deceleration rate (m/s^2)	Travel time savings (seconds/vehicle)
40	56	0.52	1.6	5.8
48	83	0.52	1.6	8.8
56	116	0.49	1.5	11.8
64	155	0.49	1.4	14.8
72	201	0.49	1.3	17.9

80	259	0.49	1.3	20.9
89	324	0.49	1.3	24.0

[a] AASHTO (*1*) criteria for curves on open highways with superelevation rate of 0.06.
1 km = 0.6 mi.

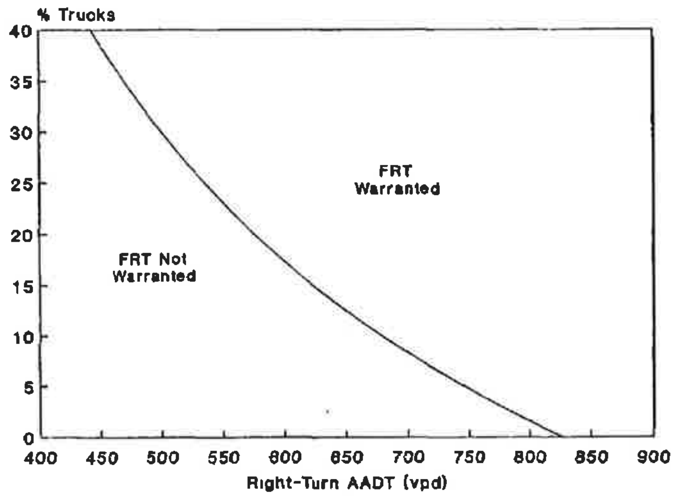


Figure 18. Volume warrant for FRT lanes.

There are, unfortunately, no comparable estimates of delay reduction or vehicle operating costs at channelized right turns on urban and suburban arterials. The evaluation logic applied by McCoy and Bonneson is as applicable to urban and suburban intersections as to rural intersections, but the magnitude of the operational effect of channelized right turns on urban and suburban arterials is not known.

A study completed by Tarawneh and McCoy (*26*) indicated that right-turn channelization affects the speed at which drivers make right turns. Drivers, especially those ages 25 to 45, perform right turns at speeds 5 to 8 km/h higher on intersection approaches with channelized right-turn lanes than on approaches without channelized right-turn lanes. Tarawneh and McCoy also found that the geometry of the right-turn lane did not affect the acceleration time of drivers.

COMPARISON OF OPERATIONAL PERFORMANCE FOR CONVENTIONAL INTERSECTIONS AND CHANNELIZED RIGHT TURNS

Channelized right turns appear to provide a net reduction in delay at intersections where they are installed, although no data and no established methodology are available to directly compare the operational performance of intersections with and without channelized right turns. It is also likely that channelized right turns may improve air quality through reducing total vehicle emissions at intersections due to reductions in the number of vehicle speed-change cycles and stops, but no quantitative estimates are available.

The HCM can be used to quantify the difference in delay between a conventional intersection and that same intersection with the right-turn volume removed. However, no data on the speed, travel time, and delay of vehicles using the channelized right-turn roadway, comparable to the estimates made by McCoy and Bonneson (*7*) for rural intersections, are available for urban and suburban intersections. Without such estimates, the estimated operational benefits of providing a channelized right turn might be exaggerated.

Furthermore, no data are available on the operational effects of installing pedestrian-activated signals along right-turn roadways. There is concern that the introduction of such signals may negate some or all of the traffic operational and air quality benefits that result from the provision of channelized right turns. There is also a concern that, if highway agencies choose to build conventional intersections, without channelized right turns, so as to avoid the need of placing a pedestrian signal on the channelized right-turn roadway, the traffic operational and air quality benefits of providing channelized right turns may also be lost. A traffic operational evaluation of channelized right turns, with and without pedestrian signals on the right-turn roadway, is needed to quantify the operational effects of installing pedestrian signals along right-turn roadways.

CHAPTER 5.

TRAFFIC SAFETY

This chapter summarizes current knowledge concerning the traffic safety performance of channelized right turns. Safety for motor vehicles, pedestrians, and bicycles are addressed separately.

SAFETY FOR MOTOR VEHICLES

It is generally accepted that channelized right turns improve safety for motor vehicles at intersections where they are used, but there is only limited quantitative data to demonstrate this. The research findings that are available are summarized below.

Dixon et al. (*4*) analyzed the crash history at 17 signalized intersections with various right-turn treatments in Cobb County, Georgia, to identify the effects of those right-turn treatments on right-turn crashes. The intersections were located on both major and minor arterials. A total of 70 right-turn movements were identified for evaluation, and 57 of these movements had one of the following five common right-turn treatments:

- Shared right-turn lane, no island, merge, and no additional control
- Exclusive right-turn lane, no island, merge, and no additional control
- Exclusive right-turn lane, raised island, acceleration lane, and no additional control
- Exclusive right-turn lane, raised island, merge, and yield control
- Shared right-turn lane, raised island, large turning radius, merge, and yield control

Table 13 summarizes the number of right-turn crashes for each treatment. The analysis was based strictly upon crash frequencies over a two-year period and did not include exposure data related to traffic volumes.

Dixon et al. (*4*) noted the following general findings, indicating that they merit future research:

- The use of a traffic island appears to reduce the number of right-angle crashes
- The addition of an exclusive right-turn lane appears to correspond to elevated sideswipe crashes
- The addition of an exclusive lane on the cross street for right-turning vehicles (i.e., an acceleration lane) does not appear to reduce the number of rear-end crashes when no additional control is implemented

TABLE 13. Comparison of Crash History for Common Right-Turn Treatments (*4*)

Treatment	Shared Right-Turn Lane, Merge, No island, No additional control	Exclusive Right-Turn Lane, Merge, No island, No additional control	Exclusive Right-Turn Lane, Acceleration lane, Raised island, No additional control	Exclusive Right-Turn Lane, Merge, Raised island, Yield control	Shared Right-Turn Lane, Large turning radius, Merge, Raised island, Yield control
Crash type	Percent of Right-Turn Crashes Observed				
Right angle	50%	31%	22%	23%	0%
Rear-end	28%	23%	64%	59%	90%
Sideswipe	17%	31%	7%	18%	0%
Other	5%	15%	7%	0%	10%
Number of sites evaluated	29	8	5	7	8
Number of right turn crashes for two-year period	18	13	14	22	10
Average number of right turn crashes per site per year	0.31	0.81	1.40	1.57	0.63

Staplin et al. (*27*) conducted an accident analysis to examine the problems that older drivers have in intersection areas. Approximately 700 accident records were reviewed during the analysis. In general, older drivers had difficulty yielding the right-of-way and making left turns at intersections, but the accident analysis did not reveal channelized right turns as a safety issue for older drivers.

Tarawneh and McCoy (*26*) conducted field investigations to study the effects of the geometrics of right-turn lanes on the turning performance of drivers. Right-turn performance of 100 subjects was evaluated at four signalized intersections of different right-turn lane channelization and skew. Three of the four intersections had a channelized right-turn lane. The investigation found that drivers turn right at speeds 5 to 8 km/h (4 to 5 mph) higher on intersection approaches with channelized right-turn lanes than they do on approaches with unchannelized right-turn lanes. In addition, it was observed that drivers are less likely to come to a complete stop before turning onto the cross street on approaches with channelized right turns. However, no explicit safety findings were inferred from this result.

McCoy et al. (*28*) conducted field studies on rural two-lane highways and found a higher incidence of merging conflicts from vehicles entering the cross street from a channelized right turn without an acceleration lane than those with an acceleration lane.

McCoy et al. (*28*) developed guidelines for channelized right-turn lanes at unsignalized intersections on rural two-lane highways. In developing the guidelines, McCoy et al. evaluated the safety effects of channelized right-turn lanes based on accident data, field studies, and computer simulation of truck dynamics. An analysis of the accident history at 89 rural intersections with and without channelized right-turn lanes over a five-year period found no effect of channelized right-turn lanes on the frequency, severity, or types of accidents that occur on approaches to unsignalized intersections. Thus, it was concluded from the accident analysis that channelized right-turn lanes do not provide the road user with any safety benefits or disbenefits. Field studies which investigated the tendency of drivers to travel faster than the design speed of the channelized roadway and to over steer at some point through the turn found that some drivers exceeded the design speeds of the channelized right-turn roadways, but they seldom exceeded the margin of safety for their vehicles. Vehicle-path data showed that nearly all of the vehicles observed were well-positioned in the lane at the center of the curve, indicating that they were able to follow the curvature of the channelized roadway with ease. Results from the truck simulation study support the use of the AASHTO criteria for curves on open highways, instead of the AASHTO criteria for minimum-radii intersection curves for the design of intersection curves on rural highways with substantial truck volumes. Results of the truck simulation also showed that the margin of safety between the maximum safe speed for trucks and the design speed is narrow.

SAFETY FOR PEDESTRIANS

No studies have been found that have used crash data to document the pedestrian safety implications of channelized right-turn lanes. Prior crash studies have focused on the vehicle-pedestrian collisions involving turning vehicles, but the geometrics of the intersection were not available to document the type of turning lane present.

A five-state analysis of more than 5,000 vehicle-pedestrian collisions found that 38 percent of all such crashes occurred at intersections (*29*). Further examination of the intersection accidents found that 30 percent of these crashes involved a turning vehicle. There was no further breakdown to determine if the vehicle was turning right or left. From a query of a North Carolina database that includes detailed crash types developed with the *Pedestrian and Bicycle Crash Analysis Tool*, one can determine the breakdown of turning vehicles (*30*, *31*). The North Carolina system includes five years of data (over 11,000 pedestrian-motor vehicle collisions). Intersection crashes account for 26 percent of those collisions. Left-turning vehicles accounted for 10 percent of the collisions at intersections, while right-turning vehicles accounted for 6 percent. Statistics gathered by the Oregon DOT (*15*) show that 19 percent of vehicle-pedestrian crashes occurring at intersections arose from drivers making right turns.

Other crash-based analyses have focused on vulnerable pedestrians, particularly the elderly. One such study that looked specifically at the types of crashes occurring at intersections showed older pedestrians to be overrepresented in collisions with both left- and right-turn collisions (*32*). Collisions involving left-turning and right-turning vehicles accounted for 17 percent and 13 percent, respectively, of all intersection accidents involving pedestrians. Pedestrians who were age 75 or older and were involved in a vehicle-pedestrian collision were struck by a left-turning vehicle in 24 percent of cases and by a right-turning vehicle 14 percent of cases. Those aged 65 to 74 were struck by a left-turning vehicle in 18 percent of cases and by a right-turning vehicle in 19 percent of cases.

The geometry of channelized right-turn lanes permits turns at higher speeds than in an unchannelized situation. Higher motor-vehicle speeds represent higher risk to pedestrians crossing the roadway. Research by Zegeer et al. (*10*) has established that, in the event that there is a collision, vehicle speed directly affects the likelihood that a pedestrian will be fatally injured. Should a pedestrian be hit by a vehicle traveling at 32 km/h (20 mph), the chance of being killed is 5 percent. For a 48-km/h (30-mph) vehicle, that likelihood of a fatality rises to 45 percent, while for vehicles traveling at 64 km/h (40 mph), the likelihood of a fatal injury is 85 percent. Motorists traveling at higher speeds have less time to see pedestrians and require more time to slow, stop, or change direction to avoid striking them.

SAFETY FOR BICYCLISTS

There is an inherent risk to bicyclists at channelized right turns because motor vehicles entering the channelized right-turn roadway must weave across the path of bicycles traveling straight through the intersection. However, no studies based on crash history are available to support this presumption. Furthermore, the same type of conflict between through bicyclists and right-turning vehicles is present at all intersections, except at intersections where right turns are prohibited or three-leg intersections where there is no leg to the right on a given approach. There are also no studies that provided data on the risk of collisions between motor vehicles and bicycles on the channelized right-turn roadway itself or at the point at which the channelized right-turn roadway joins the cross street. The following discussion presents basic statistics on bicycle safety, followed by available information on bicycle-related safety issues at right-turn lanes.

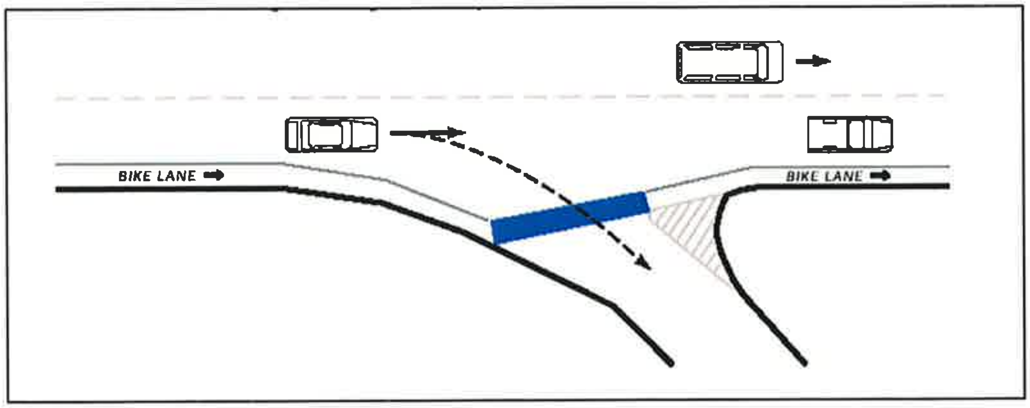
In 2002, 662 bicyclists were killed and an additional 48,000 were injured in traffic accidents (*33*). Thus, bicyclists accounted for 2 percent of all traffic fatalities. Bicyclists accounted for 12 percent of all nonmotorized traffic fatalities, while pedestrians accounted for 86 percent; the remaining 2 percent were skateboard riders, roller skaters, etc.

Oregon reports that most bicycle crashes (65 to 85 percent) do not involve collisions with motor vehicles but rather involve falls or collisions with stationary objects, other bicyclists, and pedestrians. Of the bicycle/motor vehicle crashes, 45 percent occurred at intersections (*15*). In another evaluation of bicycle/motor vehicle crashes, Tan reported that approximately 5 percent of bicycle/motor vehicle crashes occurred when a motorist made a right turn (*34*), but no information was provided on whether the respective crashes occurred at intersections with channelized right turns. Tan also reported that approximately 4 percent of bicycle/motor vehicle crashes occurred at an intersection controlled by a signal at which the motorist struck the bicyclist while making a right turn on red.

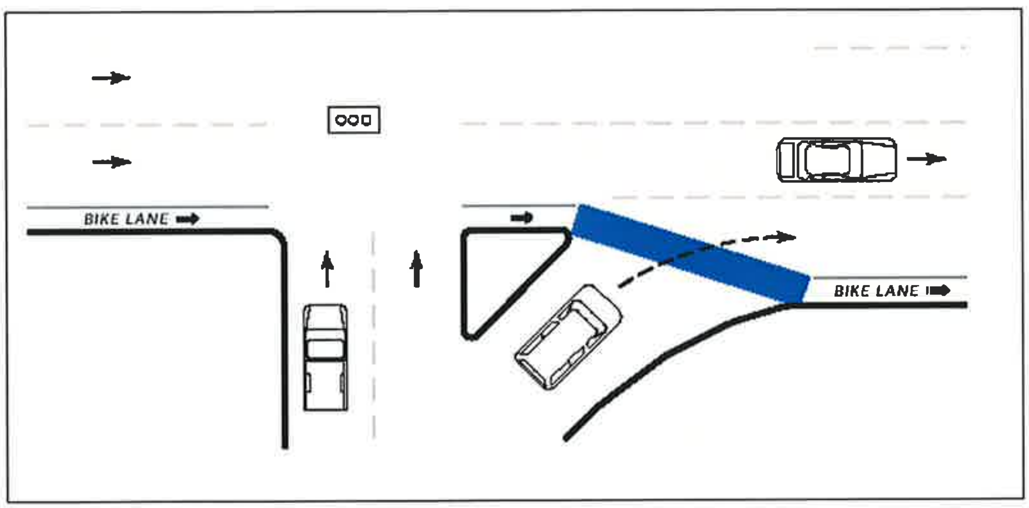
Clark and Tracy (*35*) reported that 13 percent of all bicycle/motor vehicle crashes resulted when motorists were making a right-turn movement, and a majority of these crashes involved a straight-through bicyclist being struck by a right-turning motor vehicle. Clark and Tracy indicated that many bicyclists find changing lanes difficult or choose to ignore signage and pavement markings.

Much of the advice for highway designers in dealing with intersections and right-turn lanes is applicable only to locations where bicycle lanes already exist (or are planned in the future). As indicated in Chapter 3, the MUTCD (*11*) and AASHTO bicycle guide (*14*) recommend breaking bicycle lane markings ahead of the intersection and then marking the bicycle lane again at the intersection itself, to the left of the right-turn lane. This positions bicyclists traveling straight through the intersection away from any conflict with right-turning vehicles and allows a merge area for right-turning vehicles to get into right-turn lane.

Two recently completed studies for the FHWA have included observational studies of bicyclists and motorists as they maneuvered through a variety of right-turn lane configurations (*36, 37*). One of the studies was a before-after effort in which the conflict zone, defined as the place where the paths of bicyclists and motorists crossed most often, was treated with blue pavement markings at 10 intersections in Portland, Oregon (*36*). Figure 19 illustrates the use of blue pavement markings at the entrance to and exit from a channelized right-turn lane.



a. At entrance to channelized right-turn roadway



b. At exit of channelized right-turn roadway

Figure 19. Blue pavement marking treatment at channelized right-turn lane (36)

Configurations addressed in the Oregon blue bike lane program included exit ramps, right-turn lanes, and entrance ramps. The markings were also supplemented with unique signs showing the blue markings and yield signs for motorists (see Figure 20). Both video observations and survey feedback were collected as part of the study, with approximately 850 bicyclists and 190 motorists in the before period and 1,020 bicyclists and 300 motorists in the after period. The most important results were as follows:

- There was a significant increase in motorists yielding to bicyclists after the treatment was installed, from 71 percent in the before period to 87 percent in the after period.
- Significantly more bicyclists followed the path marked for bicyclists after the blue markings were in place, 85 percent in the before period compared to 93 percent in the after period.
- There was a decrease in head-turning and scanning on the part of bicyclists after the treatment was installed, from 43 percent in the before period to 26 percent in the after period, which was a concern. The authors were not sure of the reason for this result.
- While conflicts between the two modes were rare, the conflict rate decreased from 0.95 conflicts per 100 entering bicyclists in the before period to 0.59 conflicts per 100 entering bicyclists in the after period.
- The survey data showed that 70 percent of the motorists noticed the blue markings, and 59 percent noticed the accompanying sign. When asked about safety, 49 percent of the motorists thought it would increase safety, 20 percent

thought it would be the same, 12 percent thought it would be less safe, and the remaining motorists were not sure.

- The bicyclists surveyed thought the treatment would increase safety (76 percent). Only 1 percent thought it would decrease safety.

Overall, it was found that the treatment resulted in a safer riding environment and a heightened awareness on the part of both bicyclists and motorists. The City of Portland continues to use this treatment at 6 of the 10 locations today.

The second study examined the behaviors of bicyclists and motorists at a "combined" bicycle lane/right-turn lane used in Eugene, Oregon (*37*). The results were compared to observations made at a more traditional right-turn lane. The combined lane created a 1.5-m (5-ft) bike pocket within a 3.6-m (12-ft) right-turn lane, leaving 2.1 m (7 ft) for right-turning vehicles (see Figure 21). The traditional lane location used for comparison was a 3.7-m (12-ft) right-turn lane and a 1.5-m (5-ft) bike pocket (see Figure 22). Approximately 600 bicyclists were videotaped at each location as they approached and continued straight through the intersection. The differences in the two types of right-turn lanes can be summarized as follows:

- Bicyclists and motorists tended to queue up behind one another more often in the combined lane facility (43 percent of the time) than in the standard lane facility (1 percent of the time).

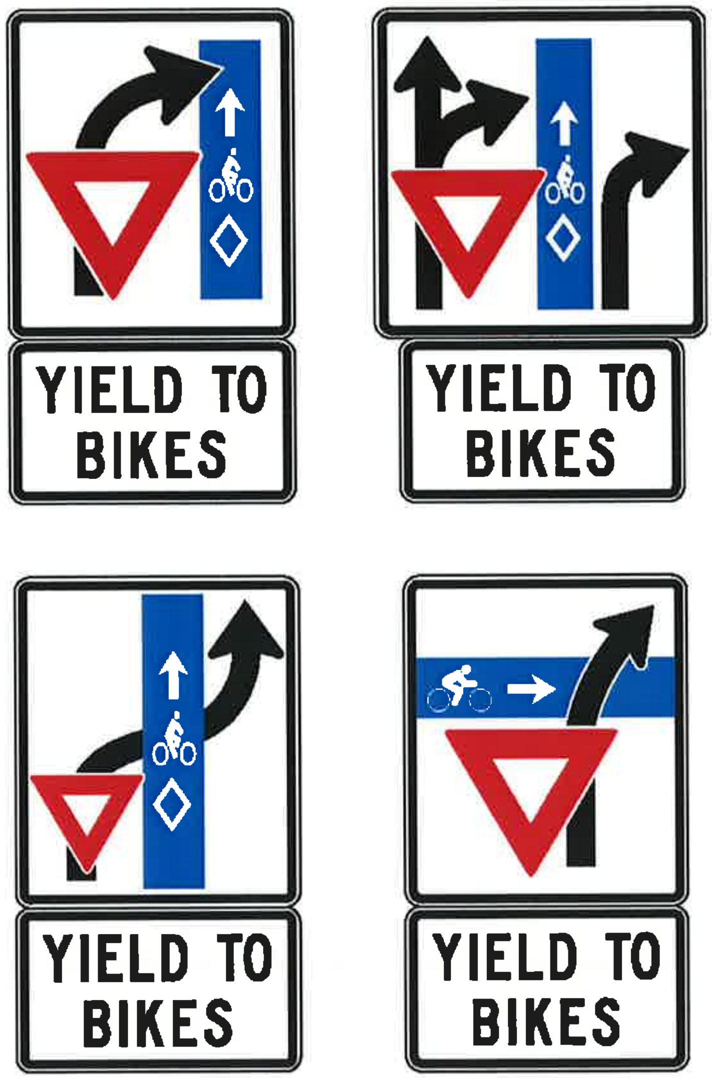


Figure 20. Signs used in Oregon blue bike lane program (36)

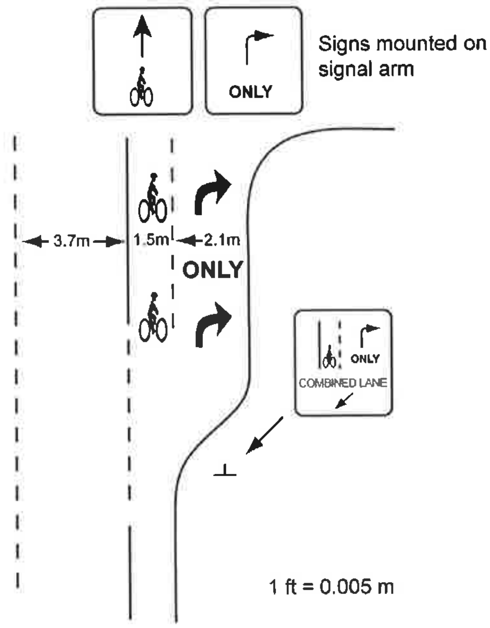


Figure 21. Combined bicycle lane/right-turn lane (37)

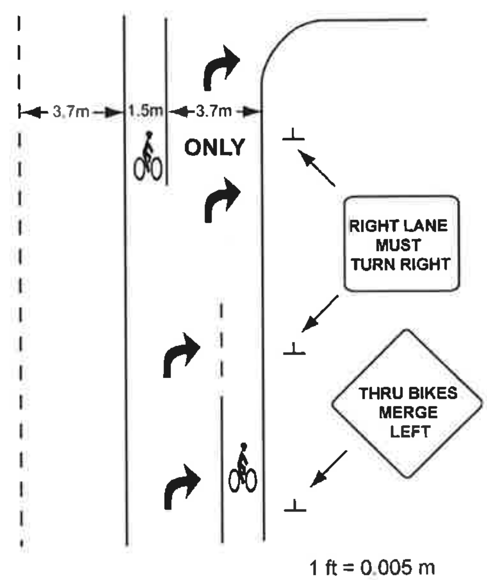


Figure 22. Traditional bike lane/right-turn lane (37)

- At both locations, bicyclists were most often able to position themselves in the bike pocket (94 percent of the time in the combined lane and 86 percent of the time in the standard lane). At the combined lane intersection, bicyclists tended to use the adjacent through lane more often (2 percent of the time) compared to virtually no such positioning at the standard lane. This was primarily due to the occasional bus that needed to turn right at the combined lane intersection, which then forced the approaching bicyclists to use the through lane.
- At both locations, the yielding behavior of each mode was captured. At the combined lane location, the motorist yielded to the bicyclist in 93 percent of the cases where the two parties would have collided had someone not slowed or stopped. At the standard lane location, motorist yield 48 percent of the time. This low percentage of yielding by motorists at the standard lane is believed to be an artifact of bicyclists having to shift to the left on the approach to the intersection in order to move from the bicycle lane adjacent to the curb to the bike pocket at the intersection.
- No conflicts requiring either mode to suddenly stop or change direction were observed at either location.

In addition to the observational data, a brief survey of a sample of bicyclists was administered at both locations. When asked to compare the two locations, 18 percent said the combined lane was safer, 27 percent said it was less safe, and 55 percent said there was no difference. Overall, the observational and survey data showed the combined bicycle lane/right-turn lane to be an effective treatment that could be beneficial at locations where right-of-way constraints exist.

There has also been a perception study conducted for FHWA in which participants were asked to view a number of right-turn lane configurations and provide a rating of how comfortable they would be interacting with right-turning traffic in an effort to continue straight through the intersection (*38*). The configurations rated included:

- A standard right/through lane in which the bicyclist could travel straight on the approach and continue through the intersection.
- An auxiliary right-turn only lane that was added at the intersection, which allowed the bicyclist to travel straight on the approach and forced the motorist to cross the path of the bicyclist.
- A travel lane that became a right-turn lane at the intersection, forcing bicyclists to shift left across the path of motorists in order to continue straight through the intersection.
- A gradual increase in pavement width on the intersection approach that became a right-turn lane at the intersection, also forcing bicyclists to shift left across the path of motorists in order to continue straight through the intersection.

A regression model was developed using the perception ratings as the dependent variable and several geometric and operational variables as independent measures. The most significant predictors of the a bicyclist's comfort level were whether there was a bike lane present on the approach and whether the bicyclist had to shift to the left across the motorist path in order to continue through the intersection. The presence of a bike lane increased the comfort level, while the requirement to shift across the motorist's path decreased the comfort level. This result confirmed some of the observational data collected in the combined bicycle/right-turn lane study previously described.

An example of a treatment for bicycle lanes at intersections that is considered inappropriate suggests channeling bicyclists onto a sidewalk or bike path and having them behave as pedestrians (*35*). Crash records suggest this approach is seriously flawed, especially since it can encourage wrong-way riding.

On streets with bicycle lanes, the current recommended designs ensure straight-though bicyclists are positioned to the left of exclusive right-turn lanes. On streets without bicycle lanes, bicyclists and motorists must perform the same maneuvers as if separate lanes were marked. They must do so, however, without the guidance offered by the bicycle lane markings and without the same amount of space available to share the road at the intersection. In both instances, there are several important design features to remember (*35*):

- As the length of the right-turn lane increases, so does the exposure of the bicyclist to traffic driving on either side of them. In addition, the speed of vehicles in the right-turn lane may be greater. Thus, exclusive right-turn lanes should be kept as short as possible.
- As both bicyclists and motorists pass through intersections, they are concentrating on their own position on the road and on traffic within the intersection. No driveways should be positioned near the intersection to cause additional conflicts.

CHAPTER 6.

SUMMARY OF ADVANTAGES AND DISADVANTAGES FOR CHANNELIZED RIGHT TURNS

This chapter summarizes the advantages and disadvantages of channelized right turns that have been noted in Chapters One through Five. These advantages and disadvantages, identified in Table 14, include geometric design, traffic operational, traffic safety, and environmental issues. While these advantages and disadvantages reflect the current knowledge and experience of highway agencies concerning channelized right turns, there is very little quantitative data on their performance. There are many unresolved issues concerning channelized right turns that indicate a need for further research.

TABLE 14. Summary of Advantages and Disadvantages of Channelized Right Turns

Advantages	Disadvantages
Motor Vehicles	
• Increase vehicular capacity not only of the right-turn movement but for the intersection as a whole • Reduce delay to drivers by allowing them to turn at higher speeds • Reduce unnecessary stops • On a signalized intersection approach with a channelized right-turn roadway, the main signal can operate more efficiently because the right-turning traffic does not pass through the signal and does not need to be accounted for in the signal timing • Clearly define the appropriate path for right-turn maneuvers at skewed intersections or at intersections with high right-turn volumes • Separate the points at which crossing conflicts and right-turn merge conflicts occur • Remove decelerating, stopped, or slow vehicles from a through-traffic stream • Provide safer merging opportunities, away from the main intersection, for right-turning vehicles to enter the cross street traffic • Larger right-turn radii permit higher-speed turns, producing smaller speed differentials with following vehicles and thus less severe rear-end conflicts • Better accommodate large trucks by allowing use	• Pedestrian crosswalk within a channelized right-turn roadway may be unexpected by motorists • Pedestrian signals within a channelized right-turn roadway may be unexpected by motorists • Depending on the design, raised islands may limit the ability to accommodate some types of vehicles

TABLE 15. Summary of Advantages and Disadvantages of Channelized Right Turns (Continued)

of larger turning radii without unnecessarily increasing the intersection pavement area • Provide an offset that moves right-turn vehicles away from the through lanes so that right-turn vehicles do not become a sight obstruction to drivers entering or crossing the major street from the cross street • Where a deceleration lane is provided, it functions as storage area for right-turning vehicles to assist in optimization of traffic signal phasing • Where acceleration lane is provided, it provides an opportunity for vehicles to complete the right-turn maneuver unimpeded and then accelerate toward the speed of the cross-street traffic prior to merging • Reduce vehicle operating costs primarily by reducing fuel usage, which implies a reduction in vehicle emissions and improved air quality	
Pedestrians	
• Permit the use of large curb return radii without unnecessarily increasing the intersection pavement area and the pedestrian crossing distance • Crossing the right-turn roadway is easier than crossing a major street because the roadway is usually narrower and because traffic is approaching from a single direction • Larger turn radii reduce the likelihood that larger vehicles will encroach on the roadside areas normally used by pedestrians • Provision of a pedestrian signal or active warning device on a channelized right-turn roadway could reduce potential vehicle-pedestrian conflicts • Right-turn-on-red maneuvers at conventional intersections, which frequently involve vehicle-pedestrian conflicts, are eliminated unless the channelized right-turn roadway is itself signalized • The channelizing island, particularly when bounded by raised curbs, serves as refuge area for pedestrians and allows pedestrians to cross the street in two stages • Where a sharper angle of entry to the cross street can be provided, there should be several positive effects with respect to pedestrian safety by slowing both the speed of approach into the turn and the exit speed	• Higher vehicle speeds on the turning roadway increases the potential severity of vehicle-pedestrian collisions • Higher vehicle speeds on the turning roadway provide less time for motorists to see pedestrians and slow, stop, or change direction • Roadway curvature may make it less likely that motorists will see pedestrians • Driver's attention may be focused on the cross-street traffic • Pedestrians with vision impairments may have difficulty detecting approaching traffic because the intersection geometry is more complex; because right-turning vehicles are traveling a curved, rather than a straight path; because there is not a systematic stopping and starting of traffic, and because the traffic sounds from the major streets may mask the sound of traffic on the right-turn roadway • For pedestrians who are blind or have vision impairments, the presence of a channelized right-turn roadway makes the intersection more complex in terms of knowing where to cross, knowing when to cross, knowing the direction to walk during the crossing, and knowing when they have reached the other side of the street
Bicyclists	
• Striping and signing for bicycle lanes are intended to encourage motorists and bicyclists to cross paths in advance of intersections in a	• Motor vehicles entering the channelized right turn must weave across bicycle traffic to execute the right-turn maneuver

TABLE 15. Summary of Advantages and Disadvantages of Channelized Right Turns (Continued)

merging fashion, away from other conflicts • Striping and signing for bicycle lanes encourage bicyclists to follow the rules of the road • By forcing bicyclists and motorists to cross in advance of the intersection, the difference in travel speeds enables the motorist to pass a bicyclist rather than travel side-by-side	• Motor vehicles from the channelized right turn lane must merge with motor vehicle and bicycle traffic on the cross street

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Appendix A

Survey Questionnaire

National Cooperative Highway Research Program
Project 3-72

"Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas"

The following survey on lane widths, right-turn deceleration lanes, and channelized right turns on urban and suburban arterials is being conducted as part of the National Cooperative Highway Research Program (NCHRP), which is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). Your responses to the following questions concerning your agency's geometric design policies and practices regarding lane widths, right-turn deceleration lanes, and channelized right turns on urban and suburban arterials would be greatly appreciated.

SURVEY QUESTIONNAIRE

*(Please return by **August 15, 2003**)*

1. What type of highway agency do you represent?

   ___ State highway agency
   ___ County highway agency
   ___ City/municipal highway agency
   ___ Metropolitan planning organization
   ___ Other: ______________________________

AGENCY DESIGN GUIDELINES

2. Does your agency use lane width criteria that differ from the AASHTO *Green Book*?
   .... ☐Yes ☐No

   Does your agency use design guidelines for right-turn deceleration lanes that differ from the AASHTO *Green Book*? .... ☐Yes ☐No

   Does your agency use design guidelines for channelized right turns that differ from the AASHTO *Green Book*?
   .... ☐Yes ☐No

   If YES, to any of the questions above, please attach a copy of your guidelines.

3. Is your agency considering any changes in your policies concerning lane widths, right-turn deceleration lanes, or channelized right turns on urban and suburban arterials? .... ☐Yes ☐No

   If YES, please elaborate: ______________________________

LANE WIDTHS

4. Does your agency use different lane widths for midblock locations and signalized intersection approaches on urban and suburban arterials? .... ☐Yes ☐No

5. What is the narrowest lane width that your agency considers will perform acceptably for urban and suburban arterials?

   ___ft (for midblock locations)
   ___ft (for signalized intersection approaches)

6. Has your agency used lanes narrower than 11 ft on urban or suburban arterials?

   ___ YES, at midblock locations only
   ___ YES, on signalized intersection approaches only
   ___ YES, at both midblock locations and signalized intersections
   ___ NO

7. What factors does your agency consider in selecting an appropriate lane width for an urban or suburban arterial? (Check all that apply)

   ___ Established geometric design policies
   ___ Level of service considerations at midblock locations
   ___ Level of service considerations at signalized intersections
   ___ Running speeds at midblock locations
   ___ Availability of space for a roadway median
   ___ Availability of space for bicycle facilities
   ___ Crossing time/distance for pedestrians
   ___ Potential interference with existing development
   ___ Other (Please describe:____)

8. What pedestrian issues (i.e., crossing distance, vehicle speeds adjacent to pedestrian areas, etc.) does your agency consider when determining lane widths on urban and suburban arterials?

   ____
   ____

9. What bicycle issues (i.e., bicycle lane, wider curb lane, shoulders, etc) does your agency consider when determining lane widths on urban and suburban arterials?

   ____
   ____

10. Has your agency evaluated the traffic operational or safety effects of using narrower lanes on urban and suburban arterials? .... ☐Yes ☐No

    If YES, please describe the results or attach a copy of the evaluation report.

11. Has your agency implemented projects within the last 5 to 7 years in which an existing urban or suburban arterial was:

    Restriped with narrower lanes (i.e., to accommodate an auxiliary lane, bicycle lane, median or wider median, etc)? .... ☐Yes ☐No

    Restriped to provide wider lanes? .... ☐Yes ☐No

    Would any of these projects be suitable for evaluation as part of this research? .... ☐Yes ☐No

RIGHT-TURN DECELERATION LANES

12. Does your agency use right-turn deceleration lanes at intersections or driveways on urban and suburban arterials? .... ☐Yes ☐No

    Does your agency have volume warrants for right-turn deceleration lanes at intersections or driveways on urban and suburban arterials? .... ☐Yes ☐No

    If YES, please elaborate **(or attach a copy of your warrants)**: ______________________

    ____

13. At what types of locations does your agency use right-turn deceleration lanes on urban and suburban arterials? (Check all that apply)
    ___ Signalized intersections or driveways
    ___ Unsignalized intersections
    ___ Unsignalized major driveways

14. How are bicycle lanes striped along right-turn deceleration lanes?

    ____

    ____

15. Has your agency encountered any traffic operational or safety problems associated with right-turn deceleration lanes on urban and suburban arterials? .... ☐Yes ☐No

    If YES, please elaborate: ______________________

    ____

    Has your agency encountered any traffic operational or safety problems associated with *the lack of* right-turn deceleration lanes on urban and suburban arterials? .... ☐Yes ☐No

    If YES to either question, please elaborate: ______________________

    ____

16. Has your agency implemented projects within the last 5 to 7 years in which a right-turn deceleration lane was installed to accommodate right-turn traffic at an intersection or driveway? .... ☐Yes ☐No

    Would any of these projects be suitable for evaluation as part of this research? .... ☐Yes ☐No

CHANNELIZED RIGHT TURNS

17. Does your agency use channelized right-turn roadways, set off from the through lanes by a triangular island, at intersections on urban and suburban arterials? .... ☐Yes ☐No

18. Where does your agency place pedestrian crosswalks at channelized right-turn roadways?
    ___ At the upstream end of the channelized roadway
    ___ In the middle of the channelized roadway
    ___ At the downstream end of the channelized roadway

19. Does your agency have a formal policy concerning the traffic control for channelized right-turn roadways?? .... ☐Yes ☐No

If YES, please attach a copy of your policy.

20. Does your agency install pedestrian-actuated signals at channelized right-turn roadways on urban and suburban arterials?

____ YES, at all locations
____ YES, at selected locations
____ NO

21. Has your agency developed or used any strategies specifically intended to assist visually impaired pedestrians in crossing channelized right-turn roadways without pedestrian signals? .... ☐Yes ☐No

If YES, please describe: ____________________

____

22. Are pedestrian considerations a factor in determining the radius and/or width of a channelized right-turn roadway? .... ☐Yes ☐No

If YES, please describe: ____________________

____

23. Has your agency encountered any safety problems related to pedestrians crossings at channelized right-turn roadways on urban and suburban arterials? .... ☐Yes ☐No

If YES, please describe: ____________________

____

24. Has your agency implemented any of the following innovative traffic control devices at channelized right-turn roadways?

High-visibility crosswalk markings (to improve conspicuity)? .... ☐Yes ☐No
Fluorescent yellow-green signs at the crosswalk and/or in advance of the crossing location? .... ☐Yes ☐No
Real-time warning device to indicate to the motorist when a pedestrian is present in the area? .... ☐Yes ☐No
Other dynamic message signs? .... ☐Yes ☐No
Other: ____________________

25. Does your agency use deceleration lanes in advance of channelized right-turn roadways? ...... ☐Yes ☐No

Does your agency use acceleration lanes downstream of channelized right-turn roadways? ..... ☐Yes ☐No

26. How are bicycle lanes striped on the approach to and within a channelized right-turn roadway?

____

____

27. Has your agency implemented projects within the last 5 to 7 years in which a conventional intersection has been reconstructed to include a channelized right-turn lane(s)? .... ☐Yes ☐No

    Would any of these projects be suitable for evaluation as part of this research? .... ☐Yes ☐No

28. Do you have any other observations or comments?

____

____

29. May we have the name of an engineer in your agency that we may contact to clarify any aspect of your response or to obtain additional information?

    Contact: ____________________ Title: ____________________

    Agency: ____________________________________

    Address: ____________________________________

    ____

    Telephone #: ____________________ Fax #: ____________________

    e-mail address: ____________________________________

Please return the completed survey by **August 15, 2003**, to:

Ingrid B. Potts, P.E.
Senior Traffic Engineer
Midwest Research Institute
425 Volker Blvd.
Kansas City, MO 64110
ipotts@mriresearch.org

Appendix B

Survey Results Concerning Current Design Policies and Practices of Highway Agencies Related to Channelized Right Turns

This appendix presents a summary of the responses of highway agencies to the questions on the survey questionnaire, which is presented in Appendix A, related to channelized right turns. The questionnaire presented in Appendix A also addresses highway agency policies concerning lane widths and right-turn deceleration lanes; the survey results on these topics are addressed in separate syntheses. Design policies at the national level are based on the AASHTO *Green Book* (*1*). Many states also have their own geometric design manuals and policies, which may differ from the *Green Book* in some particulars.

Survey Recipients

The survey questionnaire was distributed at the Urban Street Symposium, held in Anaheim in July 2003. The questionnaire was also mailed to state and local highway agencies throughout the United States. The mailing list for the survey included:

- 50 state highway agencies
- 125 local highway agencies (99 cities and 26 counties)

Thus, a total of 175 survey questionnaires were mailed.

The questionnaires for state highway agencies were generally sent to the state design engineer. The names and addresses of the design engineers were determined from the membership roster of the AASHTO Subcommittee on Design.

Most of the local highway agency engineers on the mailing list for the questionnaires were city and county traffic engineers. Their addresses were obtained from the ITE directory, city websites, and county websites. The local agencies include approximately two major cities from each state and 26 selected urban or suburban counties. Rural counties were not surveyed because the focus of the study is on urban and suburban arterials.

Response Rate

Table B-1 summarizes the responses to the survey that were received. A total of 75 responses were received out of the 175 questionnaires that were mailed. The responses received include 40 state agencies, 27 cities, and 8 counties. The overall response rate was 43 percent, including a response rate of 80 percent for state highway agencies and 28 percent for local highway agencies.

TABLE B-1. Response Rate for the Highway Agency Survey

Agency type	Number of questionnaires mailed	Number of responses received	Response rate (%)
State agencies	50	40	80.0
Local agencies	125	35	28.0
Total	175	75	42.9

Agency Design Guidelines

In Question 2, highway agencies were asked whether their design guidelines for lane widths, channelized right turns, and right-turn deceleration lanes differ from the AASHTO *Green Book*. Table B-2 summarizes the responses to this question. The responses indicate that the majority of responding agencies use the *Green Book* as their design guidelines for lane widths, channelized right turns, and right-turn deceleration lanes.

TABLE B-2. Number of Agencies With Design Policies Different From the *Green Book*

	Number (percentage) of agencies		
Type of policy	State agencies	Local agencies	Total
Lane width	2 (5.0)	10 (29.4)	12 (16.0)
Channelized right turns	4 (10.0)	4 (11.8)	8 (10.7)
Right-turn deceleration lanes	8 (20.0)	6 (17.6)	14 (18.7)
Total number of agencies responding	40	35	75

In Question 3, highway agencies were asked whether they are considering any changes in their policies concerning lane widths, channelized right turns, or right-turn deceleration lanes on urban and suburban arterials. Approximately 20 percent of state highway agencies and 26 percent of local highway agencies are considering changes to their current policies.

Design and Operation of Channelized Right Turns

Questions 17 and 18 address the use of channelized right-turn roadways and the placement of pedestrian crosswalks at channelized right-turn roadways. Approximately 87 percent of state and local highway agencies indicated that they use channelized right-turn roadways. One agency indicated that they do not use channelized right turns, and another agency indicated that the try to minimize their use, because of pedestrian considerations.

Table B-3 summarizes the locations at which highway agencies place pedestrian crosswalks on channelized right-turn roadways. Some highway agencies identified that the locations at which they place crosswalks have varied from site to site. For this reason, the column percentages in the table may exceed 100 percent.

TABLE B-3. Locations Where Agencies Place Pedestrian Crosswalks at Channelized Right-Turn Roadways

Location	Number (percentage) of agencies		
	State agencies	Local agencies	Total
At the upstream end	8 (22.9)	7 (23.3)	15 (20.0)
In the middle	27 (77.1)	20 (66.7)	47 (62.7)
At the downstream end	9 (25.7)	12 (40.0)	22 (29.3)

NOTES: 1. Columns total to more than 100 percent because of multiple responses.
2. Percentages are of those highway agencies that have used channelized right-turn roadways.

In Question 19, highway agencies were asked if they have a formal policy concerning the traffic control for channelized right-turn roadways. Of the highway agencies that use channelized right-turn roadways, 14 percent of state highway agencies and 17 percent of local highway agencies indicated that they do have a formal policy concerning the traffic control for channelized right-turn roadways. Other agencies rely on MUTCD guidance concerning the proper application of yield signs, stop signs, and signals; such guidance deals with the general application of these devices, but is not specific to channelized right turns.

In Question 20, highway agencies were asked whether they install pedestrian-actuated signals at channelized right-turn roadways on urban and suburban arterials. The responses are summarized below:

- Of the highway agencies that use channelized right-turn roadways, only 6 percent of state highway agencies and 17 percent of local highway agencies install pedestrian-actuated signals at *all* channelized right-turn roadways.
- The majority of highway agencies using channelized right-turn roadways, including 83 percent of state highway agencies and 60 percent of local highway agencies, indicated that they install pedestrian-actuated signals at *selected* locations only.
- Of the highway agencies that use channelized right-turn roadways, approximately 11 percent of state highway agencies and 23 percent of local highway agencies do not use pedestrian-actuated signals.

In Question 21, highway agencies were asked if they have developed or used any strategies specifically intended to assist pedestrians with vision impairments in crossing channelized right-turn roadways without pedestrian signals. Of the highway agencies that use channelized right-turn roadways, 23 percent of state highway agencies and 10 percent of local highway agencies have either developed or used such strategies. The general types of strategies used by the responding agencies to assist pedestrians with vision impairments in crossing channelized right-turn roadways are summarized in Table B-4. In addition to the responses shown in the table, one additional highway agency indicated that they are considering the use of pedestrian-actuated signals at channelized right turns. One highway agency reportedly installed audible signals at one intersection, but was requested by a vision impairment organization to deactivate the sound.

TABLE B-4. General Strategies to Assist Pedestrians With Vision Impairments

General strategy	State agencies	Local agencies	Total
Curb ramps with truncated domes	5	1	6
Textured curb ramps	4	1	5
Audible signals	1	0	1

Question 22 addresses pedestrian considerations in determining the radius or width of a channelized right-turn roadway. Of the highway agencies that use channelized right-turn roadways, 23 percent of state highway agencies and 40 percent of local highway agencies indicated that they consider pedestrian issues in determining the radius and/or width of a channelized right-turn roadway. Table B-5 presents a list of the pedestrian issues considered by these agencies in determining the radius or width of a channelized right-turn roadway. One highway agency does not use channelized right turns, and another is trying to get away from using them, because of pedestrian concerns.

TABLE B-5. Pedestrian Issues Considered in Determining the Radius or Width of Channelized Right-Turn Roadway

Pedestrian issue	State agencies	Local agencies	Total
Pedestrian crossing distance/time minimized	3	1	4
Vehicle speeds minimized	1	3	4
Provision of pedestrian refuge location	2		2
Improved sight distance of opposing traffic		1	1
Pedestrian volumes		1	1
General consideration of pedestrians	4	1	5

In Question 23, highway agencies were asked if they have encountered any safety problems related to pedestrians crossing at channelized right-turn roadways on urban and suburban arterials. Of the highway agencies that use channelized right-turn roadways, approximately 23 percent of state highway agencies and 17 percent of local highway agencies have encountered pedestrian-related safety problems at channelized right-turn roadways. Highway agencies reported the following safety concerns related to pedestrians crossing at channelized right turns:

- General concern about pedestrian safety at channelized right-turn roadways (5 agencies)
- Higher vehicle speeds put pedestrians at risk (3 agencies)

- Visually impaired pedestrians may expect approaching traffic to stop (1 agency)
- Truck-trailer off tracking onto sidewalk jeopardizes pedestrian safety (1 agency)
- Drivers may not yield to pedestrians (1 agency)
- Larger radii may make pedestrians less visible to drivers (1 agency)
- There is some confusion regarding the most appropriate crossing location (1 agency)
- There is greater exposure to pedestrians (1 agency)
- Small islands and snow on islands are not conducive to pedestrian use (1 agency)

Only one highway agency reported a safety problem at a specific location. One location with an unsignalized right-turn roadway and no pedestrian signals has a sight distance problem which will probably be addressed by providing a signal

In Question 24, highway agencies were asked to identify innovative traffic control devices that they have implemented at channelized right-turn roadways. Table B-6 summarizes the highway agency responses to this question. Between 40 and 50 percent of highway agencies have used high-visibility crosswalk markings and florescent yellow-green signs, but fewer than 10 percent of agencies have tried other innovative devices.

TABLE B-6. Innovative Traffic Control Devices at Channelized Right-Turn Roadways

Traffic control device	Number (percentage) of agencies					
	State agencies		Local agencies		Total	
High-visibility crosswalk markings	13	(37.1)	13	(43.3)	26	(40.0)
Fluorescent yellow-green signs	16	(45.7)	15	(50.0)	31	(47.7)
Real-time warning devices	2	(5.7)	3	(10.0)	5	(7.7)
Other dynamic message signs	2	(5.7)	2	(6.7)	4	(6.2)
Other	1	(2.9)	0	(0.0)	1	(1.5)

Notes: 1. Columns total to more than 100 percent because of multiple responses.
2. Percentages are of those highway agencies that have used channelized right-turn roadways.

In Question 25, highway agencies were asked if they use either deceleration lanes or acceleration lanes at channelized right-turn roadways. Of the highway agencies that use channelized right-turn roadways, the responses were as follows:

- Eighty-nine percent of the state highway agencies and 70 percent of local highway agencies use deceleration lanes in advance of channelized right-turn roadways for at least some locations.

- Seventy-seven percent of state highway agencies and 43 percent of local highway agencies use acceleration lanes downstream of channelized right-turn roadways for at least some locations.

In Question 26, highway agencies were asked how their agency stripes bicycle lanes on the approach to and within a channelized right-turn roadway. Table B-7 summarizes highway agency responses to this question. In some cases, multiple responses were provided.

TABLE B-7. Methods of Striping Bicycle Lanes on the Approach to and Within Channelized Right-Turn Roadway

How/where bicycle lane is striped	State agencies	Local agencies	Total
Adjacent to through lanes	11	5	16
Continued through approach	2	2	4
Continued through approach, but dashed at channelized right turn		4	4
Terminated in advance of the channelized right turn	1	3	4
Adjacent to curb		1	1
Diagonal cross hatch	1		1
In accordance with AASHTO[a]	8		8
In accordance with the MUTCD	3	2	5

[a] AASHTO *Guide for the Development of Bicycle Facilities* (*12*).

In Question 27, highway agencies were asked if they had implemented projects within the last 5 to 7 years in which a conventional intersection has been reconstructed to include a channelized right-turn lane(s). Approximately 77 percent of state highway agencies and 53 percent of local highway agencies indicated they had implemented at least one project of this type. Of these agencies, 6 state highway agencies and 7 local highway agencies indicated that their projects may be suitable for evaluation as part of this research.