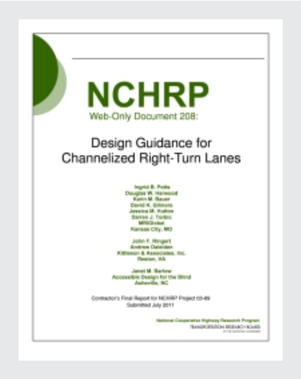

Design Guidance for Channelized Right-Turn Lanes

DETAILS

0 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-43290-0 | DOI 10.17226/22238

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ACKNOWLEDGMENT

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

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Author Acknowledgements

The research reported herein was performed under NCHRP Project 3-89 by MRIGlobal. MRIGlobal was the contractor for this study, with Kittelson and Associates, and Ms. Janet M. Barlow, Accessible Design for the Blind, serving as subcontractors.

Ms. Ingrid B. Potts, P.E., Principal Traffic Engineer at MRIGlobal, was the Principal Investigator for the research. The other authors of this report include Mr. Douglas W. Harwood, Ms. Karin M. Bauer, Mr. David K. Gilmore, Ms. Jessica M. Hutton, and Dr. Darren J. Torbic, MRIGlobal; Mr. John F. Ringert and Mr. Andrew Daleiden, Kittelson and Associates; and Ms. Janet M. Barlow, Accessible Design for the Blind. The work was done under the general supervision of Mr. Douglas W. Harwood, MRIGlobal's Transportation Research Center Director.

Abstract

This report documents and presents the results of research to develop design guidance for channelized right-turn lanes. Observational field studies were conducted at 35 intersection approaches in cities to assess pedestrian crossing behavior, motorist yield behavior, and the interaction between pedestrians and motor vehicles at channelized right-turn lanes. Simulation modeling was performed to quantify the traffic operational benefits of channelized right-turn lanes with various types of traffic control and to compare the delay reduction of channelized right-turn lanes and conventional right-turn lanes. Crash data for nearly 400 intersection approaches in Toronto, Ontario, Canada, including intersection approaches with channelized right-turn lanes, conventional right-turn lanes, and shared through/right-turn lanes, were analyzed to compare the safety performance of the three right-turn treatment types. The research results indicate that channelized right-turn lanes have a definite role in improving operations and safety at intersections. However, to achieve these benefits they should have consistent design and traffic control and should be used at appropriate locations. The research provides design guidance for channelized right-turn lanes that addresses geometric elements such as crosswalk location, special crosswalk signing and marking, island type, radius of turning roadway, angle of intersection with cross street, acceleration and deceleration lanes, and traffic control.

Executive Summary

Many transportation agencies use channelized right-turn lanes to improve operations at intersections, although their impact on safety for motorists, pedestrians, and bicyclists has not been clear in the past. A key concern with channelized right-turn lanes has been the extent of conflicts between vehicles and pedestrians that occur at the point where pedestrians cross the right-turn roadway.

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 impairment may have difficulty detecting approaching traffic because (a) right-turning vehicles are traveling a curved rather than a straight path; (b) there is not a systematic stopping and starting of traffic, as there would be at a conventional signal- or stop-controlled intersection; and (c) the traffic sounds from the major streets may mask the sound of traffic on the right-turn roadway. Despite their potential challenges for pedestrians, channelized right-turn lanes also provide advantages for pedestrians. The provision of a channelized right-turn lane, while making it necessary for pedestrians to cross two roadways, often reduces the pedestrian crossing distance of the major and cross streets. Furthermore, the channelizing island, particularly when bounded by raised curbs, serves as a refuge area for pedestrians, and may improve safety by allowing pedestrians to cross the street in two stages.

The primary traffic operational reasons for providing channelized right-turn lanes 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-turn lanes appear to provide a net reduction in motor vehicle delay at intersections where they are installed, although no existing data and no established methodology have been available to directly compare the operational performance of urban intersections with and without channelized right-turn lanes.

The safety effects of channelized right-turn lanes on motor vehicles, pedestrians, and bicyclists have been largely unknown. It is generally accepted that channelized right-turn lanes improve safety for motor vehicles at intersections where they are used, but there have been only limited quantitative data to demonstrate this. No studies have been found concerning pedestrian safety at channelized right-turn lanes that have used crash data to document the pedestrian safety implications of channelized right-turn lanes. There also appears to be an inherent risk to bicyclists at channelized right-turn lanes 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 on crash history are available to support this presumption. However, a similar conflict between through bicyclists and right-turn vehicles is present at conventional intersections as well.

It is evident that there have been many unanswered questions about channelized right-turn lanes. The research conducted for this report sought to answer many of these questions and to provide a basis for decisions, based on sound research results rather than anecdotal evidence, about where channelized right-turn lanes should and should not be used. The objective of the research was to develop design guidance for channelized right-turn lanes, based on balancing the needs of motor vehicles, pedestrians, and bicycles. Key studies in the research included field

observational studies of vehicle and pedestrian interactions at channelized right-turn lanes, interviews with orientation and mobility (O&M) specialists, traffic operational analyses of channelized right-turn lanes conducted with the VISSIM model, and safety analyses of channelized right-turn lanes.

Observational field studies were conducted at 35 intersection approaches with channelized right-turn lanes in 11 cities to assess pedestrian crossing behavior, motorist yield behavior, and the interaction between pedestrians and motor vehicles at channelized right-turn lanes. A majority of the sites (nearly 70 percent) had marked crosswalks located near the center of the channelized right-turn lane; only about 30 percent of crosswalks were located at the upstream or downstream end of the channelized right-turn lane. Pedestrians did not appear to have any particular difficulty crossing channelized right-turn lanes. Most pedestrians crossed in the crosswalk (75 percent) and, where pedestrian signals were present, most pedestrians crossed during the pedestrian crossing phase (72 percent). The pedestrians who crossed outside the crosswalk generally did so when no vehicular traffic was present and this behavior did not cause any traffic conflicts. Avoidance maneuvers by a pedestrian or motorist appear to be relatively rare, and were observed in less than 1 percent of the pedestrian crossings.

Most motorists yielded to pedestrians once they were in the crosswalk of a channelized right-turn lane, either by stopping or reducing their speed. Fewer motorists in channelized right-turn lanes yielded to pedestrians waiting at the curb to cross, although such failure to yield is typical of most pedestrian crossings and is not unique to channelized right-turn lanes. The yield behavior of motorists was slightly better at sites with special crosswalk treatments (e.g., raised crosswalk, pavement markings, signing).

Interviews with ten orientation and mobility (O&M) specialists were conducted to learn of their experience in teaching pedestrians with vision impairment to traverse intersections with channelized right-turn lanes and to determine their recommendations on how channelized right-turn lanes might be better designed for all pedestrians with disabilities. O&M specialists did not have a definite preference for crosswalk location at channelized right-turn lanes, but recommended that consistency of crosswalk location and traffic control is important to pedestrians with vision impairment. They also had a strong preference for raised islands with “cut-through” pedestrian paths, which provide better guidance and information for pedestrians with vision impairment than painted islands. O&M specialists also indicated that channelized right-turn lanes with acceleration lanes were particularly challenging for pedestrians with vision impairment to cross.

A traffic operational analysis was conducted to evaluate the traffic operational performance of right-turning vehicle movements at signalized intersections for three configurations: a conventional right-turn lane at a signalized intersection, a yield-controlled channelized right-turn lane, and a signalized channelized right-turn lane. A series of microscopic simulation runs (using VISSIM) were conducted to evaluate the traffic operational performance for both vehicles and pedestrians. The simulation studies addressed right-turn vehicle delay, delay due to pedestrian crossings, and the impact of intersection characteristics.

Channelized right-turn lanes with yield control were shown to reduce right-turn delay to vehicles by 25 to 75 percent in comparison to intersection approaches with conventional right-turn lanes. High pedestrian volumes increased right-turn delay by approximately 60 percent on a yield-controlled channelized right-turn lane. The addition of an acceleration lane at the downstream end of a channelized right-turn lane can reduce the right-turn delay by 65 to 85 percent, depending on the conflicting traffic volume on the cross street. Increasing the radius of a channelized right-turn roadway can reduce right-turn delay by approximately 10 to 20 percent for each 8-km/h (5-mi/h) increase in turning speed.

Seven (7) years of motor-vehicle and pedestrian crash and volume data were obtained for 103 four-leg signalized intersections in Toronto, Ontario, Canada. An overall comparison was performed of the safety performance of intersection approaches with channelized right-turn lanes to intersection approaches with other right-turn treatments. Specifically, a cross-sectional analysis was conducted to compare the crash experience among:

- Intersection approaches with channelized right-turn lanes
- Intersection approaches with conventional right-turn lanes
- Intersection approaches with no right-turn treatments (shared through/right-turn lanes)

Intersection approaches with channelized right-turn lanes were shown to have similar motor-vehicle safety performance as approaches with conventional right-turn lanes or shared through/right-turn lanes where the right-turning vehicle departs from the through traffic stream (the upstream end of the channelized right-turn lane). Results of the safety analysis suggest that the three right-turn treatments may differ in motor-vehicle safety performance as the right-turning vehicle merges with the cross street (the downstream end of the channelized right-turn lane), but this was not conclusively established. Intersection approaches with channelized right-turn lanes were shown to have similar pedestrian safety performance as approaches with shared through/right-turn lanes. Intersection approaches with conventional right-turn lanes had substantially more pedestrian crashes (approximately 70 to 80 percent more) than approaches with channelized right-turn lanes or shared/through right-turn lanes.

A recommendation of the research is for highway agencies to develop a consistent practice for crosswalk location. Consistency in crosswalk location is important to pedestrians with vision impairment and would make it easier for O&M specialists to teach pedestrians with vision impairment how to better traverse a channelized right-turn lane. Since current practice shows a clear preference for crosswalk locations near the center of a channelized right-turn lane, design guidance should recommend placing crosswalks near the center of the channelized right-turn lane for channelized right-turn lanes with yield control or no control at the entry to the cross street. Where STOP sign control or traffic signal control is provided at the entry to the cross street, the crosswalk should be placed immediately downstream of the stop bar, where possible. Where the channelized right-turn roadway intersects with the cross street at nearly a right angle, the stop bar and crosswalk can be placed at the downstream end of the channelized right-turn roadway.

Raised islands should be considered because they serve as a refuge area so that pedestrians may cross the street in two stages. Raised islands with "cut-through" paths also provide better guidance for pedestrians with vision impairment than painted islands.

Channelized right-turn lanes with acceleration lanes appear to be difficult for pedestrians with vision impairment to cross. Therefore, the use of acceleration lanes at the downstream end of a channelized right-turn lane should generally be reserved for locations where no pedestrians or very few pedestrians are present. Typically, these would be locations without sidewalks or pedestrian crossings; at such locations, the reduction in vehicle delay resulting from addition of an acceleration lane becomes very desirable.

Channelized right-turn lanes are most appropriate for improving traffic operations at intersections where pedestrian volumes crossing the channelized right-turn lane are expected to be low to moderate (e.g., up to approximately 1,000 pedestrians per day). This recommendation is based on the 85th percentile pedestrian volume—1,000 pedestrians per day—in the Toronto intersection database that was used for the safety evaluation. While channelized right-turn lanes may be suitable for higher pedestrian volumes, the research cannot predict the safety performance of channelized right-turn lanes with pedestrian volumes beyond the range evaluated in the research.

The research results indicate that channelized right-turn lanes have a definite role in improving operations and safety at intersections. However, to achieve these benefits they should have consistent design and traffic control and should be used at appropriate locations. The research provides design guidance for channelized right-turn lanes that addresses geometric elements such as crosswalk location, special crosswalk signing and marking, island type, radius of turning roadway, angle of intersection with cross street, acceleration and deceleration lanes, and traffic control.

Chapter 1.
Introduction

This chapter summarizes the background for the research, the research objectives and scope, and the organization of this report.

1.1 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-turn lanes in all quadrants of the intersection, channelized right-turn lanes may be appropriate in some quadrants, but not in others, depending on intersection geometry and traffic demands.

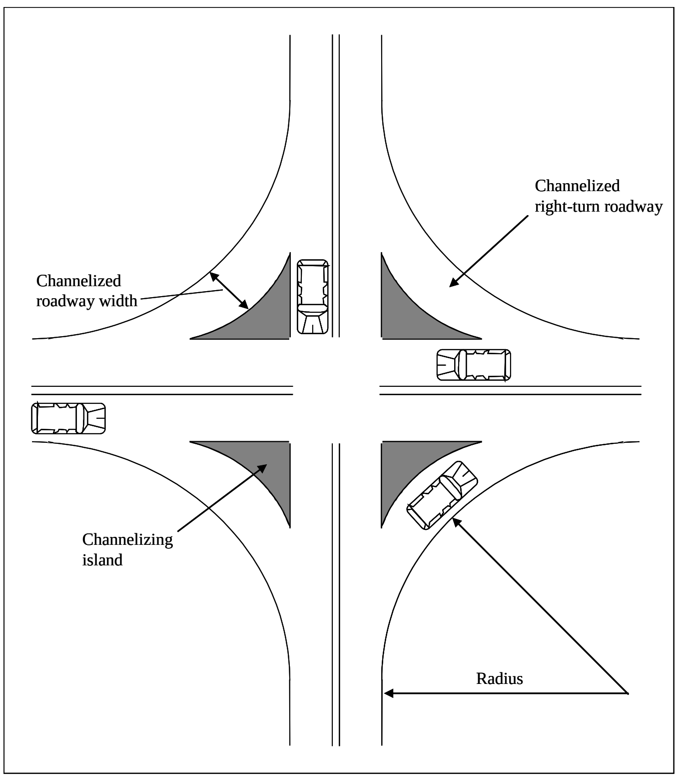


Figure 1. Typical Intersection with Channelized Right-Turn Lanes

The primary reasons for providing a channelized right-turn lane are (*1*):

- 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

Many transportation agencies use channelized right-turn lanes to improve operations at intersections, although their impact on safety for motorists, pedestrians, and bicyclists has not been clear. A key concern with channelized right-turn lanes has been the extent of conflicts between vehicles and pedestrians that occur at the point where pedestrians cross the right-turn roadway. Conflicts with pedestrians may occur 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 impairment may have difficulty detecting approaching traffic because (a) right-turning vehicles are traveling a curved rather than a straight path; (b) there is not a systematic stopping and starting of traffic, as there would be at a conventional signal- or stop-controlled intersection; and (c) the traffic sounds from the major streets may mask the sound of traffic on the right-turn roadway. The Americans with Disabilities Act (ADA) requires that all pedestrian facilities, including sidewalks and crosswalks, be accessible to pedestrians with disabilities. The U.S. Access Board has published draft rights-of-way guidelines requiring pedestrian-activated signals at multi-lane crossings of channelized right-turn lanes with pedestrian signal indications (*2*). Specifically, it states:

> "**R305.7 Channelized Turn Lanes at Intersections.** Where pedestrian crosswalks are provided at multi-lane right or left channelized turn lanes at intersections with pedestrian signal indications, a pedestrian-activated signal complying with R306 shall be provided.
>
> **Advisory R305.7 Channelized Turn Lanes at Intersections.** Accessible pedestrian signal devices installed at splitter and 'pork chop' islands must be carefully located and separated so that signal spillover does not give conflicting information about which crossing has the WALK indication displayed.
>
> Additional guidance on signal types is provided in Advisory R305.6.2."

Despite their potential challenges for pedestrians, channelized right-turn lanes also provide advantages for pedestrians. The provision of a channelized right-turn lane, while making it necessary for pedestrians to cross two roadways, often reduces the pedestrian crossing distance of the major and cross streets. Furthermore, the channelizing island serves as a refuge area for pedestrians, particularly when bounded by raised curbs, and improves safety by allowing pedestrians to cross the street in two stages.

The primary traffic operational reasons for providing channelized right-turn lanes 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-turn lanes appear to provide a net reduction in motor vehicle delay at intersections where they are installed, although no existing data and no established methodology have been available to directly compare the operational performance of urban intersections with and without channelized right-turn lanes. Furthermore, no data are available on the operational effects of installing pedestrian-activated signals along right-turn roadways.

The safety effects of channelized right-turn lanes on motor vehicles, pedestrians, and bicyclists have been largely unknown. It is generally accepted that channelized right-turn lanes improve safety for motor vehicles at intersections where they are used, but there have been only limited quantitative data to demonstrate this. No studies have been found concerning pedestrian safety at channelized right-turn lanes that have used crash data to document the pedestrian safety implications of channelized right-turn lanes. There also appears to be an inherent risk to bicyclists at channelized right-turn lanes 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 on 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.

It is evident that there have been many unanswered questions about channelized right-turn lanes. The research conducted for this report sought to answer many of these questions and to provide a basis for decisions, based on sound research results rather than anecdotal evidence, about where channelized right-turn lanes should and should not be used.

1.2 Research Objectives and Scope

The objective of the research was to develop design guidance for channelized right-turn lanes, based on balancing the needs of passenger cars, trucks, buses, pedestrians (including pedestrians with disabilities), and bicycles. For the purposes of this project, a channelized right-turn lane is characterized by separation from the through and left-turn lanes on the approach by an island and separate traffic control from the primary intersection. The channelized right-turn lane may have a deceleration lane entering it and it may have a merge or an auxiliary lane at the exiting end. The results of the research include general design guidance on channelized right-turn lanes for highway engineers and specific recommended language for consideration in future updates to key AASHTO and FHWA documents.

1.3 Organization of This Report

This report presents the results of the research on channelized right-turn lanes. The remainder of this report is organized as follows. Chapter 2 presents an overview of the state of knowledge and practice with channelized right-turn lanes, based on a review of literature and a survey of highway agency experience. Chapter 3 discusses pedestrian behavior at channelized right-turn lanes based on observational field studies and interviews with orientation and mobility specialists. Chapter 4 presents the results of a traffic operational analysis of channelized right-turn lanes. Chapter 5 presents the results of a safety analysis of channelized right-turn lanes. Chapter 6 presents the interpretation of the research results. Chapter 7 presents the conclusions and recommendations of the research. Chapter 8 presents a list of references cited in this report. Appendix A includes a design guide for channelized right-turn lanes. Appendix B presents suggested text concerning channelized right-turn lanes for consideration by AASHTO for potential inclusion in future editions of the *Green Book*.

Chapter 2.
State of Knowledge and Practice with Channelized Right-Turn Lanes

This chapter presents the results of a review of completed and ongoing research related to the design and safety of channelized right-turn lanes, and summarizes the results of a survey of highway agency experience with channelized right-turn lanes.

2.1 Literature Review

A literature review was conducted to update the information presented in a recent synthesis on channelized right turns (*3*) that was prepared in NCHRP Project 3-72, *Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas*. This section summarizes current knowledge concerning the traffic safety performance of channelized right turns and presents information obtained from the literature review of both NCHRP Project 3-72 and the current research. Safety for motor vehicles, pedestrians, and bicycles are addressed separately.

2.1.1 Motor Vehicle Safety at Channelized Right-Turn Lanes

It is generally accepted that channelized right turns improve safety for motor vehicles at intersections where they are used, but there has been 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 1 summarizes the number of right-turn crashes for each treatment. The analysis was based strictly upon crash frequencies over a 2-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 1. 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
Number of sites evaluated	29	8	5	7	8
Number of right turn crashes for 2-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
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

The Texas Department of Transportation sponsored a study (*5*) similar to that performed by Dixon (*4*). In the Texas study, crash data for six intersections were reviewed. A total of 30 approaches with one of the following treatments were evaluated:

- Right-turn lane with lane lines
- Right-turn lane with raised island
- Shared through-right lane
- Shared through right lane with raised island

Table 2 summarizes the number of right-turn crashes for each treatment over a 3-year period. The values do not include consideration of right-turn volume; however, they can provide an appreciation of the variability in the number of right-turn crashes among the different treatments.

Table 2. Annual Right-Turn Crashes by Type of Right-Turn Treatment (*5*)

Intersection	Total	Treatment: RTL w/island	RTL w/striping	Shared lane	Shared lane w/island
Number of approaches	30	14	6	8	2
Number of crashes	16	9	2	1	4
TxDOT project—Average number of right -turn crashes per site per year	0.18	0.21	0.11	0.04	0.67
Dixon project—average number of right-turn crashes per site per year	N/A	1.57	0.81	0.31	0.63

RTL = right-turn lane; SL = shared through-right lane.

The majority of the crashes (10 out of 16) were rear-end crashes. Of the 10 rear-end crashes, 5 crashes occurred in a right-turn lane with a raised island. As shown in Table 2, the shared-lane configuration experienced the lowest average number of right-turn crashes per site per year. The right-turn lane separated by a raised island showed the highest number of crashes in Dixon's study and the second highest number of crashes in the TxDOT study.

Staplin et al. (*6*) 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 (*7*) 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. (*8*) 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. (*8*) 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 5-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.

In a 2006 study by Abdel-Aty and Nawathe (*9*), artificial neural networks were used to analyze the safety of signalized intersections. Geometry, traffic, and crash data were obtained for 1,562 signalized intersections from six counties in Florida. Neural network trees were used to determine the relationship between intersection geometry/configuration and the frequency of specific types of crashes. The study found that:

- The presence of channelized right-turn lanes on the major road was shown to have no significant effect on total crashes, but was linked to an increase in turning and sideswipe crashes.
- On the minor road, the presence of channelized right-turn lanes was associated with a decrease in total crashes and an increase in rear-end crashes.

2.1.2 Pedestrian Safety at Channelized Right-Turn Lanes

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 (*10*). 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 (*11*, *12*). The North Carolina system includes 5 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 (*13*) show that 19 percent of vehicle-pedestrian crashes occurring at intersections arose from drivers making right turns.

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. (*14*) 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.

Geruschat and Hassan (*15*) evaluated drivers' behavior in yielding the right-of-way to sighted and blind pedestrians who stood at three different positions relative to the curb at the crosswalk at entry and exit lanes at two different roundabouts. The researchers found that a driver's willingness to yield to a pedestrian was related to the speed of the vehicle. Specifically, at low speeds [less than 24 km/h (15 mi/h)], drivers yielded approximately 75 percent of the time, whereas at higher speeds [greater than 32 km/h (20 mi/h)], they typically yielded less than 50 percent of the time.

Safety for Pedestrians with Special Needs

Other crash-based analyses have focused on pedestrians with special needs, 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 (*16*). 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.

Schroeder et al. (*17*) conducted a paired comparison study of blind and sighted pedestrians at three channelized right-turn locations. At each location, pedestrians were observed as they assessed gaps in traffic and identified opportunities to cross the channelized right-turn roadway. A key issue in the study was whether the geometry of channelized right-turn lanes and/or the lack of signal control at channelized right-turn roadways negatively affect the delay and safety for blind pedestrians. Blind pedestrians rely on auditory cues when crossing the roadway because they cannot use visual information to identify approaching vehicles and assess appropriate gaps in traffic. However, at channelized right-turn roadways, blind pedestrians have to judge traffic moving in a circular path while dealing with a significant amount of background noise from traffic at the intersection. The objectives of the study were to:

- Identify difficulties experienced by blind pedestrians in crossing a channelized right-turn lane safely.
- Test the effect of crosswalk location, geometry of the channelized right-turn lane, and traffic volumes on pedestrian delay and risk performance measures.

Study participants consisted of nine blind and nine sighted pedestrians, who were tested in pairs (one blind and one sighted). The pedestrians were asked to stand by the roadside as though they were going to cross and indicate when they felt it was safe to cross. No actual crossings were performed in the study. The blind pedestrians signaled when they would cross by pushing a button and holding it down as long as they felt it was safe to cross. The participants released the button when they no longer felt it was safe to cross. The sighted pedestrians gave similar indications by raising and lowering a white pocket folder they held in their hand.

Key findings in the research were:

- On average, blind pedestrians require more time to make a crossing decision. The greater time consists of longer lead and lag times.
- Blind pedestrians make a greater percentage of risky "go" decisions and a greater percentage of unnecessary "no go" decisions than sighted pedestrians.
- The percentage of risky "go" decisions tends to increase with higher conflicting vehicle volumes in the turn lane, while the percentage of unnecessary "no go" decisions tends to decrease at high volumes.
- Background traffic volumes had similar effects for sighted pedestrians. This may suggest that the "noise" of background traffic, which complicated the decision process for blind pedestrians, may be partially offset by the uncertainty of sighted pedestrians in knowing whether vehicles upstream of the turn lane were entering the channelized right-turn lane or continuing straight through the intersection. The effect of background volume on blind pedestrian performance was not significant.
- The comparison of crossing performance at two crosswalk locations (in the center vs. downstream of the channelized right-turn lane) showed no significant effect for either group of pedestrians. The center crossing location appeared to result in slightly better performance in terms of reducing risky and unnecessary decisions, but additional data are necessary to show significance.

Pedestrian Safety at Roundabouts

The geometry of roundabouts is similar to channelized right-turn lanes in some respects, and roundabouts and channelized right-turn lanes pose similar challenges to pedestrians with vision impairment attempting to cross the road. In both situations, the pedestrian with vision impairment has to judge traffic moving on a circular path and the vehicle movement is not controlled by signals. In both cases, traffic may be free-flowing or may yield to other vehicles (e.g., at the downstream end of the channelized right-turn roadway or roundabout approach). The pedestrian with vision impairment is faced with the task of identifying gaps in traffic, distinguishing between sounds from traffic in the turn lane and background traffic noise at the intersection, and judging yield behavior of drivers. Researchers from Western Michigan University and Vanderbilt University recently conducted a series of studies of blind pedestrians crossing at roundabouts (*18, 19*).

One study evaluated the crossing behavior of blind and sighted pedestrians at three roundabouts in the Baltimore, Maryland, metropolitan area (*18*). The research evaluated how well each pedestrian group judged whether gaps in traffic were long enough to safely cross to the splitter island. Using six blind and six sighted participants that each had experience maneuvering urban environments and roundabouts, the study found that the blind pedestrians were nearly 2.5 times less likely to make correct judgments than sighted pedestrians, took longer to detect crossable gaps, and were more likely to miss crossable gaps altogether. Results were found to be most significant at high-volume intersections. A follow-up study was conducted at three different roundabouts to determine if the presence of visible indicators of a blind pedestrian (e.g., guide dog or long cane) would produce better yielding patterns from drivers. At each location, pedestrians holding long canes elicited more yielding maneuvers. Also, drivers were more likely to yield at the entry of a roundabout than at the exit.

Another study evaluated pedestrian crossings at a double-lane urban roundabout in Nashville, Tennessee (*19*). Participants included six blind and six sighted pedestrians. Each pedestrian participated in two sessions; each session consisted of six trials. On three trials, pedestrians crossed the roadway independently, followed by a certified orientation and mobility (O&M) specialist. On the other three trials, they used a hand signal to indicate when they would have started crossing, but did not actually cross the roadway. The research found that:

- Blind pedestrians waited three times longer to cross than sighted pedestrians.
- Nearly 6 percent of the crossing attempts by blind pedestrians were judged dangerous enough to require intervention.
- In high-volume conditions, blind pedestrians waited almost twice as long to make a crossing than in low-volume conditions; traffic volumes had much less of an effect on the wait time of sighted pedestrians.
- Sighted pedestrians made the crossing 41 percent of the time without waiting for any approaching vehicles to pass the location. In contrast, only 15 percent of crossings by blind pedestrians were made before a vehicle passed; with most participants waiting for a period of time that allowed five or six vehicles to pass before crossing.
- Drivers yielded frequently on the entry lanes but not the exit lanes.
- Sighted pedestrians were much more inclined to accept a driver's yield than a blind pedestrian.

In post-session interviews, blind participants indicated that they would likely take measures to avoid crossing the roundabout test site on a daily basis due to the significant number of self-initiated and experimenter-initiated interventions from potential vehicle-pedestrian conflicts. While these studies focused on roundabouts, the free-flow conditions of vehicles entering a roundabout are very similar to those of a channelized right-turn lane and, therefore, the findings may potentially be applicable to channelized right-turn lanes.

In a recent study, Inman et al. (*20*) tested the ability of an audible surface treatment (similar to a rumble strip) to improve pedestrian safety at crosswalks upstream of roundabouts. Using a controlled environment, the research team documented the reactions of seven pedestrians with vision impairment to vehicles approaching an intersection with and without the proposed treatment. In two lanes of traffic, test vehicles approached an intersection where pedestrians were waiting for audible cues to signal their approach and yield. In order to simulate a real-world situation of pedestrians encountering an innovative treatment, study participants were not provided any specific information on the treatment prior to the study. The treatment layout consisted of four sound strips upstream of the crosswalk that would be activated by all vehicles and then two more strips at the crosswalk that would only be traversed by non-yielding vehicles. Based on hand gestures from the pedestrians, the research team documented the number of times each pedestrian correctly detected a yielded vehicle, the number of false detections, and the number of missed vehicles.

Results of the study found that, after the surface treatment was added, detection accuracy improved by an average of approximately 58 percent. There were also a substantial number of false detections, which would have resulted in pedestrians crossing in an environment that they believed was protected by stopped vehicles but that would have, in fact, been vulnerable to approaching vehicles. The authors suggest, however, that the treatment may be more effective in single-lane approach situations where one lane of traffic would not create the false security for both lanes.

Pedestrian Research in NCHRP Project 3-78A

The effects of channelized right-turn lanes on pedestrians with vision impairment were studied as part of NCHRP Project 3-78A, *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities* (*21*). The objectives of the research were to assess pedestrians with vision impairment crossing a channelized right-turn lane and evaluate treatment installations to assist those pedestrians in crossing.

The study site for NCHRP Project 3-78A was located in Charlotte, North Carolina, and consisted of channelized right-turn lanes on all four intersection approaches. Data were collected at two of the four turn lanes, as indicated in Figure 2. Each turn lane has a deceleration lane on the approach, but does not have an acceleration lane for vehicles to merge onto the cross street. A pedestrian crosswalk is located at the center of each island, perpendicular to the sidewalk.

Safety improvement treatments were installed at the channelized right-turn lanes during Summer 2008:

- Sound strips—devices intended to provide audible cues to pedestrians with vision impairment about approaching vehicles
- Sound strips in combination with pedestrian-actuated beacons

The sound strips, spaced approximately 9-m (30-ft) apart, were installed on each of the deceleration lanes. The sound strips were a modification of a treatment used in recent FHWA research at roundabouts (*20*), with minor modifications in treatment placement. The pedestrian-actuated beacon was installed, in conjunction with an audible indication that the beacon was flashing, at one of the crosswalks. Lane delineators were also installed as part of the treatment to prevent last-minute entry by vehicles into the deceleration lane.

Pedestrians with vision impairment participated in both the pre-treatment and post-treatment phases of the study. During the study, participants were asked to navigate across the channelized right-turn lane to the best of their ability using the existing cues provided at the crosswalk. In the event that a participant moved into an unsafe situation, research team members were available to intervene.

During the pre-treatment data collection, observations of the research team included:

- The channelized right-turn lane study site experienced high traffic volumes.
- Pedestrian delays were relatively high.
- Gap acceptance and yield utilization were relatively low.
- Experimenter interventions were in the range of 8 to 10 percent, with several other "self-interventions" by the participants.

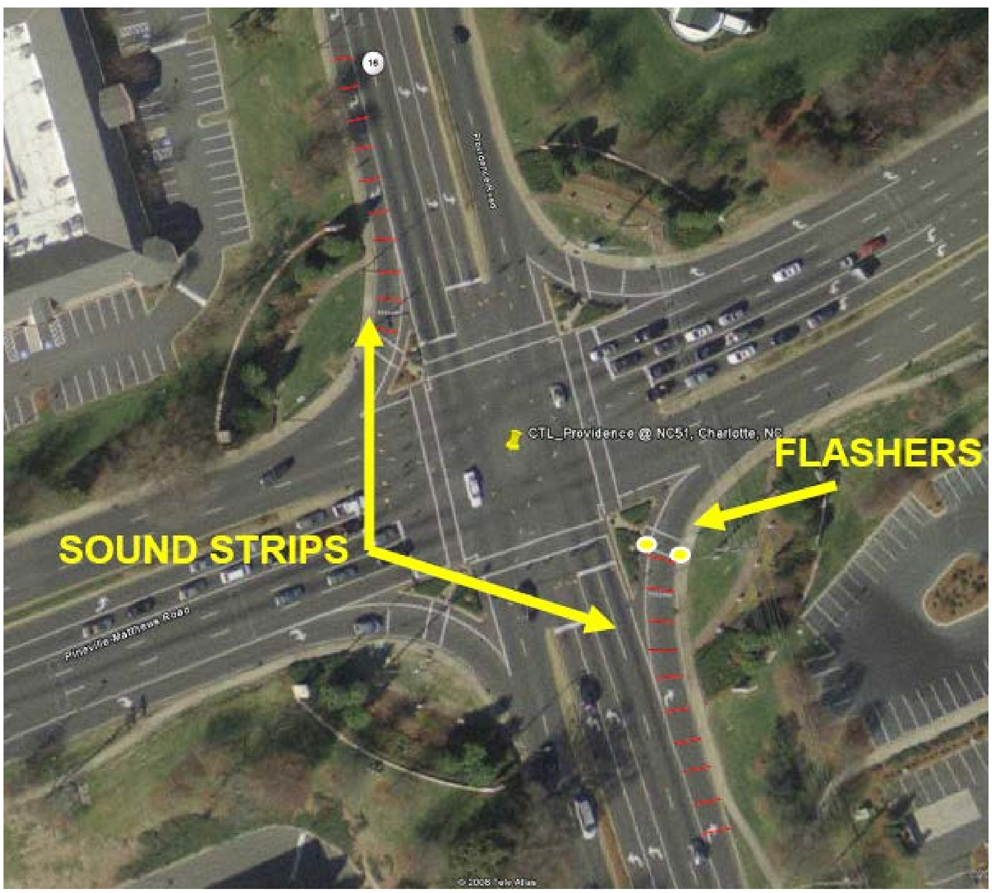


Figure 2. Channelized Right-Turn Lane Study Location for NCHRP Project 3-78A (*21*)

Post-treatment data collection was conducted to determine if sound strips, either alone or in combination with pedestrian-actuated beacons, have any effect on yield behavior of drivers or on risky crossings (i.e., interventions) by pedestrians with vision impairment. Analysis of post-treatment data suggested the following:

- Yield rates of drivers increased slightly (from 15.2 to 22.0 percent) where sound strips were installed in combination with flashing beacons. There was no change where sound strips were installed as the only treatment.
- Installation of treatments reduced, but did not eliminate, interventions.
- Several participants noted that they could hear better to make crossing decisions from the curb than from the island. They stated that the sound of traffic behind them, when waiting on the island, made the crossing decision more difficult.

2.1.3 Bicycle Safety at Channelized Right-Turn Lanes

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, a similar 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.

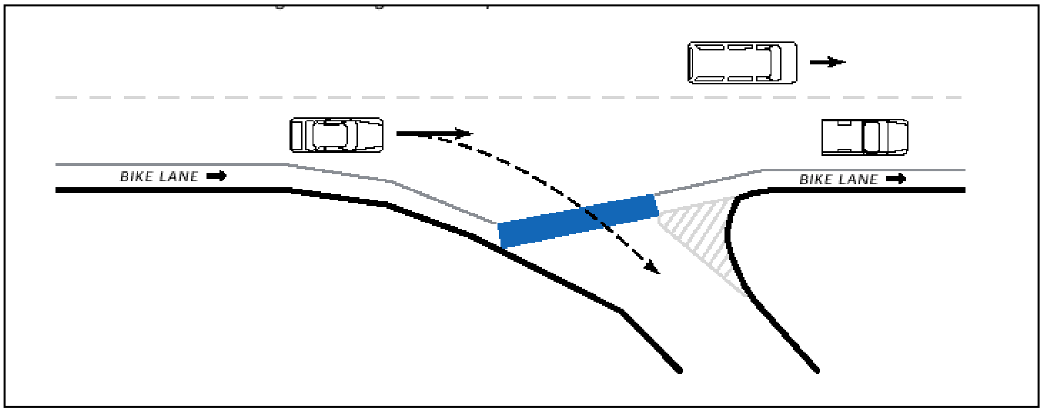
In 2002, 662 bicyclists were killed and an additional 48,000 were injured in traffic accidents in the U.S. (*22*). Thus, bicyclists accounted for about 2 percent of all traffic fatalities. Bicyclists accounted for approximately 12 percent of all nonmotorized traffic fatalities, while pedestrians accounted 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 (*13*). 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 (*23*), 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.

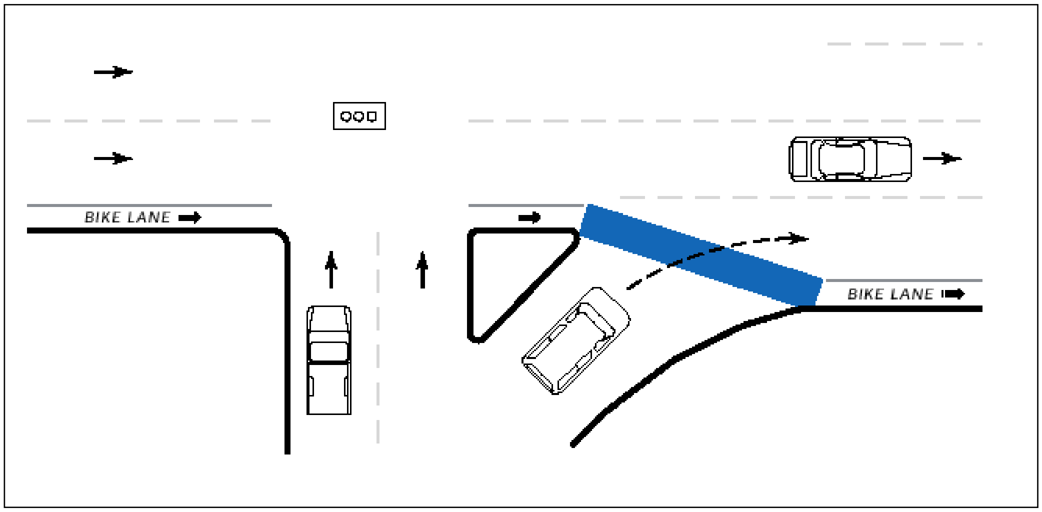
Clark and Tracy (*24*) reported that 13 percent of all bicycle/motor vehicle crashes resulted when motorists were making a right-turn movement, and a majority of these crashes involved a straight-through bicyclist being struck by a right-turning motor vehicle. Clark and Tracy indicated that many bicyclists 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 (*25*) and AASHTO bicycle guide (*25*) 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 (*27, 28*). 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 (*27*). Figure 3 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 3. Blue Pavement Marking Treatment at Channelized Right-turn Lane (*27*)

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 4). 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 (*28*). 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 5). The traditional lane location used for comparison was a 3.6-m (12-ft) right-turn lane and a 1.5-m (5-ft) bike pocket (see Figure 6). 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).
- 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.

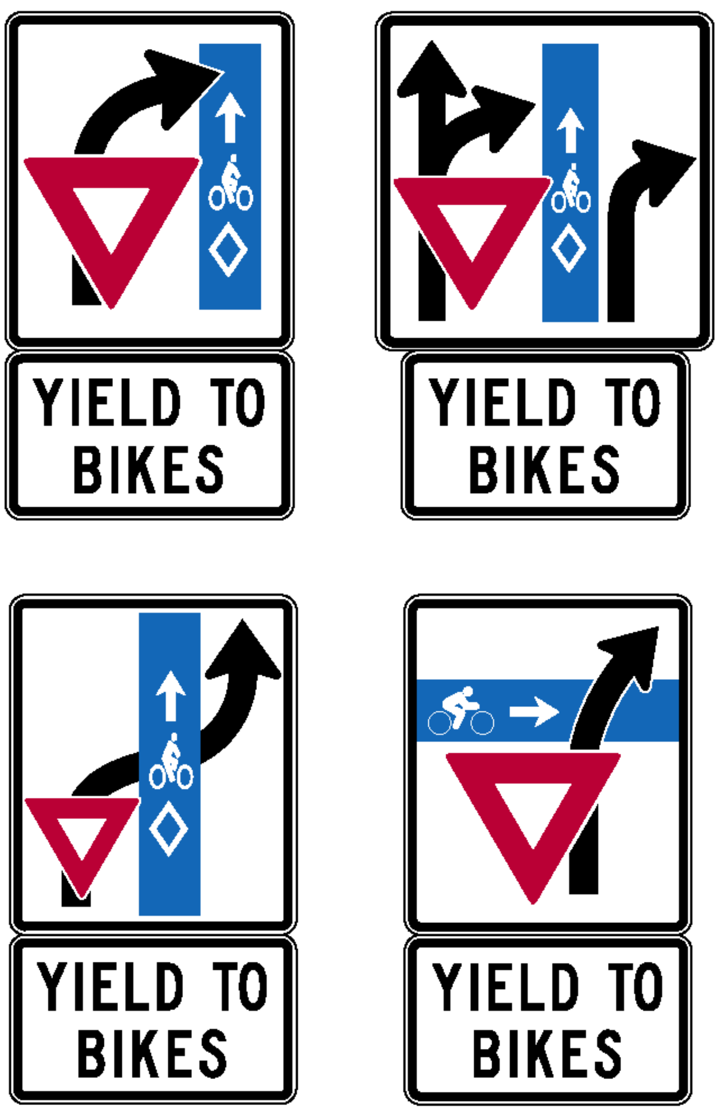


Figure 4. Signs Used in Oregon Blue Bike Lane Program (*27*)

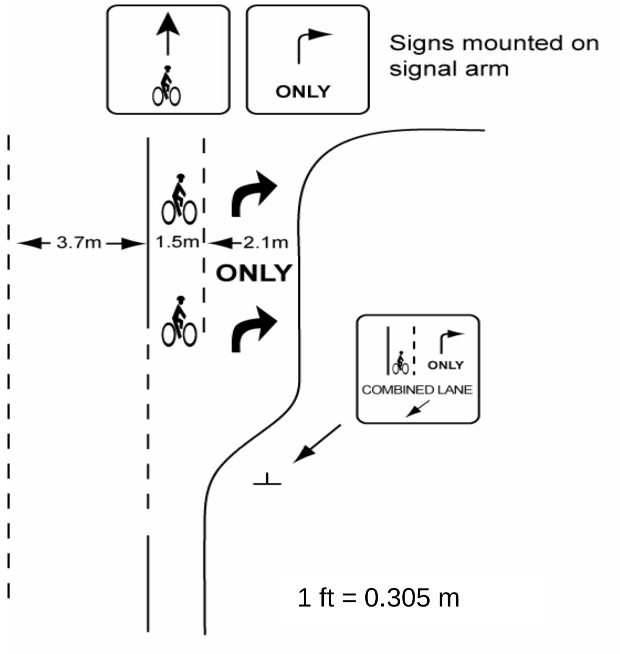


Figure 5. Combined Bicycle Lane/Right-Turn Lane (*27*)

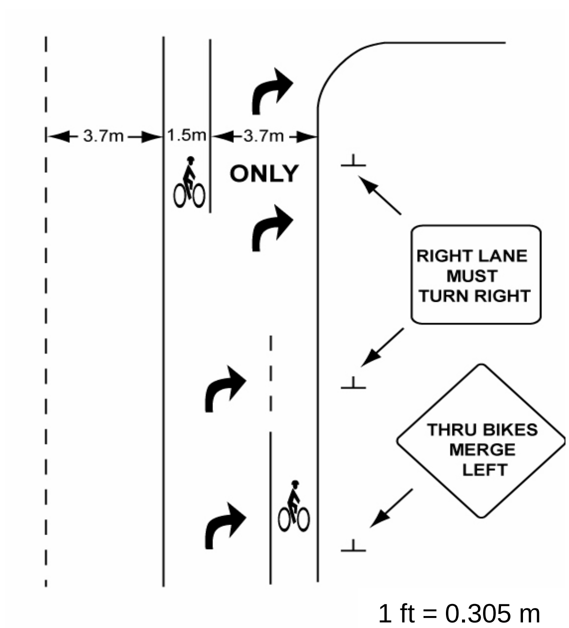


Figure 6. Traditional Bike Lane/Right-Turn Lane (*28*)

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 (*29*). 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 (*24*). 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 (*24*):

- 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.

2.2 Highway Agency Experience

A formal highway agency survey on channelized right-turn lanes was conducted as part of NCHRP Project 3-72, the results of which were reflected in the *Synthesis on Channelized Right Turns* (*3*) that was also developed as part of that research. Therefore, no formal survey was needed as part of the current research. However, because the survey was conducted in 2003, there was a clear need to update the results. To assure that any new research, design practice, or agency experiences were identified, the research team asked the AASHTO Standing Committee on Highway Traffic Safety (SCOHTS) to send an email through their list-serve to all 50 state highway agencies asking for new or updated information on channelized right-turn lanes. The following seven states responded to the request for information: Idaho, New York, Rhode Island, Tennessee, Texas, Virginia, and West Virginia. This section presents key findings from both research projects—NCHRP Project 3-72 and the current research—related to highway agency practice with channelized right-turn lanes and focuses on geometric design issues, traffic control, and pedestrian considerations at channelized right-turn lanes.

2.2.1 Geometric Design Issues at Channelized Right-Turn Lanes

The highway agency survey (*3*) conducted in NCHRP Project 3-72 indicated that 87 percent of state and local highway agencies use channelized right turns; all seven highway agencies that provided additional information in the current research indicated that they utilize channelized right-turn lanes. Even casual observation suggests that channelized right-turn lanes are a relatively common geometric feature at intersections on urban and suburban arterials.

Deceleration Lanes

Right-turn deceleration lanes serve one or more of the following functions (30):

- A means for 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 for 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 lane provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway. In response to the survey (*3*) conducted in NCHRP Project 3-72, 89 percent of the state highway agencies and 70 percent of the local agencies that use channelized right-turn lanes indicated that they have used deceleration lanes in advance of those channelized right-turn lanes 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. In response to the survey (*3*) conducted in NCHRP Project 3-72, 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. In the recent informal survey, one agency responded that acceleration lanes are generally used when the angle between turning roadway and intersecting roadway is less than 60 degrees.

Crosswalks

Crosswalks that are parallel to and constitute an extension of the sidewalk may provide the best alignment information for pedestrians with vision impairment because they allow the pedestrian to continue along a straight travel path. Also, the sounds of traffic moving 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 7, 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 with vision impairment, 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 (*3*). 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. The recent informal survey produced similar results, where six out of seven highway agencies indicated that they place the crosswalk near the middle of the right-turn roadway.

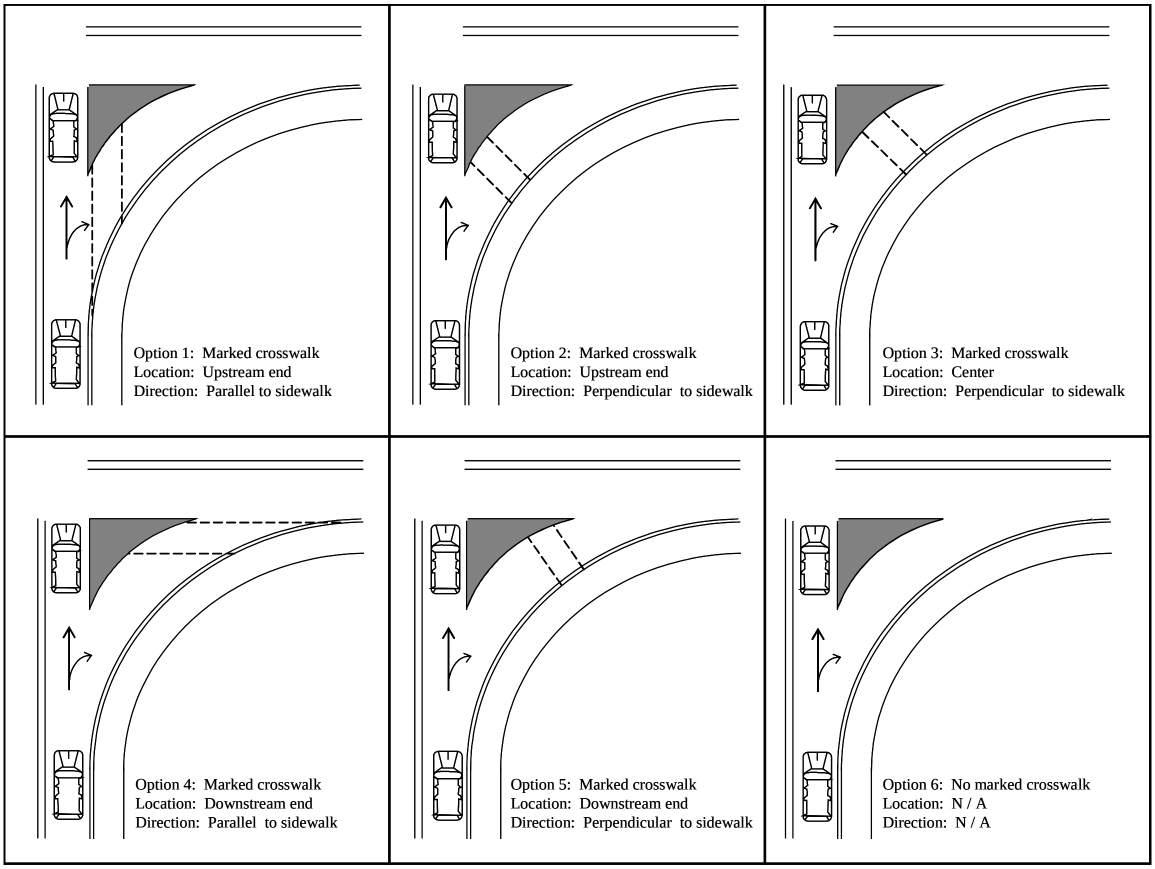


Figure 7. Alternative Crosswalk Locations

Table 3. Locations Where Highway Agencies Place Pedestrian Crosswalks at Channelized Right-Turn Roadways (*3*)

Location	Number (percentage) of agencies		
	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.

The Wisconsin DOT (WisDOT) has been implementing a newer design for channelized right-turn lanes that incorporates a different shape for the island—an isosceles triangle rather than an equilateral triangle configuration—as illustrated in Figure 8 (*31*).

Figure 8. Isosceles-Triangle Island Shape Used by WisDOT

Angle of Intersection With Cross Street

The survey results indicate that the alignment of a channelized right-turn lane and the angle between the channelized right-turn roadway and the cross street can be designed in two different ways:

- A flat-angle entry to the cross street like the channelized right-turn lanes illustrated in Figures 1 through 3 and Figure 7
- A nearly-right-angle entry to the cross street like that partially visible on the right side of the photograph in Figure 8

These two designs are compared in Figure 9.

The two designs shown in Figure 9 differ in the shape of the island that creates the channelized right-turn lane. The flat-angle entry design has an island that is typically shaped like an equilateral triangle (often with one curved side), while the nearly-right-angle design is typically shaped like an isosceles triangle. The flat-angle entry design is appropriate for use in channelized right-turn lanes with either yield control or no control for vehicles at the entry to the cross street. The nearly-right-angle entry design can be used with STOP sign control or traffic signal control for vehicles at the entry to the cross street; yield control can also be used with this design where the angle of entry and sight distance along the cross street are appropriate.

2.2.2 Traffic Control at Channelized Right-Turn Lanes

The survey results (*3*) from NCHRP Project 3-72 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*

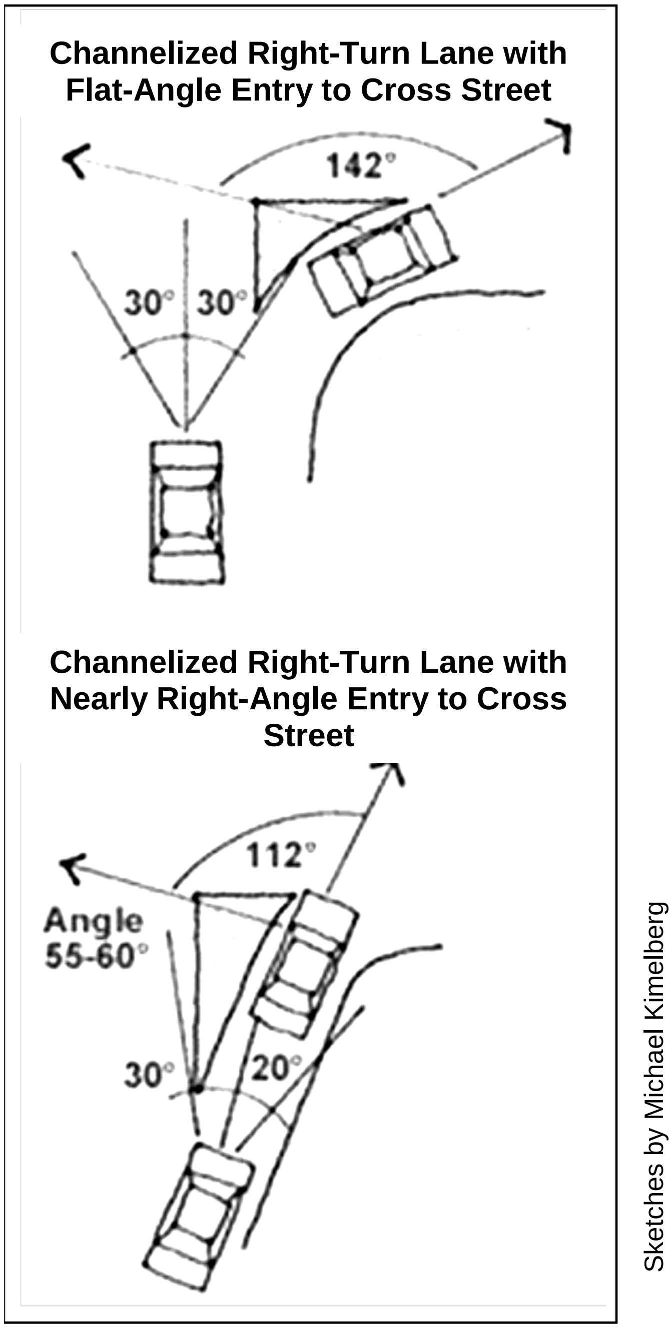


Figure 9. Typical Channelized Right-Turn Lanes with Differing Entry Angles to the Cross Street [Adapted From (*14*)]

Uniform Traffic Control Devices (MUTCD) (*24*) 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 informal survey conducted in the current research had similar results; five out of seven agencies did *not* have a formal policy concerning traffic control at channelized right-turn lanes. One agency stated that yield signs are the most commonly used traffic control. Another agency has a policy in which if the end of the channelized right-turn lane is more than 9 m (30 ft) from the primary intersection control, it operates under its own signal, stop, or yield sign.

Highway agencies were asked to identify innovative traffic control devices they have implemented at channelized right-turn roadways. Table 4 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. In the recent informal survey, one agency reported using the fluorescent yellow-green signs; another has implemented flashing warning signs for motorists to warn of a pedestrian crossing. One agency uses a sign that states “TURNING TRAFFIC MUST YIELD TO PEDESTRIANS;” another agency uses imprint to help create high-visibility crosswalks.

Table 4. Innovative Traffic Control Devices at Channelized Right-Turn Roadways (*3*)

	Number (percentage) of agencies					
Traffic control device	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.

In the survey (*3*) conducted in NCHRP Project 3-72, 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.

In the recent informal survey, four out of the seven agencies indicated that they have installed pedestrian-actuated signals at select locations.

Highway agencies were also asked whether they have developed or used any strategies specifically intended to assist pedestrians with vision impairment 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 impairment 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-turn lanes is considering their use. One highway agency reportedly installed audible signals at one intersection, but was requested by an organization representing pedestrians with vision impairment to deactivate the sound. In the recent informal survey, one agency reported using different curb configurations to facilitate crossing the right-turn lane. One agency uses a short crossing distance, perpendicular to the roadway, with detectable warning devices and way-finding cues within the turning roadway island. In the recent informal survey, four out of seven agencies indicated that they do not implement any strategies specifically aimed at pedestrians with vision impairment. One agency uses signs stating "TURNING TRAFFIC MUST YIELD TO PEDESTRIANS." One agency uses different curb configurations to facilitate crossing the right-turn lane. One agency uses a short crossing distance, perpendicular to turning roadway, with detectable warning devices and way-finding cues within the turning roadway island.

Table 5. General Strategies Used by Highway Agencies to Assist Pedestrians with Vision Impairment (*3*)

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

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

2.2.3 Pedestrian Considerations at Channelized Right-Turn Lanes

In the survey conducted in NCHRP Project 3-72, 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. On the other hand, in the informal survey of highway agencies, six of the seven agencies stated that they use design vehicles rather than pedestrian considerations to determine the radius of a channelized right-turn lane. One agency stated that pedestrians have been used in some cases as a factor in determining the radius. 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 (*3*)

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)
- Pedestrians with vision impairment 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. In the informal survey, five out of the seven agencies reported no safety issues. Two agencies reported occasional pedestrian safety concerns.

Chapter 3.
Pedestrian Behavior at Channelized Right-Turn Lanes

This chapter presents the results from studies of pedestrian behavior at channelized right-turn lanes conducted as part of the research, including observational field studies of pedestrian crossing behavior and interviews with orientation and mobility (O&M) specialists who teach pedestrians with vision impairment to traverse intersections with channelized right-turn lanes.

3.1 Observational Field Studies

One of the concerns with channelized right-turn lanes has been the interaction between vehicles and pedestrians at the point where pedestrians cross the right-turn roadway. Figure 10 illustrates a typical channelized right-turn lane with vehicles yielding to a pedestrian. While the yield behavior of drivers at channelized right-turn lanes has not been well documented, channelized right-turn lanes present a scenario where a driver's attention could be focused on the cross-street traffic or the placement of pedestrian crosswalks or signals may violate driver expectancy.

Figure 10. Channelized Right-Turn Lane with Vehicle Yielding to Pedestrian

Another concern with channelized right-turn lanes has been the potential challenge for pedestrians with vision impairment. For pedestrians with *no* vision impairment, watching for a gap in traffic and then physically negotiating the crossing of a channelized right-turn roadway may be a relatively easy task because such roadways are not very wide and because traffic is approaching from a single direction. However, pedestrians with vision impairment may have difficulty detecting approaching traffic because (a) right-turning vehicles are traveling a curved rather than a straight path; (b) there is not a systematic stopping and starting of traffic, as there would be at a conventional signal- or stop-controlled intersection; and (c) the traffic sounds from the major streets may mask the sound of traffic on the right-turn roadway.

To address the concerns of interactions between pedestrians and vehicles at channelized right-turn lanes, observational field studies were conducted at intersection approaches with channelized right-turn lanes to document pedestrian and vehicle behaviors and interactions. To address the concern of pedestrians with vision impairment at channelized right-turn lanes, interviews with orientation and mobility specialists were conducted. Each is described below.

Observational field studies were conducted at 35 intersection approaches with channelized right-turn lanes. The primary objectives of the observational studies were to:

- Observe the interaction of motor vehicles, pedestrians, and bicycles at various channelized right-turn lane configurations.
- Document the frequency of given types of interactions considering geometric design, traffic control, and traffic volume data.
- Observe how well pedestrians "obey" crosswalks and traffic control at different crosswalk locations (i.e., upstream end, center, and downstream end) and directions (i.e., perpendicular or parallel to the sidewalk) within a channelized right-turn roadway.
- Observe how well motorists yield to pedestrians at different crosswalk locations (i.e., upstream end, center, and downstream end) and directions (i.e., perpendicular or parallel to the sidewalk) within a channelized right-turn roadway.

3.1.1 Site Selection

Over 100 candidate study sites were identified and reviewed for geometric, pedestrian, and traffic characteristics in Arizona, California, Colorado, Florida, Idaho, Illinois, Maryland, Missouri, Oregon, and Washington. A key priority was the selection of intersections where pedestrian activity was estimated to be moderate to high. Figure 11 illustrates the geographic locations (city and state) of the 35 sites that were ultimately selected for conducting observational field studies.

Intersections were selected to best represent an accurate cross section of channelized right-turn lanes based on differing geometric design and traffic control characteristics that make up such facilities, such as island type and size, presence of deceleration or acceleration lane, crosswalk location, and traffic control on the channelized right-turn roadway.

3.1.2 Data Collection Methodology

At each site, video cameras were used to observe motor vehicle, pedestrian, and bicycle interactions, document pedestrian crossing behavior and motor vehicle yielding behavior, and record motor vehicle and pedestrian volumes at each channelized right-turn lane site. Video cameras were mounted unobtrusively on utility poles or traffic signal poles at the study intersection approaches. Three video cameras were typically used at each site to cover the entire channelized right-turn lane. The data collection methodology and general camera setup was similar at all sites, although the specific camera locations were determined on a site-by-site basis to optimize the viewing angle for each camera. Figures 12 and 13 illustrate the video camera setup for two typical sites, one in Baltimore, Maryland, and one in San Francisco, California, respectively.

Figure 11. Observational Field Study Locations

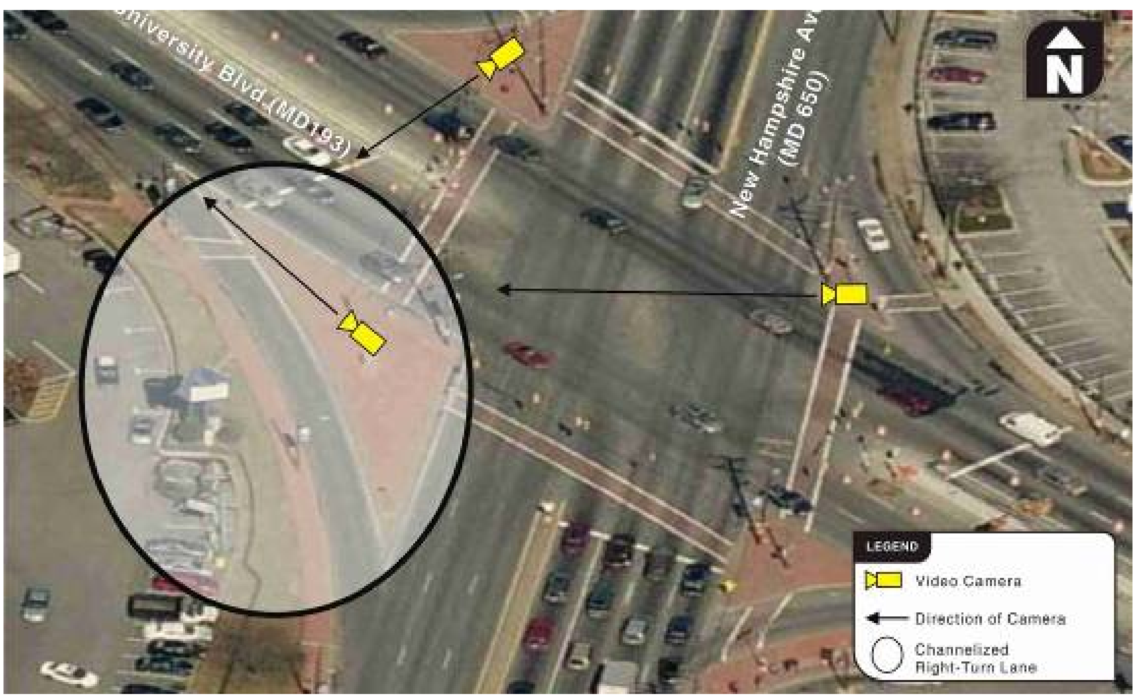


Figure 12. Data Collection Field Setup for an Intersection in Baltimore, Maryland

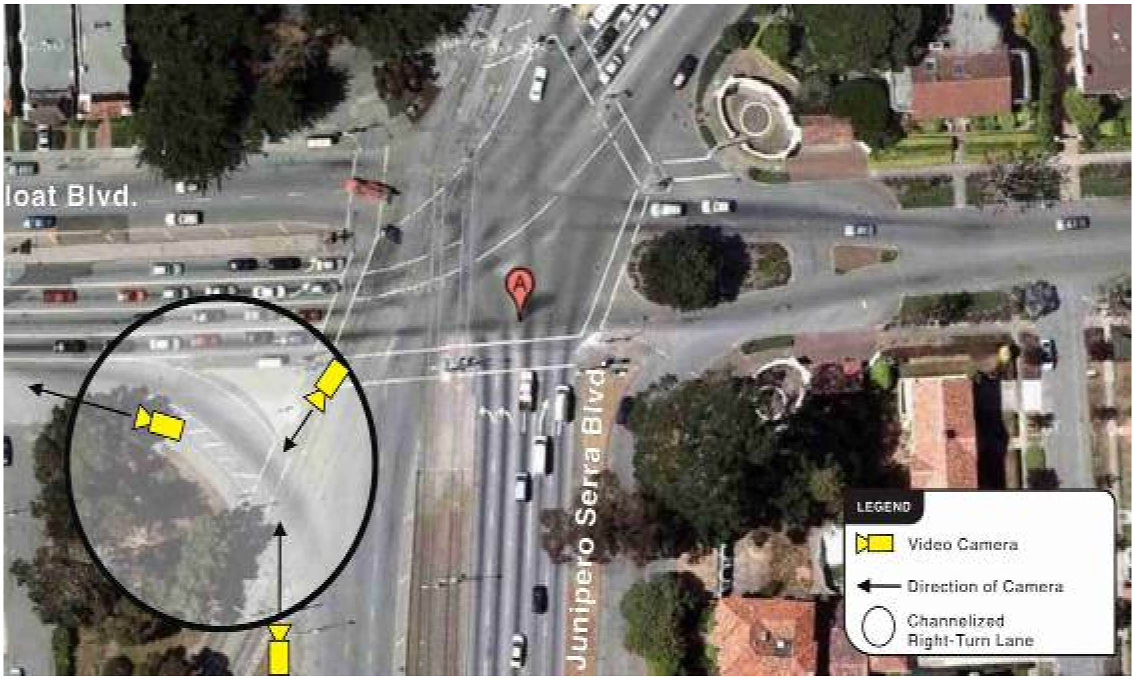


Figure 13. Data Collection Field Setup for an Intersection in San Francisco, California

A minimum of 8 hours of video was recorded at each site. The following information was documented for each channelized right-turn lane:

- Number of pedestrians crossing the channelized right-turn lane
- Number of vehicles traversing the channelized right-turn lane
- Geometric design and traffic control information
- Area type (residential/commercial/industrial)
- Posted speed limit on major road and minor road
- Intersection traffic control (signalized/unsignalized)
- Traffic control on channelized right-turn lane (STOP/yield/signal/none)
- Type (raised or painted) and size (small/medium/large) of channelizing island
- Width of channelized right-turn roadway
- Type of pedestrian signal head (countdown, hand/person, other)
- Presence of crosswalk (yes/no)
- Location of crosswalk (upstream/middle/downstream)
- Presence of bicycle lane on major road (yes/no)
- Driveways present within 76 m (250 ft) of channelized right-turn lane

3.1.3 Site Characteristics

The site characteristics of the observational field study sites are summarized as follows:

		Number of sites
Area type	Residential	4
	Commercial	28
	Industrial	3
Intersection traffic control	Signalized	35
	Unsignalized	0
Island type	Painted	0
	Raised	35
Island size	Small	9
	Medium	20
	Large	6
Deceleration lane	Yes	21
	No	14
Acceleration lane	Yes	7
	No	28
Crosswalk location	Upstream	6
	Middle	25
	Downstream	4
Traffic control for CRT	Yield	19
	Stop	2
	Signal	5
	None (free)	9

3.1.4 Vehicle and Pedestrian Counts

Table 7 presents the vehicle and pedestrian counts that were obtained during the evening peak period (5:00 p.m. to 6:00 p.m.) of each observational study. Right-turn volumes ranged from 11 veh/h to 719 veh/h, but about half of the study sites had volumes between 100 and 300 veh/h. Most sites experienced peak-period volumes of 200 ped/h or fewer, although two sites had nearly 350 ped/h during the peak period (Boulder and Chicago), and one site in San Francisco had over 1,800 ped/h in the peak period.

Table 7. Vehicle and Pedestrian Counts During Evening Peak Period (5:00 p.m. to 6:00 p.m.)

Location	Intersection	Traffic control (direction)	Right-turn volume (veh/h)	Conflicting through volume (veh/h)	Pedestrian volume (ped/h)
Boise, ID	Broadway Street and Myrtle Street	Unsignalized (EB)	719	690	10
	Broadway Street and Warm Springs Boulevard	Unsignalized (EB)	299	875	11
Eagle, ID	SH 44 and SH 55	Unsignalized (NB)	549	384	0
	Eagle Road and Fairview Avenue	Unsignalized (EB)	176	1,070	5
Boulder, CO	Arapahoe Avenue and 28th Street	Unsignalized (WB)	299	1,487	104
	Colorado Avenue and 28th Street	Unsignalized (SB)	162	564	73
		Unsignalized (EB)	533	2,116	57
	Arapahoe Avenue and 30th Street	Unsignalized (EB)	222	737	44
		Unsignalized (SB)	300	1,301	196
	Baseline Avenue and Broadway Street	Unsignalized (WB)	491	694	120
	Broadway Street and University Avenue	Unsignalized (NB)	335	152	335
Chicago, IL	S. Cicero Avenue and 55th Street	Signalized (SB)	58	771	4
	Grand Avenue and Lake Shore Drive	Signalized (WB)	53	594	429
	Franklin Boulevard and Sacramento Boulevard	Unsignalized (EB)	52	0	0
		Unsignalized (SB)	112	62	1
College Park, MD	MD 193 (University Boulevard) and New Hampshire Avenue (MD 650)	Unsignalized (NB)	230	968	163
		Unsignalized (EB)	291	678	39
Towson, MD	Dulaney Valley Road and Fairmont Avenue	Unsignalized (WB)	638	1,206	50
		Unsignalized (SB)	219	629	29
Tualatin, OR	Highway 99W and 124th Avenue	Signalized (WB)	391	930	0
	Bridgeport Road and 72nd Avenue	Unsignalized (WB)	614	95	7
Portland, OR	23rd Avenue and Burnside Road	Unsignalized (SB)	175	1,111	82

Table 7. Vehicle and Pedestrian Counts During Evening Peak Period (5:00 p.m. to 6:00 p.m.) (Continued)

Location	Intersection	Traffic control (direction)	Right-turn volume (veh/h)	Conflicting through volume (veh/h)	Pedestrian volume (ped/h)
Sacramento, CA	J Street and Carlson Drive	Unsignalized (EB)	221	617	118
		Unsignalized (NB)	631	1,498	7
	Franklin Boulevard and Fruitridge Boulevard	Unsignalized (WB)	174	896	12
	Fruitridge Road and Freeport Boulevard	Unsignalized (WB)	556	157	3
	Bruceville Road and Consumnes River	Signalized (NB)	759	1,111	27
San Francisco, CA	Market Street and Duboce Avenue	Unsignalized (WB)	22	743	166
	Ocean Avenue and Phelan Avenue	Unsignalized (SB)	130	992	116
		Unsignalized (WB)	604	170	60
	Sloat Boulevard and Junipero Serra Boulevard	Signalized (EB)	463	1,089	48
	Stockton Street and Post Street	Unsignalized (EB)	154	827	1,810
Seattle, WA	Aurora Avenue and Denny Way	Unsignalized (WB)	189	1,008	74
	Lake Washington Boulevard and E. Madison Street	Unsignalized (WB)	217	451	22
	Yesler Way and 3rd Avenue	Unsignalized (SB)	11	307	197

3.1.5 Observational Study Results

Pedestrian crossing behavior and yield behavior of motorists were documented from the video for each pedestrian crossing at each of the sites. From the 35 sites, over 2,800 pedestrian crossing observations were recorded, primarily during the evening peak period. In addition to general information that was documented (e.g., pedestrian arrival and crossing time, number of vehicles present during crossing, whether pedestrian was traveling alone or in a group), the pedestrian and motorist behavior obtained from the video was organized into three categories:

- Avoidance maneuvers
- Pedestrian crossing behaviors
- Yield behavior of motorists

Avoidance Maneuvers

The types of avoidance maneuvers that were documented include:

- Pedestrian hesitates, stops, or retreats in crosswalk due to presence of vehicle
- Motorist swerves or abruptly stops to avoid pedestrian

Results of the observational field studies suggest that avoidance maneuvers are relatively rare. Approximately 17 percent of the over 2,800 pedestrian crossings occurred with a motor vehicle present in the channelized right-turn lane; and out of those, only 12 pedestrian and 10 vehicle avoidance maneuvers were observed. Thus, avoidance maneuvers were made in less than one percent of all observations and less than five percent of observations with approaching vehicles.

Pedestrian Crossing Behaviors

The types of pedestrian crossing behaviors that were documented include:

- Pedestrian uses the crosswalk for the entire crossing
- Pedestrian follows ("obeys") the pedestrian signal (if present)
- Pedestrian has difficulty finding a gap
- Pedestrian crosses aggressively (e.g., runs) or crosses between stopped vehicles

Overall, the results showed that 72 percent of all pedestrians crossed the entire channelized right-turn roadway within the crosswalk. With respect to following the pedestrian signal, the results showed that 72 percent of all pedestrians crossed during the pedestrian crossing phase and 28 percent crossed against the signal. While 21 percent of pedestrians crossed the channelized right-turn lane aggressively (i.e., running or darting across the roadway, potentially in a small gap of traffic), only 4 percent of pedestrians walked between stopped vehicles to cross the channelized right-turn lane.

Yield Behavior of Motorists

The types of motorist yield behavior that were documented include:

- Motorist yields to pedestrian in crosswalk
- Motorist or pedestrian performs an avoidance maneuver
- Motorist yields to pedestrian waiting at curb
- Motorist stops but blocks the crosswalk

Over 96 percent of the observations in which a vehicle was present and a pedestrian was in the crosswalk, the vehicle yielded to the pedestrian or was unaffected by the pedestrian crossing. In some cases, the vehicle slowed or stopped; in other cases, the pedestrian crossed without substantially impacting the vehicle speed. This finding also confirmed the resulted that avoidance maneuvers occurred at approximately 1 percent of all observations.

When pedestrians were waiting at the curb, a yield rate of approximately 41 percent was observed. Some of the data points included both a pedestrian in the crosswalk as well a pedestrian at the curb at the same time, which could have confounded the observed yield rate.

Stopped or queued vehicles tended to keep the crosswalk open to pedestrians. Only 7 percent of vehicles stopped in a location that blocked the crosswalk. At those locations where a stop bar was present, 62 percent of observed vehicles stopped at the proper location relative to the stop bar.

Effect of Special Crosswalk Signing and Marking

The observational field study sites in Boulder, Colorado, included special crosswalk signing and marking. Figure 14 illustrates a raised crosswalk on a channelized right-turn roadway with special pavement markings. An informal comparison of pedestrian and motorist behavior was made between the sites in Boulder, which have special crosswalk treatments, and the observational field study sites at all other locations. Table 8 presents the results of the informal comparison. While no statistical analyses can be performed due to the small sample sizes, the comparison suggests that the additional signage and pedestrian crosswalk treatments may improve the motorist yield behavior and pedestrian use of the crosswalk.

Figure 14. Raised Crosswalk at Channelized Right-Turn Lane in Boulder, Colorado

Table 8. Comparison of Pedestrian and Motorist Behavior Between Boulder, Colorado, Sites and Other Sites

Pedestrian or motorist behavior	Percent of total observations	
	Boulder, CO, sites	All other sites
Pedestrians use entire crosswalk	86	72
Vehicles yield to pedestrians waiting at curb	47	40
Vehicles yield to pedestrians in crosswalk	99	96
Vehicles block crosswalk when stopped	4	7

3.2 Interviews with Orientation and Mobility Specialists

Interviews with ten orientation and mobility (O&M) specialists were conducted to learn of their experience in teaching pedestrians with vision impairment to traverse intersections with channelized right-turn lanes and to determine their recommendations on how channelized right-turn lanes might be better designed for all pedestrians with disabilities. During the interviews, O&M specialists were asked to describe strategies that pedestrians with vision impairment use at intersections with channelized right-turn lanes to:

- Locate the crossing starting point
- Align to cross
- Decide when to start crossing
- Alert drivers of their intention to cross
- Other techniques or comments

These interviews were conducted by Ms. Janet Barlow, the O&M specialist on the research team. Interviews were conducted via email, phone, or in person depending on the preference and location of the respondent.

3.2.1 Design and Crosswalk Location

It was apparent from the interviews that there is considerable variation in the design of channelized right-turn lanes. Most of the O&M specialists stated that the channelized right-turn lanes in their area were yield-controlled, although two of the O&M specialists were aware of locations in their area where the channelized right-turn roadway was signalized. One person commented that many channelized right-turn lanes in her area had STOP signs, rather than yield signs. Another noted that the designs in his area were mostly low speed without deceleration or acceleration lanes.

Variation in locations for crosswalks was noted by all, with frustration expressed about not being able to easily provide clients with a clear understanding of channelized right-turn lane layout because of the lack of consistency in geometry, crosswalk location, and control. One instructor noted that “the more rounded the corner, the more difficult it seems to be to get a good read of the traffic. These lanes appear to make the intersection wider and add to confusion to sound cues.” Most commented that channelized right-turn lanes with acceleration lanes were virtually uncrossable for their clients/students, because of the speed of vehicles and lack of yielding by drivers.

The interview participants' opinions about crosswalk location (upstream, center, or downstream) varied. Four of the instructors indicated a preference for the crosswalk at the downstream end because the vehicles on the downstream street serve as "blocker cars," preventing vehicles from exiting the channelized right-turn lane and providing a cue about a time to begin crossing. Additional arguments for the downstream location were:

- *"I like downstream better because that's where the two streets actually merge (and thus where the merging car must yield if traffic on the entering street is moving) and that's where I teach my clients to cross in most cases. The ones that are upstream I think are done that way because field of view to see oncoming cars is better. That often confuses a lot of my clients who have some vision but poor depth perception."*
- *"I prefer the downstream end because this is where drivers tend to slow down and look around before continuing. Of course, this makes more of a difference if the pedestrian is going from the driver's left to his right (island to curb), because the driver is already looking left for oncoming traffic."*

Four other instructors supported the center location because they felt their clients were more visible at that location, as well as for reasons associated with alignment for crossing:

- *Crosswalks at the center of the turn "seem best, as this may put the pedestrian and driver in better line of sight, and also it's easier for a blind pedestrian to hear, as the cars about to turn are less masked by traffic in the intersection. Also, it may be easier for some to get their alignment as the curb is straighter here."*

Two instructors described pros and cons of each location, with one stating that the upstream position, especially with a deceleration lane, usually provides the best visibility position for the pedestrian to see/hear and be seen and allowed another crossing timing (of crossing in front of a stopped car without driver contact). The other instructor stated that the center crosswalk location made it easiest to find the island, but more difficult to use traffic cues. Both said that the center position allows the pedestrian with vision impairment to use the curb, ramp, and detectable warning edges for alignment to cross, while the alignment to cross is more challenging at upstream and downstream crosswalk locations.

O&M specialists were asked about the techniques and strategies they teach at channelized right-turn lanes. Some commented that painted islands were of little use to their clients/students because they do not provide the tactile cues provided by a raised island, particularly a raised island with a "cut-through" pedestrian path. In fact, the importance of cut-through areas with detectable warnings was emphasized. One instructor said that it was better to have some slope on the cut-through area to provide an additional cue to the pedestrian with vision impairment that they had reached the island, and to prevent accumulation of debris in the cut-through area. Some instructors stated that landscaping on islands (if difficult to step into, such as holly bushes), or low signs on islands, could be problematic if a pedestrian with vision impairment is not aligned correctly when crossing to an island. Some instructors commented that channelized right-turn lanes with acceleration lanes are very difficult for pedestrians with vision impairment to cross due to higher vehicle speeds and lower yield rates by motorists.

3.2.2 Relevant Findings from NCHRP Project 3-78A

As part of NCHRP Project 3-78A, Cr*ossing Solutions at Roundabouts and Channelized Right Turn Lanes for Pedestrians with Vision Disabilities* (*20*), data were collected on crossings by pedestrians with vision impairment at a channelized right-turn lane in Charlotte, NC. The data were collected by Ms. Janet Barlow, the same O&M specialist who conducted the interviews for the current research. The data from NCHRP Project 3-78A showed that many of the pedestrians with vision impairment had very little experience with channelized right-turn lanes. Although they may have crossed a channelized right-turn roadway, they had minimal understanding of the layout and variations in design of channelized right-turn lanes. Some pedestrians crossed the channelized right-turn lane when it seemed quieter, or when they thought there was a break in traffic, but it was difficult for most participants to clearly describe their strategy for crossing a channelized right-turn lane. Interesting anecdotal information from that research is that several participants said they could hear better to make crossing decision from the curb as opposed to from the island. They stated that the sound of traffic behind them made the crossing decision more difficult when waiting on the island. This is an interesting point because it is expected that pedestrians are more visible to drivers when on the island, since drivers are predominantly focusing to their left, on the traffic they will be merging into.

3.3 Summary of Findings from Observational Field Studies and Interviews with Orientation and Mobility Specialists

Channelized right-turn lanes generally operate well for motorists and most pedestrians. There are very few instances of motorist or pedestrian avoidance maneuvers, and motorists generally yield to pedestrians. Pedestrians with vision impairment, however, find channelized right-turn lanes to be more of a challenge to traverse. Key findings from the observational field studies and interviews with O&M specialists are as follows:

- Field observational studies of vehicle and pedestrian intersections were conducted at 35 channelized right-turn lanes with pedestrian crossings. A majority of the sites (nearly 70 percent) had marked crosswalks located near the center of the channelized right-turn roadway; only about 30 percent of crosswalks were located at the upstream or downstream end of a channelized right-turn lane. The highway agency survey conducted in NCHRP Project 3-72 (*3*) confirms that highway agencies prefer a crosswalk location near the center of a channelized right-turn lane; over 70 percent of highway agencies reported that their practice was to place crosswalks near the center of channelized right-turn lanes.
- Over 2,800 pedestrian crossings of channelized right-turn lanes were observed in the observational field studies. Avoidance maneuvers (e.g., pedestrian hesitates, stops, or retreats in crosswalk due to presence of vehicle; motorist swerves of abruptly stops to

avoid pedestrian) appear to be relatively rare and were made in less than one percent of all observations.

- Approximately 25 percent of pedestrians did not cross within the crosswalk. This may indicate the need to better plan pedestrian routing adjacent to the intersection such that the crosswalk provides the most direct route. However, the pedestrians who crossed outside the crosswalk generally did so when no vehicular traffic was presented and this behavior did not cause any traffic conflicts.
- At sites with pedestrian signals, approximately 72 percent of pedestrians crossed during the pedestrian crossing phase; the remainder crossed against the signal. However, the pedestrians who crossed against the pedestrian signal indication generally did so when no vehicular traffic was present and this behavior did not cause any traffic conflicts.
- While 21 percent of pedestrians crossed aggressively, only 4 percent walked between stopped vehicles to cross the channelized right-turn lane.
- Less than half (40 percent) of observed vehicles yielded to a pedestrian waiting at the curb, but nearly all motorists yielded to pedestrians when they were in the crosswalk (rather than waiting at the curb). The failure of vehicles in yielding to pedestrians waiting to cross at a marked crosswalk is a general problem at pedestrian crossing that is not unique to channelized right-turn lanes. The yield behavior of motorists was slightly better (47 percent vs. 40 percent) at sites with special crosswalk treatments (e.g., raised crosswalk, pavement markings, signing). This may indicate that additional emphasis on signing or other treatments may be needed to increase yielding for pedestrians waiting at the curb.
- Only 7 percent of vehicles stopped in a location that blocked the crosswalk.
- O&M specialists do not have a unified preference for crosswalk location at channelized right-turn lanes, but would like to see more of a consistency in crosswalk locations. This would make it easier to teach pedestrians with vision impairment how to better traverse a channelized right-turn lane.
- O&M specialists have a strong preference for raised islands with “cut-through” pedestrian paths, which provide better guidance for pedestrians with vision impairment than painted islands.
- Use of a consistent design with respect to traffic control and crosswalk location is recommended.
- Channelized right-turn lanes with acceleration lanes are very difficult for pedestrians with vision impairment to cross due to higher vehicle speeds and lower yield rates by motorists.

Chapter 4. Traffic Operational Analysis of Channelized Right-Turn Lanes

This chapter presents the results of a traffic operational analysis of channelized right-turn lanes conducted with the VISSIM simulation model.

The primary traffic operational reasons for providing channelized right-turn lanes 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-turn lanes appear to provide a net reduction in motor vehicle delay at intersections where they are installed, although no existing data and no established methodology have been available to directly compare the operational performance of urban intersections with and without channelized right-turn lanes. A traffic operational evaluation of channelized right-turn lanes, with and without pedestrian signals on the right-turn roadway, was conducted to quantify the differences between alternative designs.

Four key questions related to traffic operations at channelized right-turn lanes were central to the traffic operational analysis. They are:

- What is the traffic operational performance of channelized right-turns lanes?
- What traffic operational benefits would be lost if channelized right-turn lanes were not used?
- What are the effects of different geometric designs of channelized right-turn lanes (location of crosswalk, turning radius, etc.) on traffic operational performance?
- What are the effects of traffic control strategies on the operation of channelized right-turn lanes?

The answers to these questions play a key role in the decision of whether a channelized right-turn lane should be installed at an intersection. In order to answer these questions, the operational research focused on specific issues that could be addressed through the use of traditional traffic analysis modeling. These included:

- Impact of providing a channelized right-turn lane on traffic delay at various traffic volume levels
- Impact of pedestrians on signalized and unsignalized right-turn movements
- Impact of key design features on the operational performance of a channelized right-turn lane including:
    - Location of pedestrian crosswalk
    - Radius of channelized right-turn roadway
    - Speed of the cross-street onto which the right-turn vehicle is turning
    - Provision of acceleration and deceleration lanes
    - Effects of signal timing strategies

4.1 Traffic Operational Modeling

The majority of the traffic operational studies were performed using simulation modeling, which can test many design, traffic volume, and pedestrian volume combinations. Simulation modeling allows for the evaluation of vehicle-to-vehicle and vehicle-to-pedestrian interactions in a controlled environment.

The traffic operational analysis was conducted to evaluate the traffic operational performance of right-turning vehicle movements at signalized intersections for three configurations (illustrated in Figure 15): a conventional right-turn lane at a signalized intersection, a yield-controlled channelized right-turn lane, and a signalized channelized right-turn lane. These configurations were chosen because they represent the most typical urban situations in which a channelize right-turn lane is either used or being considered for use. A series of microscopic simulation runs (using VISSIM) were conducted to evaluate the traffic operational performance for both vehicles and pedestrians. Three key simulation studies were performed for this evaluation:

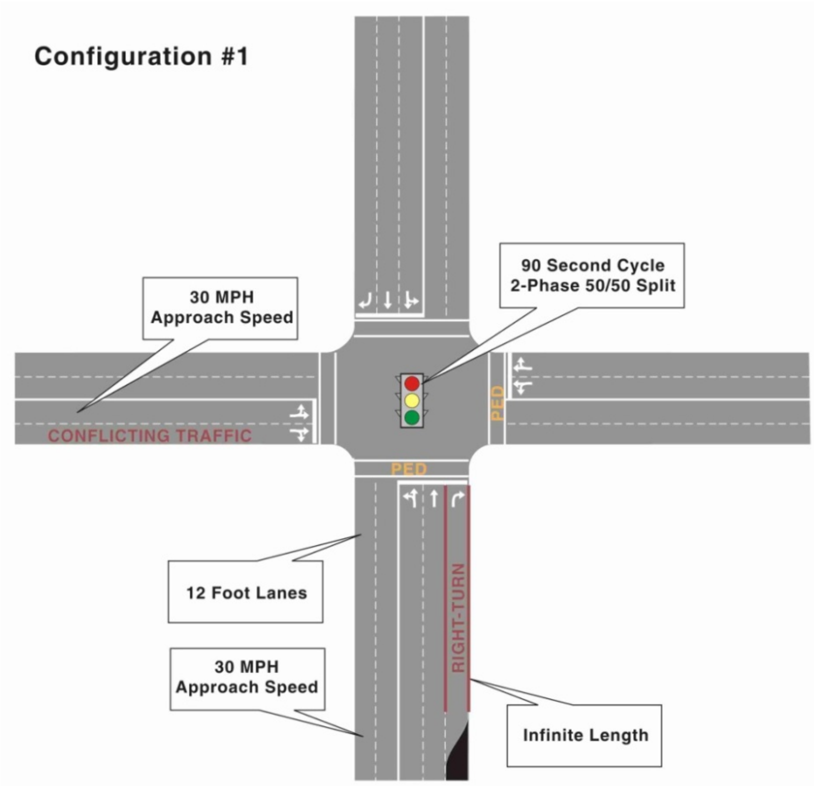
- *Right-turn vehicle delay:* The impact of the right-turn volume and conflicting through volume on delay to the right-turning vehicle.
- *Delay due to pedestrian crossings:* The impact of pedestrian volume crossing the conflicting crosswalk on the delay to the right-turning vehicle.
- *Impact of intersection characteristics:* The changes in right-turn vehicle delay due to design of the channelized right-turn lane and different signal strategies, including:
    - Speed of vehicles on the cross street
    - Speed/radius of the right-turning movement
    - Effects of the a right-turn overlap phase for the signalized movements
    - Impacts of an acceleration lane on the delay to right turns

4.1.1 Modeling Configurations

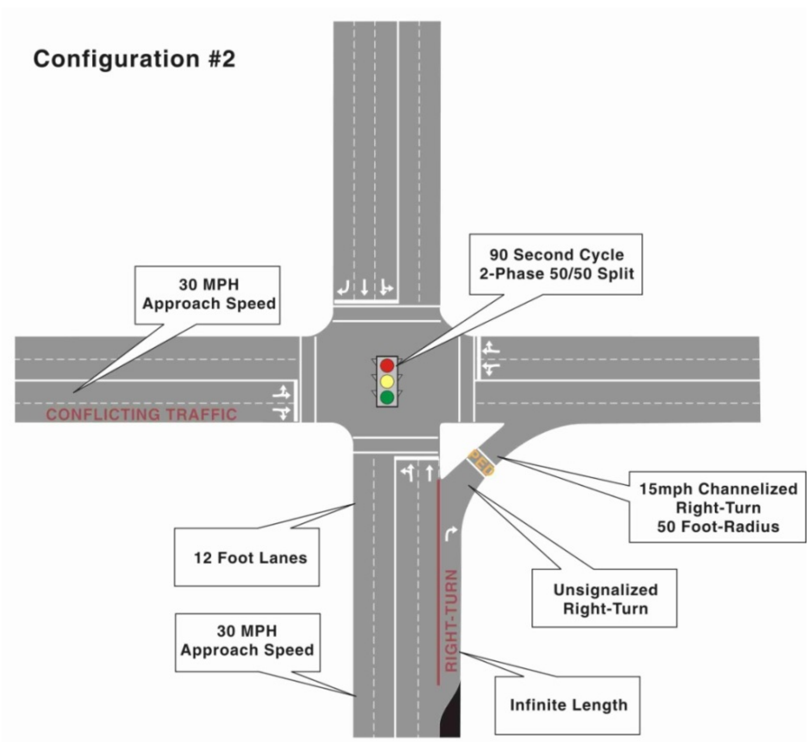
The three modeling configurations used for the simulation analysis are described and illustrated below. In order to reduce the number of variables that might affect the results of the analysis, many assumptions with respect to the intersection design were held constant. These included roadway approach speed, signal cycle length, and lane widths. In addition, the following assumptions were made for the right-turn lane:

- Approach speeds of 48 km/h (30 mi/h)
- Infinite storage in the subject right-turn lane
- Standard 3.6-m (12-ft) travel lanes
- A two-phase signal with a 90-second cycle and 50 percent of the time allocated to the right-turn phase

Each configuration is described below.

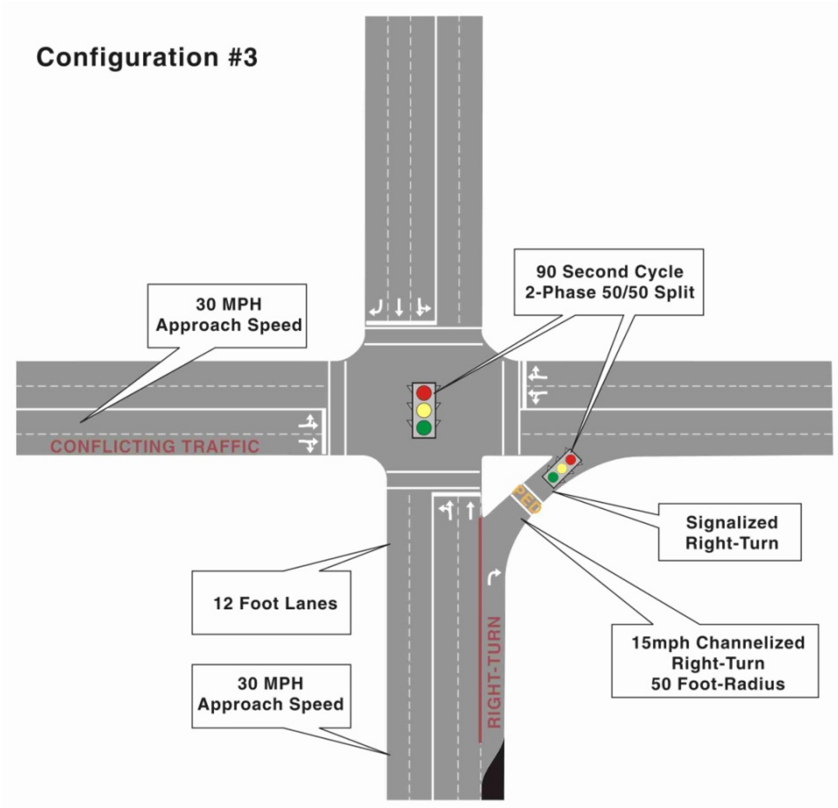


Configuration 1 is a typical signalized intersection with a conventional (i.e., non-channelized) right-turn lane. The evaluation for this configuration focused on the delay for right-turning vehicles based on a range of right-turn volumes and conflicting through volumes. In addition, delay to right-turning traffic due to pedestrian crossings was evaluated.



Configuration 2 is a typical signalized intersection with a yield-controlled channelized right-turn lane. The evaluation for this configuration focused on the delay to right-turning vehicles due to conflicting traffic on the cross street and pedestrians crossing the channelized right-turn lane. In addition, key geometric characteristics of the channelized right-turn lane (turning radius, location of crosswalk) were evaluated.

Figure 15. Intersection Configurations for Traffic Operational Analysis



Configuration 3 assumes a signal-controlled channelized right-turn lane. The evaluation for this configuration focused on the differences in right-turn delay due to signalization of the right turn assuming similar signal timing to that assumed in Configuration 1.

Figure 15. Intersection Configurations for Traffic Operational Analysis (Continued)

4.1.2 Modeling Approach

A total of 349 scenarios were modeled in order to cover a range of vehicle and pedestrian volumes. For each scenario, 30 simulations were run using VISSIM. Thirty runs were completed for each scenario to ensure a large enough sample size to provide a 95 percent confidence level in the results. A total of 10,470 simulation runs were conducted.

4.1.3 Model Calibration and Validation

To ensure the results generated in the VISSIM model were accurate and reasonable, two model validation analyses were conducted. The first evaluated the delay parameters for the three configurations described above using the *Highway Capacity Manual* (*32*) procedures as implemented in the Highway Capacity Software Release 5 (HCS), and by using the Synchro 7 software program. Volume and delay data were collected at two of the observational field study locations and used in the second validation analysis.

In VISSIM, saturation flow rates values cannot be modified directly because they are a function of the car following model, and therefore determined through safety distance parameters. Conversations with PTV America, vendor of VISSIM in North America, indicated

VISSIM simulation can result in various saturation flow rates depending on a number of factors. A series of tests were conducted to determine the correct set of safety distance parameters to produce results similar to those produced by HCS and Synchro. Saturation flow rates, right-turn delay, and queue lengths produced in the VISSIM model closely correlated to the results measured in the field.

HCS and Synchro Comparison

For Configuration 1, HCS and Synchro were used to analyze the right-turn delay for various volume alternatives, and results such as delay, queue length, and saturation flow rates were obtained and used for validation. The HCS analysis and Synchro analysis produced similar saturation flow rates and delay results. Table 9 compares the results of the HCS, Synchro, and VISSIM analyses.

Table 9. HCS and Synchro Right-Turn Movement Delay Calibration Results

Traffic volume (veh/h)	Right-turn volume (veh/h)								
	50			250			500		
	HCS	Synchro	VISSIM	HCS	Synchro	VISSIM	HCS	Synchro	VISSIM
200	14.5	14.2	13.7				25.1	17.2	27.8
800				17.7	16.7	17.4			
1600	14.5	14.5	13.7				25.1	25.4	27.8

As shown in Table 9, the VISSIM results were similar to the HCS and Synchro for all cases with the exception of the case when the right-turn volume is 500 veh/h per hour and the conflicting through traffic volume is 200 veh/h. Further review identified that the VISSIM model delay for the right-turning movement increased rapidly around 500 veh/h especially at low conflicting through traffic volumes. However, it was determined that the other measurements at lower right-turning volumes were well calibrated and changing the VISSIM parameters further might reduce the overall accuracy for the range of modeling scenarios.

Field Observation Comparison

For Configuration 2, two sites were chosen to collect volume and delay data for the calibration. The two sites used for the calibration are located in Portland, Oregon, and Boise, Idaho. The results of the field data and VISSIM model comparison are shown below:

- Portland, Oregon: 23rd Street and Burnside Street
  - Field measurement of right-turn delay—8.3 sec
  - VISSIM model estimate of right-turn delay—8.3 sec
- Boise, Idaho: Broadway Avenue and Warm Springs Avenue (skewed intersection)
  - Field measurement of right-turn delay—8.3 sec
  - VISSIM model estimate of right-turn delay—7.2 sec

As shown above, the VISSIM results for right-turn delay matched the field measurements at the intersection in Portland, and were only 0.9 sec (13.3 percent) lower than the field measurements for the site in Boise.

Based on the comparison of the VISSIM results to the delays from HCS, Synchro, and field data, it was determined that the VISSIM model was adequately calibrated for use.

4.2 Base Modeling Results for Each Configuration

The base modeling results for Configurations 1, 2, and 3 are presented below.

4.2.1 Configuration 1

For Configuration 1, two signal operational scenarios were evaluated. The first scenario assumes the typical right-turn-on-red (RTOR) operation in which a right turn can be made after stopping if there is a sufficient gap in the conflicting through traffic stream and if no pedestrians are present near the crosswalk conflicting with the turning vehicle. The second scenario assumes that RTOR is not allowed and the right-turning vehicle cannot proceed until it receives a green signal indication and the conflicting through traffic is stopped. Figure 16 illustrates the RTOR movement and the pedestrian crossing movement.

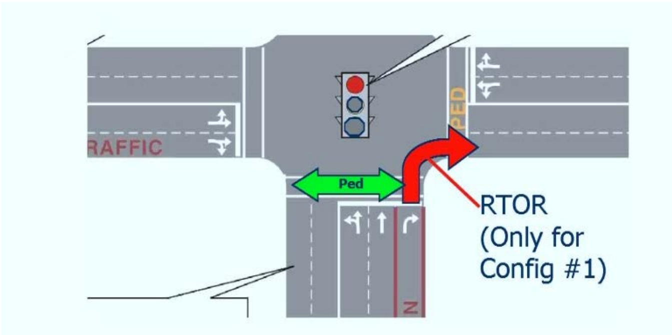


Figure 16. RTOR and Pedestrian Crossing Movement Considered in Analysis

Figure 17 shows the delay for right-turning vehicles for three right-turn volumes for each scenario. As shown in Figure 17, the conflicting through-traffic volume has a substantial impact on the amount of delay for a right-turning vehicle when RTOR is permitted. When conflicting through-traffic volumes approach 1,600 veh/h, and few gaps exist for right-turning vehicles, the delay experienced by vehicles at RTOR intersections approach that of vehicles at intersections where RTOR is not permitted. When RTOR is not permitted, the delay is greater for higher right-turn volumes, but is not impacted by the volume of conflicting through traffic, since the traffic signal green phase is fixed. The greatest benefit of RTOR appears to be achieved when conflicting through traffic volumes are low.

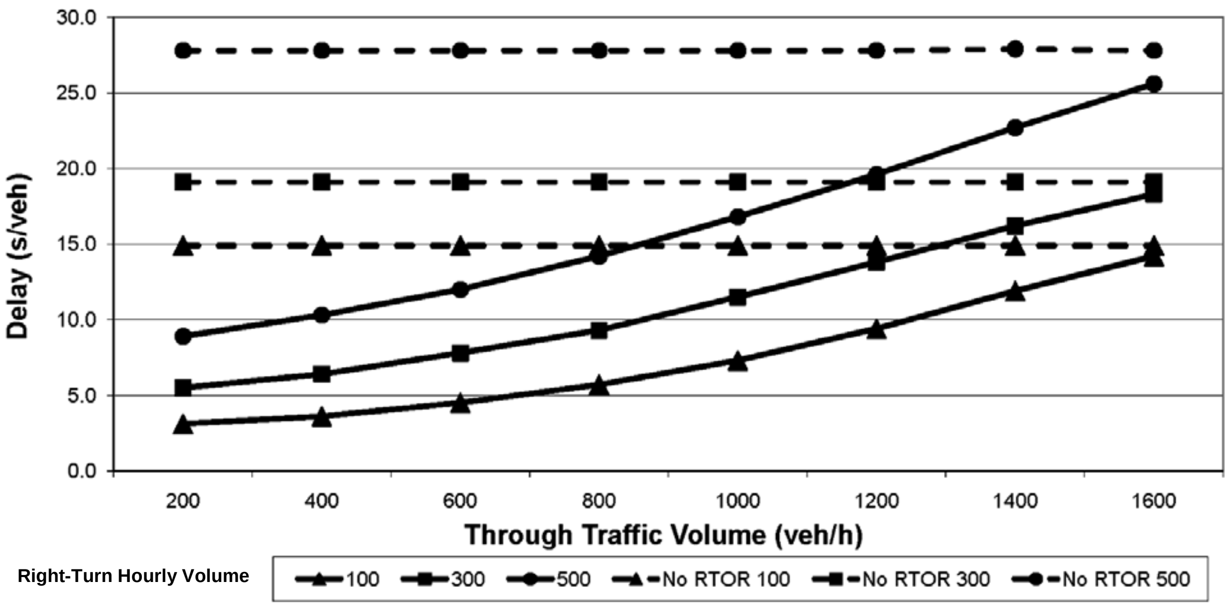


Figure 17. Delay Comparison of Configuration 1 - Conventional Right-Turn Lane (With and Without RTOR)

4.2.2 Configuration 2

Figure 18 shows the delay for the right-turn movement for Configuration 2 (channelized right-turn lane with Yield control). As shown in Figure 17, delay increases from approximately 1 to 2 sec/veh for the lower conflicting through volume of 200 veh/h to approximately 10 to 15 sec/veh at a conflicting through volume of 1,600 veh/h. As conflicting through volume increases, the impact of right-turn volume on delay also increases.

4.2.3 Configuration 3

Figure 19 shows the delay for the right-turn movement for Configuration 3 (channelized right-turn lane with a signal-controlled right turn). For this configuration, it was assumed that RTOR was not permitted, although it is recognized that many intersections with signalized channelized right-turn lanes allow RTOR for single-lane right-turn configurations. The reasons for assuming no RTOR is because, in most cases, signalization of the right-turn is typically implemented at locations with high right-turn volumes, high pedestrian crossing volumes, or both. Under these circumstances, RTOR is typically considered problematic due to pedestrian conflicts and not as beneficial to vehicles since a majority of the right-turning vehicles will be served during the green phase of signal. In addition, a primary purpose of evaluating Configuration 3 is to compare the results to Configuration 1 under similar signal operational assumptions to determine the extent of delay change by channelizing the signalized right turn.

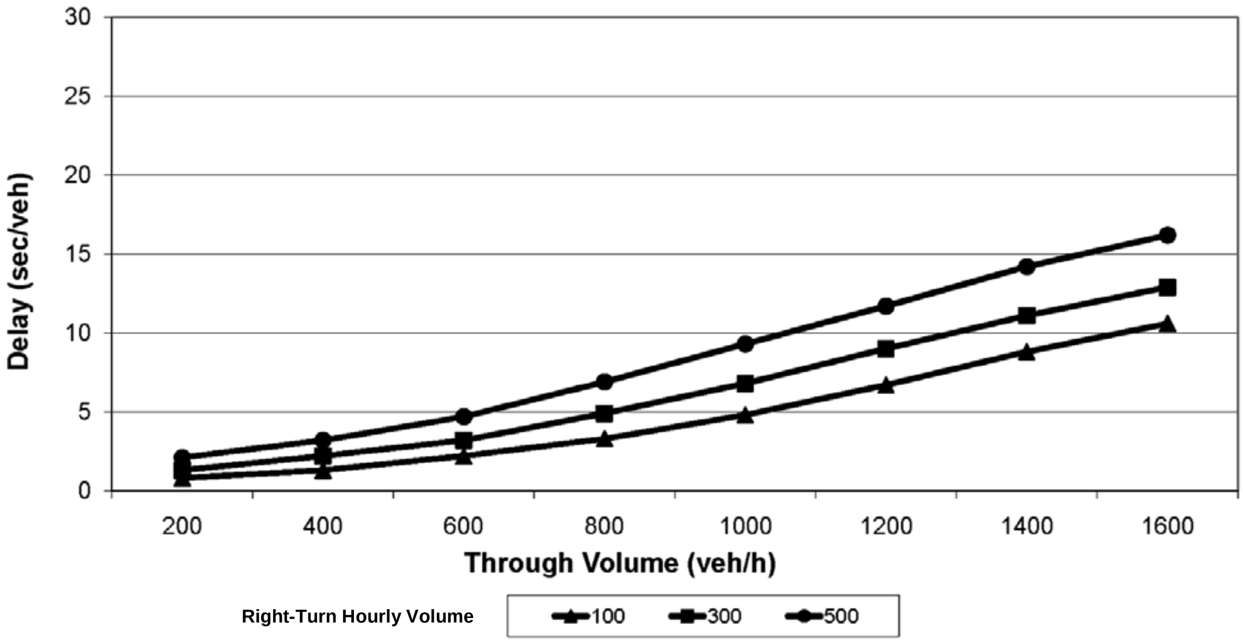


Figure 18. Delay for Configuration 2 (Yield-Controlled Channelized Right-Turn Lane)

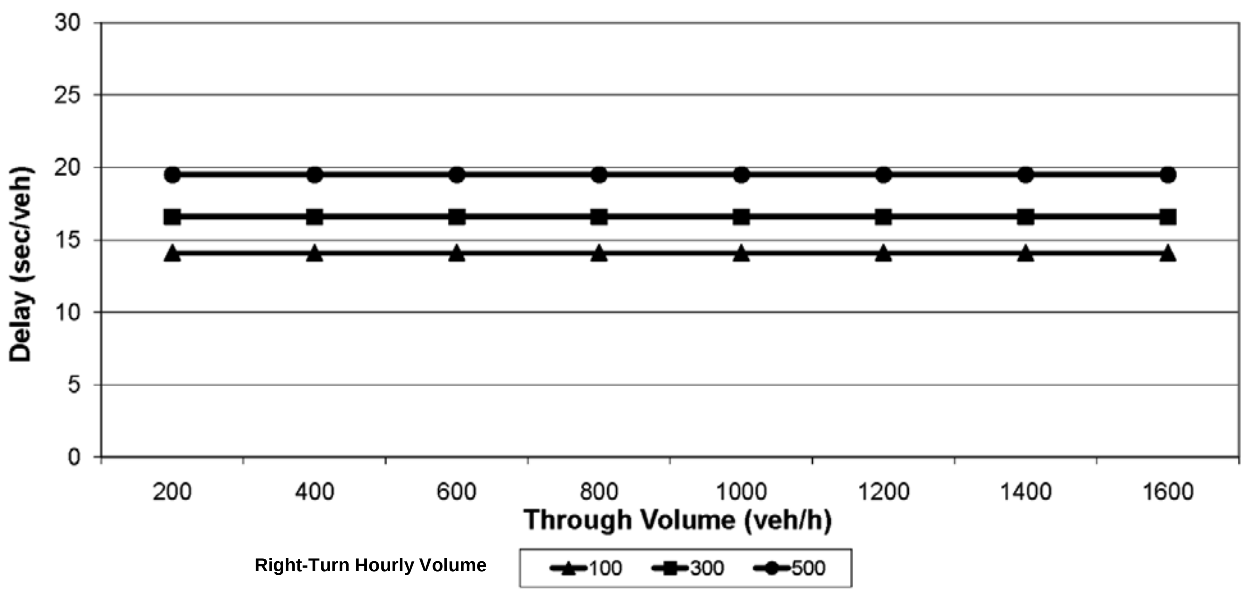


Figure 19. Delay for Configuration 3 (Signalized Channelized Right-Turn Lane)

As shown in Figure 19, the right-turn delays ranged from approximately 14 sec for a right-turn volume of 100 veh/h to approximately 20 sec for a right-turn volume of 500 veh/h. This is compared to approximately 15 and 29 sec, respectively, for Configuration 1.

When comparing the results shown in Figure 19 with those shown in Figure 17 for the “No RTOR” scenario, there appears to be a much larger difference in delay between the three volume levels for Configuration 1 (conventional right-turn lane) than for Configuration 3 (signalized channelized right-turn lane). Since traffic volumes and traffic control assumptions were identical in both scenarios, this difference does not seem reasonable. Further review found that the delay for right-turn volume increased substantially between 400 and 500 veh/h for Configuration 1 with No RTOR. This delay increase did not occur for Configuration 3. Other programs such as HCS and Synchro model both configurations identically and therefore do not support such a substantial difference. Therefore, caution is recommended with regard to the specific values shown reported for the 500 veh/h right-turn scenarios.

4.2.4 Right-Turn Delay Reduction Due to Channelized Right-Turn Lane for Base Configurations

Figure 20 shows the right-turn vehicle delay for each configuration for right-turning volumes of 100 veh/h, 300 veh/h, and 500 veh/h. The No RTOR option for Configuration 1 is not included in Figure 20 because it is typically only used at complex intersections where signal strategies, such as overlap phasing for the right-turns, are utilized.

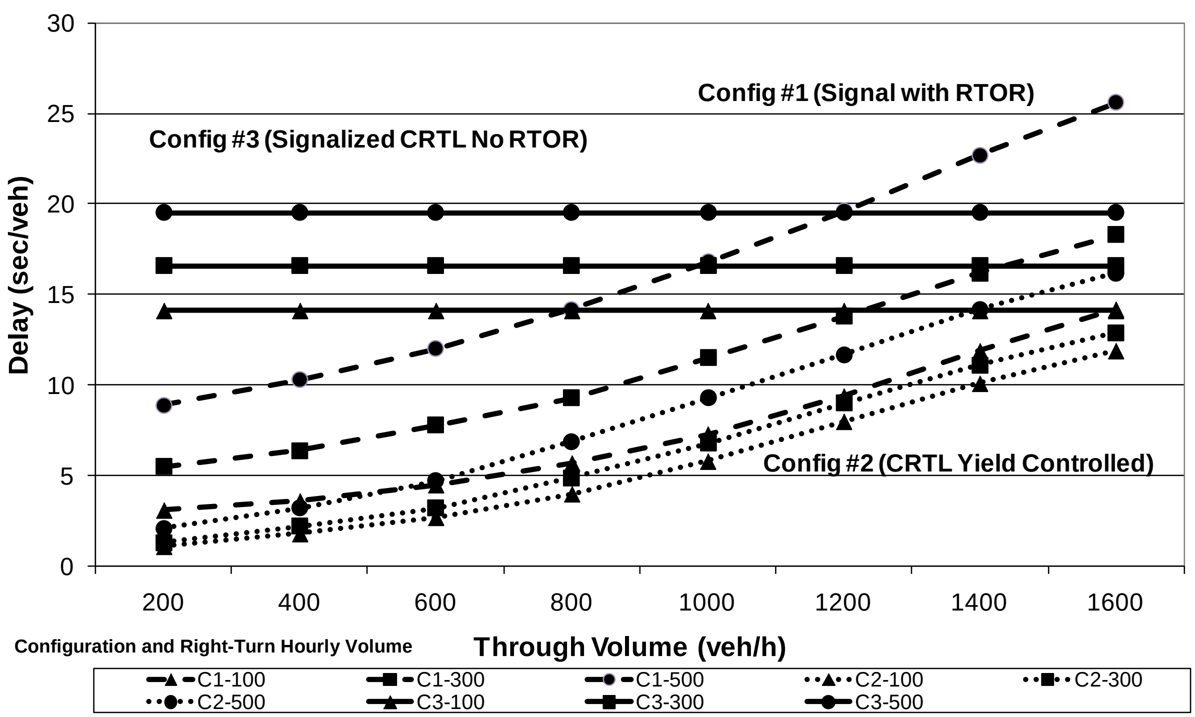


Figure 20. Delay Comparison of Configurations 1, 2, and 3

The yield-controlled channelized right-turn lane has the lowest delay of the three configurations. At very low right-turn volumes, the impact of a yield-controlled channelized right-turn lane compared with a conventional traffic signal with RTOR is relatively small. This is due to the fact that delays are low in general when right-turn volumes are low. However, the impact of a yield-controlled channelized right-turn lane increases as the conflicting through traffic volume increases.

When the conflicting through traffic volume is between 1,200 veh/h and 1,600 veh/h, Configuration 3 (signalized channelized right-turn lane) experiences similar delays to Configuration 1 (signalized conventional right-turn lane with RTOR), which indicates that there are fewer gaps for RTOR vehicles at these conflicting through-traffic volumes. At a conflicting through volume of approximately 1,400 veh/h, the right-turn vehicle delays for Configuration 3 are similar to those in Configuration 2.

Figure 21 shows the resulting delay reductions due to the channelized right-turn lane in Configuration 2 versus the conventional right-turn lane with RTOR in Configuration 1.

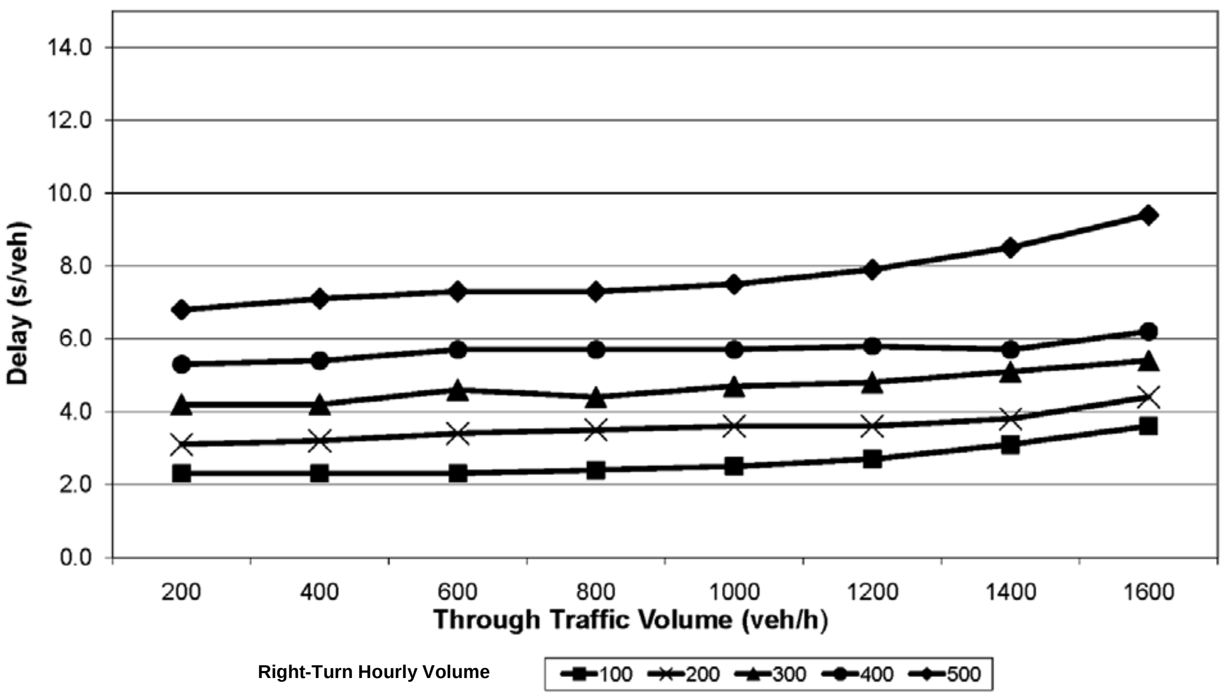


Figure 21. Right-Turn Delay Reduction Due to a Channelized Right-Turn Lane Configuration 1 (RTOR) Vs. Configuration 2

As shown in Figure 21, the average vehicle delay reduction for right-turning vehicles at the yield-controlled channelized right-turn lane increases slightly as the right-turn volume increases. This indicates that the channelized right-turn lane reduces delay compared to a conventional right-turn lane with RTOR, even at high conflicting through traffic volumes. The delay shown in Figure 21 equates to a 25 to 75 percent reduction for right-turning vehicles.

The greater reduction in delay that results from the increase in conflicting through traffic volumes is likely because the RTOR vehicles for Configuration 1 require a larger gap in traffic than the merging vehicles for Configuration 2 during the red signal phase. Figure 22 shows a similar comparison with the Configuration 1 without RTOR option. As shown in Figure 22, the delay reduction due to the channelized right-turn lane decreases as the conflicting through traffic volume increases, even without the RTOR for Configuration 1.

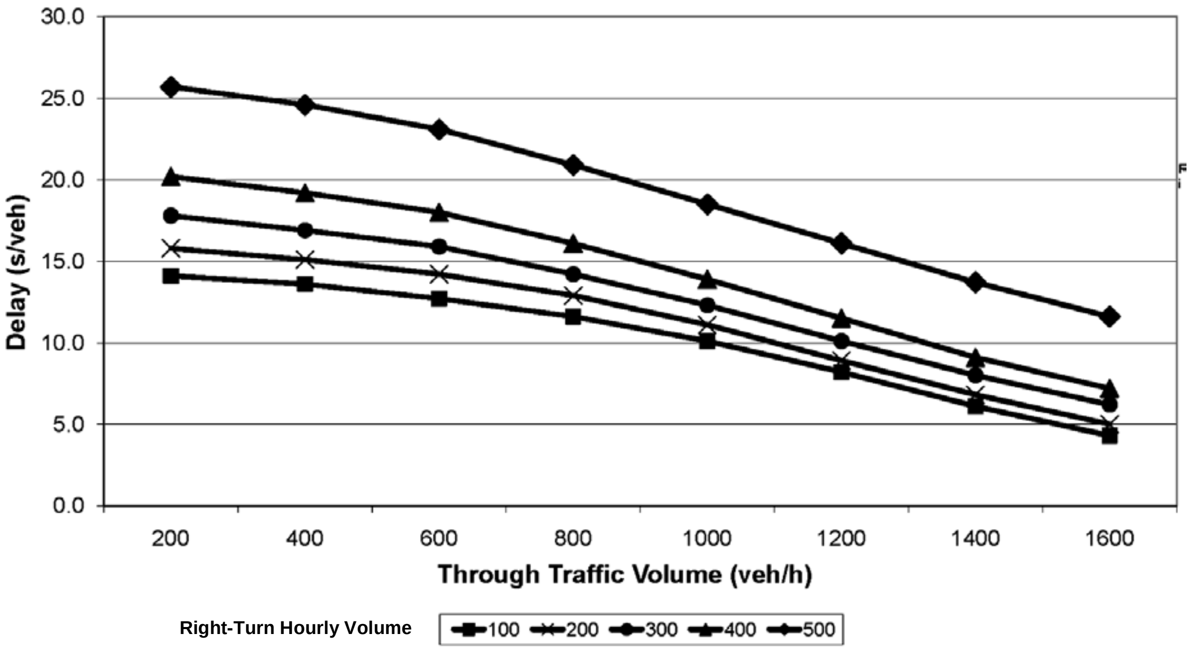


Figure 22. Right Turn Delay Reduction Due to a Channelized Right-Turn Lane Configuration 1 (Without RTOR) Versus Configuration 2

4.2.5 Summary of Results for Base Configurations

The analysis results of right-turn delay for each base configuration are summarized below:

- For Configuration 1 (conventional right-turn lane), conflicting through-traffic volume has a substantial impact on the amount of delay for a right-turning vehicle when RTOR is permitted. When conflicting through-traffic volumes approach 1,600 veh/h, few gaps exist for right-turning vehicles, and the delay experienced by vehicles at RTOR intersections approaches that of vehicles at intersections where RTOR is not permitted. Thus, the greatest benefit of RTOR appears to be achieved when conflicting through traffic volumes are low.
- For Configuration 2 (yield-controlled channelized right-turn lane), delay increases from approximately 1 to 2 sec/veh at a conflicting through volume of 200 veh/h to approximately 10 to 15 sec/veh at a conflicting through volume of 1,600 veh/h. As conflicting through volume increases, the impact of right-turn volume on delay also increases.

- For Configuration 3 (signalized channelized right-turn lane), delay is generally not impacted by the volume of conflicting traffic on the cross street, unless the signal timing is changed to accommodate conflicting traffic volumes. Therefore, signalization of the channelized right-turn lane provides traffic operational benefits only at high conflicting volumes on the cross street. Delays ranged from approximately 14 to 20 seconds for right-turn volumes of 100 to 500 veh/h, respectively.

Based on these findings, the following can be concluded:

- The use of a yield-controlled channelized right-turn lane can substantially reduce the delay experienced by right-turning vehicles. Comparing Configuration 2 to Configuration 1 with RTOR, the channelized right-turn lane provides a delay reduction of between 25 and 75 percent for right-turning vehicles, and provides a delay reduction even at high conflicting through traffic volumes.
- At lower right-turn volumes, the traffic operational benefit of a channelized right-turn lane is relatively small as compared with the conventional right-turn lane in Configuration 1.
- At high conflicting traffic volumes on the cross street, delay experienced by right-turning vehicles becomes similar for yield- and signal-controlled conditions at channelized right-turn lanes.

4.3 Impacts of Pedestrians on Base Configuration Results

A key focus of this research was on how pedestrians use the channelized right-turn lane and the effects of pedestrians on the operation of the channelized right-turn lane. In order to evaluate the operational effects of pedestrians, the following issues were evaluated:

- The impact of pedestrian crossings on right-turn delay for Configuration 2 (yield condition)
- The effect of crosswalk location on the delay to right-turning vehicles for Configuration 2
- Delay to pedestrians waiting to find a gap in right-turning traffic

Each of these issues was evaluated using the VISSIM models developed for the base configurations.

4.3.1 Impact of Pedestrian Crossings on Delay at Channelized Right-Turn Lanes

Figure 23 shows the impact to right-turning delay of various pedestrian volumes for the three study configurations. The model assumes that all vehicles yield to pedestrians approaching the crosswalk; however, the observational studies discussed in Chapter 3 of this report indicate that drivers often do not yield to pedestrians waiting to cross, but instead only to those who have begun crossing. Therefore, the delay data shown in Figure 23 may be slightly greater than what would be experienced in a location in which a portion of the vehicles do not yield to pedestrians approaching the crosswalk.

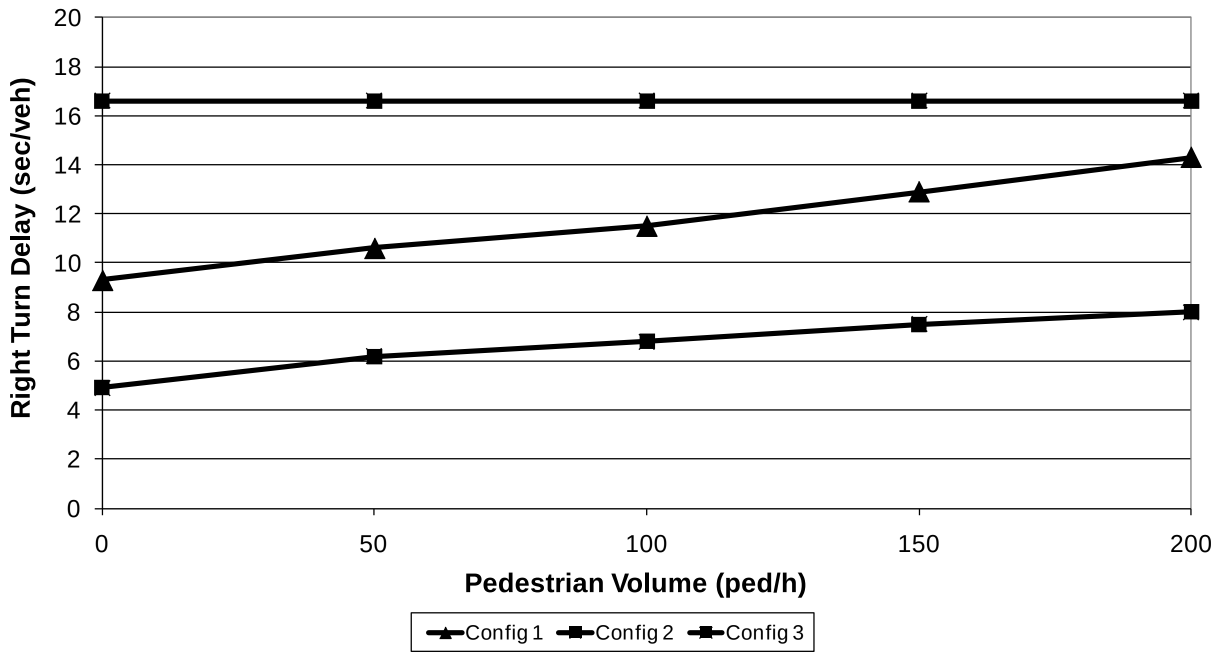


Figure 23. Delay Due to Pedestrian Crossings—Configuration 2 Channelized Right Turn Lane (300 veh/h Right-Turn and 800 veh/h Conflicting Through)

As shown in Figure 23, pedestrian volume has a clear effect on the right-turn delay in Configurations 1 and 2. The increase in delay from zero pedestrians to a pedestrian crossing volume of 200 ped/h is about 50 percent for Configuration 1 and 60 percent for Configuration 2. For all pedestrian volumes, the yield-controlled channelized right-turn lane configuration results in lower delay for right-turning vehicles than a conventional right-turn lane, but at the higher pedestrian volumes the delay for right-turning vehicles nearly doubles. The delay for Configuration 1 with RTOR is close to the delay for Configuration 3 (which does not have RTOR) at the highest pedestrian volumes, indicating that pedestrian crossings substantially reduce the ability of vehicles to turn right during the red signal phase (when the pedestrian have the “walk” indication at the traffic signal). This supports the notion that if pedestrian crossing volumes are very high, RTOR has marginal benefit.

Figure 24 shows the analysis results for Configuration 2 with right-turn volumes of 100, 300, and 500 veh/h. As shown in the figure, all three right-turn volume scenarios are affected similarly by the pedestrian crossings. At right-turn volumes of 500 veh/h, there is an increase in delay of 4.5 sec (70 percent)—from 0 to 200 ped/h—and at right-turn volumes of 100 veh/h, the increase in delay from 0 to 200 ped/h is about 2.5 sec (70 percent).

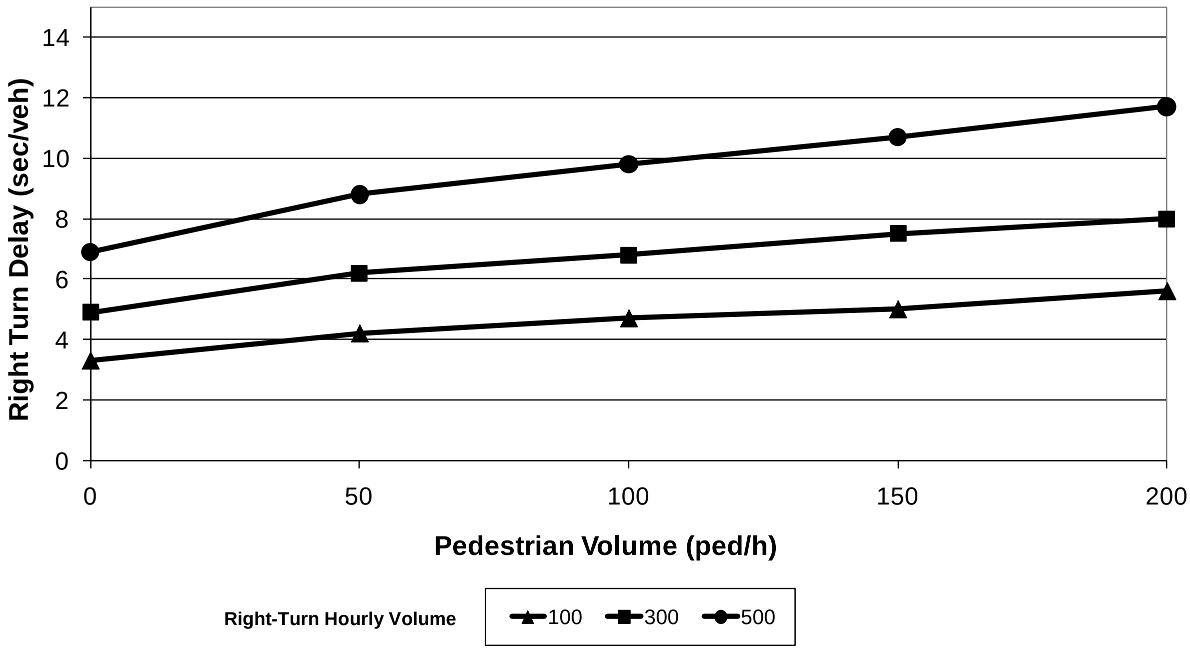


Figure 24. Delay Due to Pedestrian Crossings—Configuration 2 Channelized Right-Turn Lane (800 veh/h Conflicting Through Volume)

4.3.2 Impact of Crosswalk Location

Three separate crosswalk locations (upstream, center, and downstream) were modeled for Configuration 2. Table 10 shows the results of the crosswalk location on right-turn delay for a location with a right-turn volume of 300 veh/h and a pedestrian volume of 50 ped/h. The results show a marginal difference in average delay.

Table 10. Delay Impacts of Crosswalk Location (300 vph and 50 ped/h)

Crosswalk location	Upstream	Middle	Downstream
Delay (sec)	5.7	6.2	5.9

4.3.3 Potential Delay to Pedestrians

Figure 25 shows the potential delay a pedestrian might experience for pedestrian volumes ranging from 50 to 200 ped/h and right-turn volumes of 100 to 500 veh/h and assuming that vehicles do not yield to pedestrians. This scenario represents a “worst case scenario” for pedestrians, since observational studies revealed that approximately 40 percent of the vehicles do yield to pedestrians waiting to cross and nearly all yield once a pedestrian enters the crosswalk.

As shown in Figure 25, the potential delay for pedestrians is relatively large at right-turn volumes of 300 and 500 veh/h. At such high right-turn volumes, pedestrians may become frustrated while trying to cross a channelized right-turn lane and may run across or accept very small gaps in traffic.

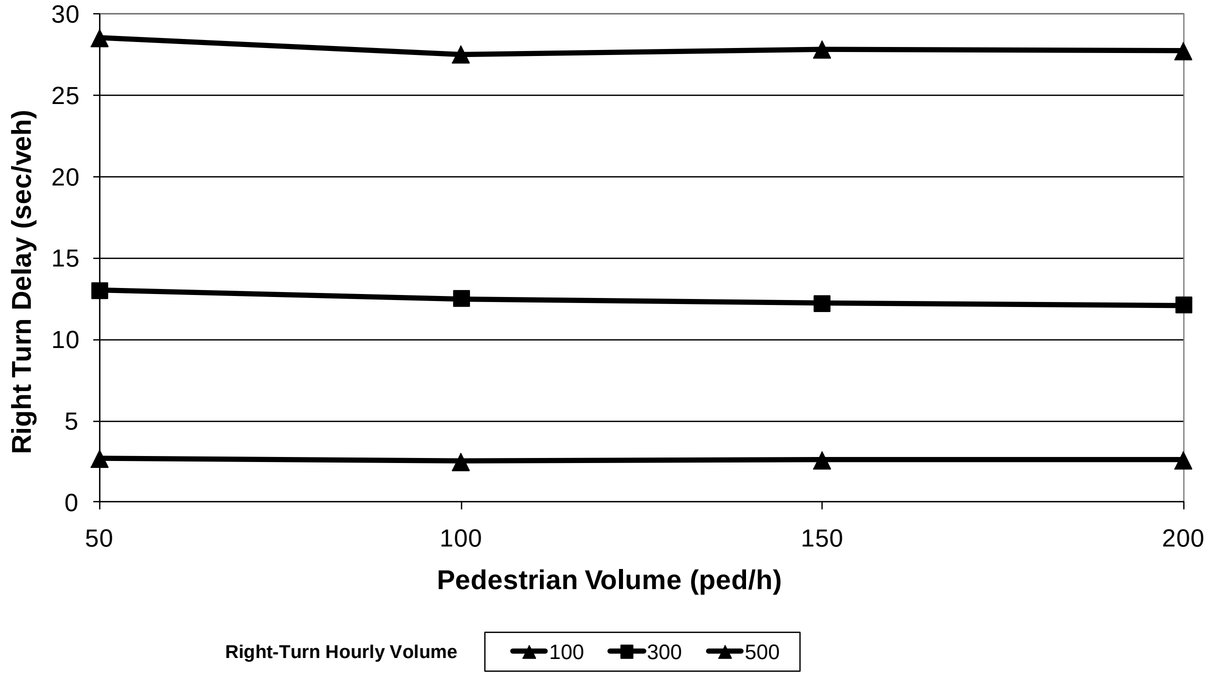


Figure 25. Pedestrian Delay Waiting for a Gap in Right-Turning Traffic

4.3.4 Summary of Results for Pedestrian Impacts on Traffic Operations

The results of the pedestrian analysis are summarized below:

- Pedestrian volume increases right-turn vehicle delay by 50 to 70 percent for Configurations 1 and 2. This is due to a substantially reduced ability of motorists to turn right during a red signal phase.
- The location of the crosswalk is not a key factor with respect to delay for right-turn vehicles.
- Three separate crosswalk locations (upstream, center, and downstream) were modeled for Configuration 2. Results suggest that crosswalk location has a marginal effect (no more than 0.5 sec) on delay.
- At moderate right-turn volumes (300 veh/h), the potential delay to pedestrians waiting for a gap under Configuration 2 is between 15 and 30 seconds, which is likely similar to the level of delay that might be experienced for a signalized crossing.

4.4 Impacts of Geometric Characteristics and Signal Phasing on Channelized Right-Turn Lane Delay

The geometry of the channelized right-turn lane for Configuration 2 as well as the type of signal phasing for Configuration 3 are thought to affect the delay experienced by right-turning vehicles. The VISSIM simulation models created for the delay studies were used to quantify the relative impact of these factors:

- Addition of an acceleration lane (Configuration 2)
- Channelized right-turn lane radius (Configuration 2)
- Impact of adding additional green time by implementing an overlap phase for a signalized channelized right-turn lane (Configuration 3)

4.4.1 Acceleration Lane

Figure 26 shows the simulation results for Configuration 2 with and without a 61-m (200-ft), full-width acceleration lane. The addition of an acceleration lane reduces the delay for the full range of conflicting through volumes and right-turning volumes. The acceleration lane reduces the right-turn delay by 65 percent at low conflicting through volumes and by 85 percent at higher conflicting through volumes.

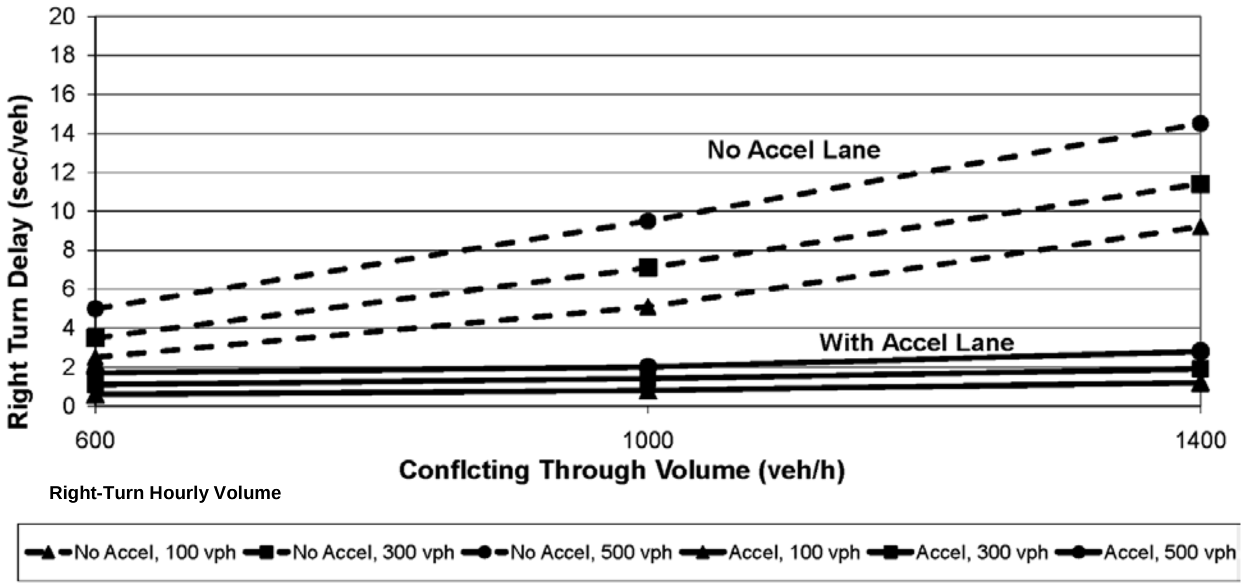


Figure 26. Delay Comparison With Acceleration Lane (Configuration 2)

4.4.2 Channelized Right-Turn Lane Radius and Speed Impacts

The effect of channelized right-turn lane radius on right-turn delay was evaluated by changing the speed of the channelized right-turn lane for various conflicting through volumes and for two roadway speeds. Vehicle speed along the channelized right-turn lane was used as a surrogate for channelized right-turn lane radius, since vehicle speed is limited on narrower curves (smaller radius channelized right-turn lanes) and higher for channelized right-turn lanes with larger radii. Table 11 shows the results of the analysis for Configuration 2.

Table 11. Delay Impacts of Channelized Right-Turn Lane Speed/Radius for Configuration 2

Two through lanes traffic volume (veh/h)	Delay for right-turning vehicles		
	10 mi/h (15- to 20-ft radius)	15 mi/h (40- to 60-ft radius)	20 mi/h (90- to 110-ft radius)
Conflicting through volume speed = 35 mi/h			
600	4.3	3.4	2.9
1,000	8.4	7.1	6.5
1,400	13.3	11.5	10.8
Conflicting through volume speed = 45 mi/h			
600	4.5	3.6	3.1
1,000	8.0	6.8	6.1
1,000	12.6	11.0	10.3

As shown in Table 11, increasing the radius of the right turn (which increases the travel speed along the channelized right-turn lane) reduces the delay by approximately 10 to 20 percent for each 8-km/h (5-mi/h) increase in turning speed. Larger delay reductions are seen at lower through-lane volumes. Delay decreases slightly when the speed of the conflicting through volume is increased from 56 to 72 km/h (35 to 45 mi/h) for through volumes of 1,000 veh/h or greater, but increases slightly for the lower volumes. Based on the observational studies, most of the medium island sizes had a radius of 18 to 31 m (60 to 100 ft).

4.4.3 Traffic Signal Phasing for Signalized Channelized Right-Turn Lanes

At a signalized channelized right-turn lane (Configuration 3), it is common for traffic engineers to provide extra green time to the right-turn movement without increasing cycle length by overlapping the right turn with the cross street left turn. Figure 27 illustrates the concept of a right-turn overlap. A potential drawback of the right-turn overlap phasing is that U-turns cannot be permitted from the cross-street left-turn lane, as they may conflict with right-turning vehicles. The elimination of the U-turn can be a significant issue in states where U-turns are allowed at all intersections and in areas that have median access control and U-turns are the primary means of providing left-turn access to businesses.

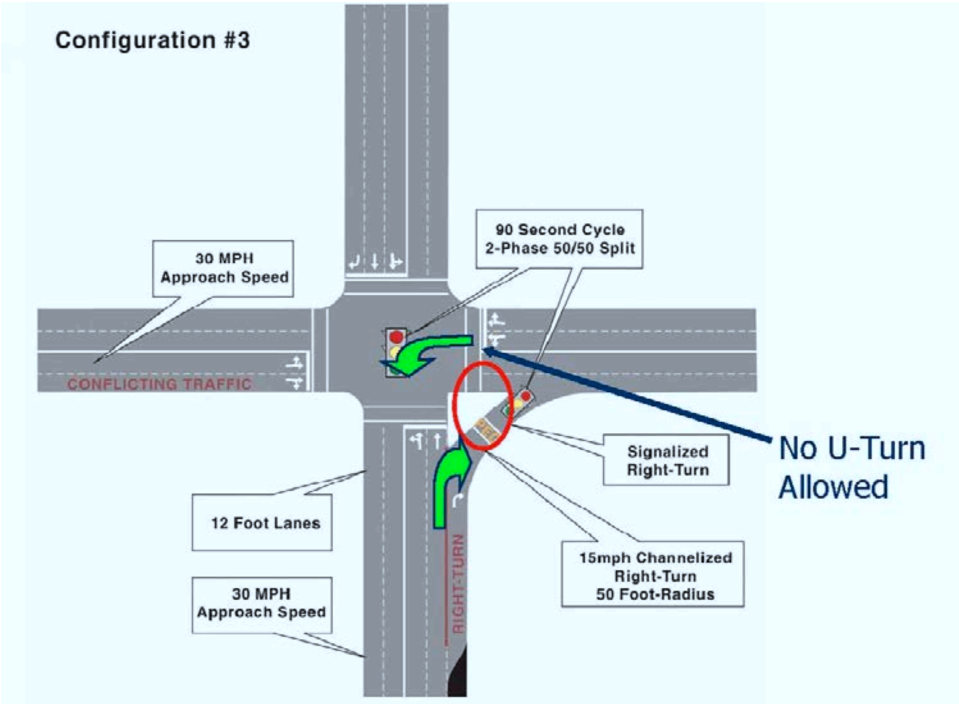


Figure 27. Right-Turn Overlap

Table 12 compares the delay for the base condition to providing additional green time through use of an overlap signal phase. An analysis was conducted for provision of 10, 15, and 20 seconds of additional green time to the 45-sec signal phase under the base condition for the right-turn movement.

Table 12. Delay Impacts of Adding Additional Green Time to Right-Turn Movement

Overlap/added green time for right turn (sec)	Average right-turn delay (sec) (for pedestrian volume of 100 ped/h) Right-turn volume (veh/h)		
	100	300	500
0	6.2	10.7	19.9
10	5.9	9.5	16.0
15	5.8	9.0	14.8
20	5.5	8.5	13.5

As shown in Table 12, the additional green time is more effective at reducing delay as the right-turn volume increases from 100 to 500 veh/h. Each increment of addition green time for the right turn movement provides approximately a 5 to 10 percent decrease in delay for the right-turn vehicles.

4.4.4 Summary of Results for Geometric and Signal Element on Channelized Right-Turn Lane Traffic Operations

The results of the geometric and signal operations analysis of right-turn delay suggest the following:

- Acceleration lanes substantially reduce right-turn delay at all volume levels.
- Increasing the radius of the channelized right-turn roadway reduced the delay by approximately 10 to 20 percent for each 8 km/h (5-mi/h) increase in turning speed. Larger delay reductions were observed at lower through-lane volumes.
- Use of an overlap phase or other methods of providing additional green time to right-turning vehicles can substantially reduce the delay for a signalized channelized right-turn lane but may result in other impacts to intersection operations such as restricting U-turns maneuvers.

4.5 Summary of Traffic Operational Analysis Findings

Based on the results of the simulation modeling, channelized right-turn lanes can substantially reduce delay for right-turning vehicles in nearly every traffic volume scenario. Site-specific factors, such as pedestrian volumes and the geometry of the channelized right-turn lane, have an effect on the level of improvement. Therefore, these factors are important in determining the delay benefits that may result from installation of the channelized right-turn lane. Following are the key findings:

- A yield-controlled channelized right-turn lane can decrease right-turn delay by 25 to 75 percent compared with a conventional right-turn lane at a signalized intersection. At most volume levels, a conventional right-turn lane at a signalized intersection provides lower delay than a signalized channelized right-turn lane due to the use of RTOR. At high pedestrian volumes or high conflicting cross-street traffic volumes, a conventional right-turn lane with RTOR results in similar delays to signal control without RTOR. Thus, the greatest traffic operational benefit of a conventional right-turn lane with RTOR appears to be achieved when conflicting traffic volumes on the cross street are low to moderate.
- A pedestrian volume of approximately 200 ped/h increases right-turn delay by approximately 60 percent on a yield-controlled channelized right-turn lane compared to a base condition of no pedestrians, assuming vehicles yield to pedestrians. However, for all pedestrian volumes, the channelized right-turn lane results in lower delay for right-turning vehicles than a conventional right-turn lane.
- When right-turn volumes are greater than 300 veh/h, the potential delay for pedestrians waiting for a gap to cross a channelized right-turn lane could be between 15 and 30 seconds.
- The addition of an acceleration lane reduces the right-turn delay by 65 to 85 percent depending on the conflicting through traffic volume.

- Increasing the radius of the yield-controlled channelized right-turn lane from approximately 5 to 6 m (15 to 20 ft) up to 24 to 31 m (80 to 100 ft) results in a decrease in right-turn delay of approximately 20 to 50 percent.
- Three separate crosswalk locations (upstream, center, and downstream) were modeled for Configuration 2. Results suggest that crosswalk location has a marginal effect (no more than 0.5 sec) on delay.
- Use of an overlap phase, or other methods of providing additional green time to right-turning vehicles, can substantially reduce the delay for a signalized channelized right-turn lane, but may result in other impacts to intersection operations, such as restricting U-turn maneuvers.

Chapter 5.
Safety Analysis of Channelized Right Turns

This chapter presents the results of a safety analysis of channelized right-turn lanes.

A safety analysis of channelized right-turn lanes, in comparison to other right-turn treatments, was undertaken because of concerns expressed at the outset of the research that channelized right-turn lanes might experience more crashes (and, in particular, more pedestrian crashes) than other right-turn treatments. To investigate this concern, two key questions related to safety at channelized right-turn lanes were addressed in the safety analysis:

- What is the safety performance of channelized right-turn lanes? Specifically, how does the safety performance of intersection approaches with channelized right-turn lanes compare to that of intersection approaches with conventional right-turn lanes or shared through/right-turn lanes?
- What safety benefits would be lost if channelized right-turn lanes were not used?

An overall comparison was performed of the safety performance of intersection approaches with channelized right-turn lanes to intersection approaches with other right-turn treatments. Specifically, a cross-sectional analysis was conducted to compare the crash experience among:

- Intersection approaches with channelized right-turn lanes
- Intersection approaches with conventional right-turn lanes
- Intersection approaches with no right-turn treatments (shared through/right-turn lanes)

The cross-sectional analysis involved comparing mean and median crash frequencies and rates for each of the three intersection approach types and developing negative binomial regression relationships for crash frequencies as a function of traffic volume. The crash data analyses looked separately at motor-vehicle crashes and pedestrian crashes.

5.1 Database Development

Seven (7) years (1999 to 2005) of motor-vehicle and pedestrian crash and volume data were obtained for a total of 103 four-leg signalized intersections in Toronto, Ontario, Canada. The Toronto data represent a unique resource because they include both vehicles turning movement volumes and pedestrian crossing volumes by intersection approach, as well as crash data that can be classified by intersection approach and turning movement. These are the same data that were used to develop the pedestrian safety prediction model for Chapter 12 of the *Highway Safety Manual* (HSM) (*33*, *34*).

Initially, a comparison of intersections with and without channelized right-turn lanes was planned, but the intersections with channelized right-turn lanes did not have a consistent pattern of approaches with and without channelized right-turn lanes. That is, some intersections had a channelized right-turn lane on one approach; others had a channelized right-turn lane on two or more approaches. Therefore, the analysis was conducted at the intersection approach rather than at the intersection level. The number of intersection approaches of each right-turn treatment type included in the analysis was:

- Shared through/right-turn lane (designated as STR): 217 intersection approaches
- Conventional right-turn lane (designated as RTL): 95 intersection approaches
- Channelized right-turn lane (designated as CRT): 83 intersection approaches

5.2 Cross-Sectional Crash Analysis Approach

The safety analysis focused on right-turn crashes involving motor vehicles and/or pedestrians; separate analyses were conducted for motor-vehicle crashes and pedestrian crashes. The effect of right-turn channelization on motor-vehicle and pedestrian crashes of interest was estimated by means of a cross-sectional analysis in which a single statistical model, including an indicator variable for approach type (STR, RTL, or CRT) and right-turn motor-vehicle and pedestrian volumes, was developed using all three approach types. A negative binomial (NB) regression model was used, with the general form as follows, for motor-vehicle and pedestrian crashes, respectively:

$$N_{MV} = \exp[a + b_i I_{Type(i)} + c\ln(Vol_1) + d\ln(Vol_2) + e\ln(Vol_3)] \quad \textbf{(1)}$$

or

$$N_{Ped} = \exp[a + b_i I_{Type(i)} + c\ln(Vol_1) + d\ln(Vol_{ped})] \quad \textbf{(2)}$$

where:
N_{MV} = predicted number of motor-vehicle crashes per year per approach
N_{Ped} = predicted number of pedestrian crashes per year per approach
$I_{Type(i)}$ = indicator (0,1) variable for approach type i, i = 1, 2, or 3; for STR approaches, the value of the coefficient is b_1; for RTL approaches, the value of the coefficient is b_2; for CRT approaches, the value of the coefficient is 0
Vol_1 = right-turning motor-vehicle (MV) volume (24-hour count); same turning movement for all analysis models
Vol_2 = MV volume (24-hour count); turning movements represented by Vol_2 vary with analysis model
Vol_3 = MV volume (24-hour count); turning movements represented by Vol_3 vary with analysis model
Vol_{Ped} = pedestrian volume crossing intersection approaches of interest (24-hour count)
a, b_i, c, d, e = regression coefficients
ln() represents the natural logarithm function

Figure 28 illustrates all of the possible vehicle turning movements at a typical intersection, where the right-turn movement, designated in red (Movement 3), represents the right-turn movement at a particular intersection approach. The other turning movements at the intersection are numbered as shown in the figure in relation to the intersection approach being analyzed. A multiple-vehicle right-turn crash involving the intersection approach being analyzed by definition includes a right-turning vehicle (Movement 3). The other involved vehicle could potentially be making any other turning movement at the intersection, but the right-turning vehicle is *more likely* to conflict with certain turning movements (Movements 1, 2, 3, 7, and 11) than with others.

The research team did not want to presuppose which movements would most likely conflict with the right-turning vehicle without evaluating all possible movements first. Therefore, a multi-tiered analysis approach was conducted in which all movements were initially included in the analysis, and then each subsequent analysis became more focused on the movements most likely to conflict with the right-turn movement in question (Movement 3). Each individual analysis is referred to in the following discussion as an "analysis model." In all, nine different analysis models were investigated—labeled as Analysis Models 1, 2, 3, 4, 5, 6a, 6b, 6c, and 7—three of which are only slight variations of one another. A detailed description of each analysis model is provided later in this section.

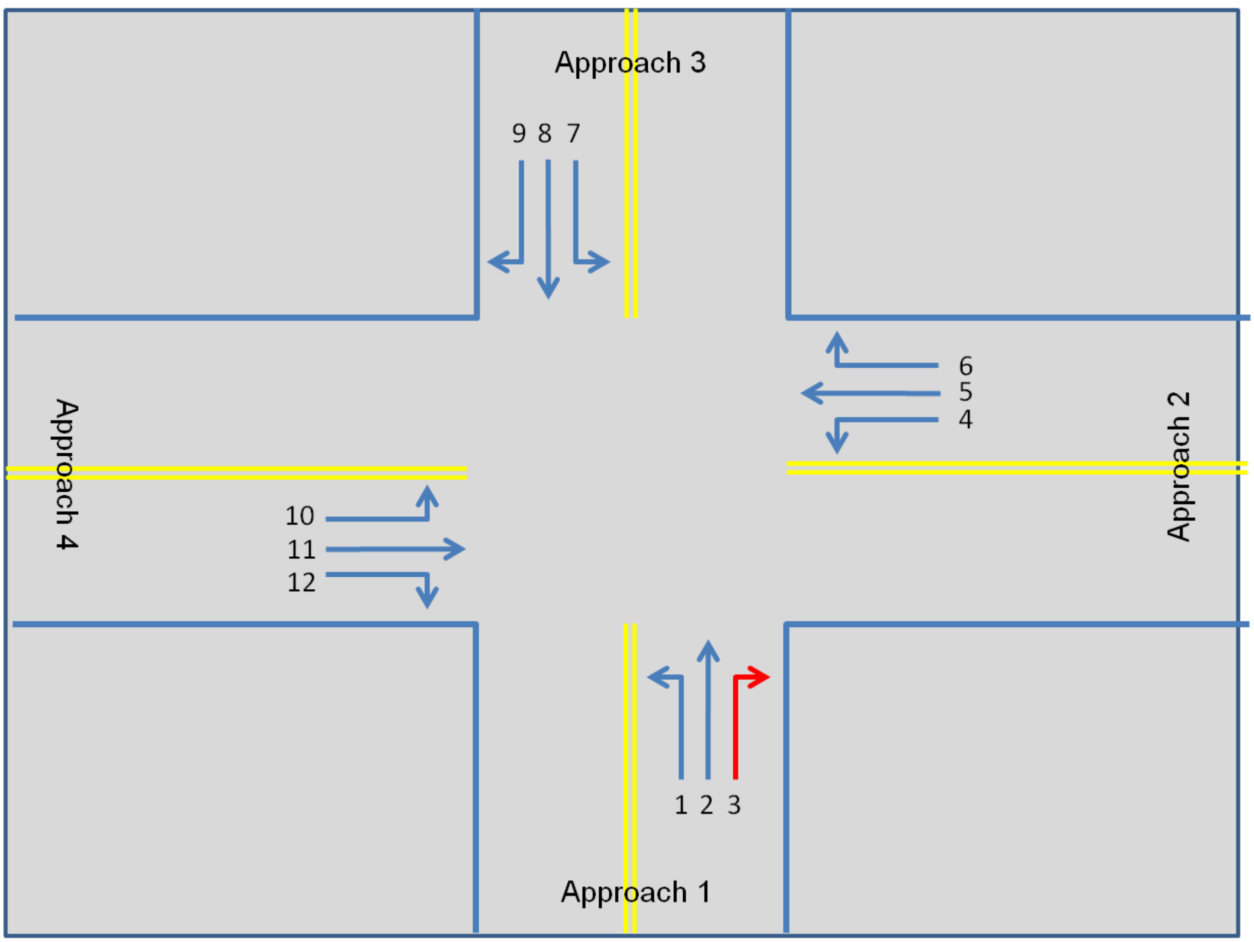


Figure 28. Intersection Turning Movements Relative to an Intersection Approach (Approach 1) with a Specific Right-Turn Treatment (CRT, RTL, or STR)

The following sections present the statistical analysis results, separately for each analysis model. Each section presents the following information:

1. Summary of analysis inputs and criteria: this includes a discussion of the choice of vehicle maneuvers, initial impact types, directional vehicle movements, and aggregated motor-vehicle volumes considered; exceptions are also discussed
2. Mean and median motor-vehicle and pedestrian volumes (based on 24-hour counts), separately for each intersection approach type
3. Motor-vehicle and pedestrian crash statistics—minimum, maximum, and sum of crashes in the seven-year period, separately for total and fatal-and-injury (FI) crashes and for each intersection approach type
4. Regression results, separately for total and FI crashes and for each intersection approach type
5. Statistical comparison of crash rates between CRT and STR or RTL approaches (these results are only provided when the right-turn treatment had an **overall** statistically significant effect on safety), separately for total and FI crashes
6. Predicted yearly crash counts, separately for total and FI crashes and for each intersection approach type

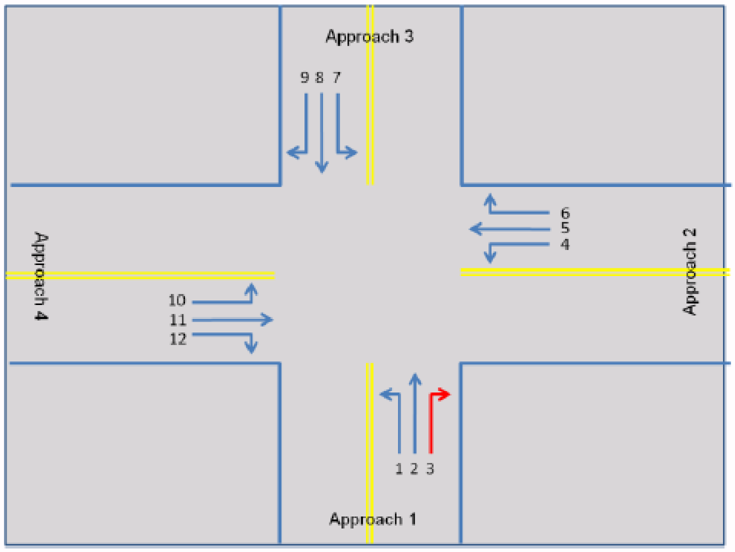
5.3 Cross-Sectional Crash Analysis Results

5.3.1 Analysis Model 1 Results

Analysis Model 1 includes consideration of all possible vehicle maneuvers at each intersection and all possible initial impact types involving Movement 3 and any other vehicle, including single-vehicle crashes involving only Movement 3. While certain conflicts appear to be highly unlikely (e.g., a conflict between Movements 3 and 9), this first analysis was conducted to represent a comprehensive comparison of the safety performance of the three intersection approach types (CRT, RTL, STR) considering all possible maneuvers and impact types. Pedestrian crashes are excluded.

The layout for this analysis model is presented in Figure 29. The graphic in Figure 29 shows all vehicle turning movements, labeled 1 through 12, at a typical four-way intersection. Each such intersection provided four intersection approaches as separate observations for the statistical analysis, with each approach categorized depending on its right-turn treatment. Approach 1 always refers to the analysis approach considered as the primary approach for a particular observation—it can therefore be the NB, WB, SB, or EB intersection approach. The information in Figure 29 (and similar subsequent figures) is explained from the perspective of Approach 1.

The three motor-vehicle volumes used for Analysis Model 1 in Equation 1 are explained in Figure 29, based on the 12 vehicle movements as follows:



Vehicle maneuvers for crashes included in the analysis					
Vehicle number	1	2			
Approach number	1	1	2	3	4
Turning left		✓	✓	✓	✓
Making "U" turn		✓	✓	✓	✓
Going ahead		✓	✓	✓	✓
Slowing or stopping		✓	✓	✓	✓
Overtaking		✓	✓	✓	✓
Changing lanes		✓	✓	✓	✓
Reversing		✓	✓	✓	✓
Stopped		✓	✓	✓	✓
Pulling away from shoulder or curb		✓	✓	✓	✓
Pulling onto from shoulder or curb		✓	✓	✓	✓
Turning right	✓	✓	✓	✓	✓
Merging	✓	✓	✓	✓	✓
Parked		✓	✓	✓	✓
Disabled		✓	✓	✓	✓
Blank		✓	✓	✓	✓
Unknown		✓	✓	✓	✓
Other		✓	✓	✓	✓

Analysis Model 1 includes in the analysis all possible vehicle maneuvers and initial impact types involving at least one vehicle making Movement 3, as labeled in the figure above. The following criteria apply:

- Single-vehicle crashes involving a vehicle turning right from the study approach are *included*.
- Crashes where the maneuver of the second vehicle is coded as "unknown" or "other" or is left blank are *included*.
- Pedestrian crashes are *excluded*.

Volume variables used in modeling	
Vol_1	3
Vol_2	1+2
Vol_3	4+5+6+7+8+9+10+11+12

Initial impact types included	
Approaching	✓
Angle	✓
Rear end	✓
Sideswipe	✓
Turning movement	✓

Figure 29. Summary of Analysis Model 1 Inputs and Criteria

- Vol_1 always represents the right-turning MV volume (i.e., Vol_1 corresponds to vehicle Movement 3, indicated in red)
- Vol_2 always represents the sum of the remaining MV volumes of the same direction included in the model (i.e., Vol_2 corresponds to the sum of vehicle Movements 1 and 2)
- Vol_3 always represents the sum of the MV volumes of the other directions included in the model (i.e., Vol_3 corresponds to the sum of vehicle Movements 4 through 12)

Initial impact types and possible vehicle maneuvers are indicated in the subtables in Figure 29. The possible vehicle maneuvers are those used in standard Ontario crash data format. The subtable in Figure 29 (and in subsequent figures with the same format), entitled "vehicle maneuvers for crashes included in the analysis," defines which crashes were considered in the analysis. Vehicle 1 always represents a right-turning vehicle. Vehicle 2 identifies the vehicle maneuvers considered for the second crash-involved vehicle in multiple-vehicle crashes. The accompanying text in the figure identifies whether single-vehicle crashes involving a right-turning vehicle were included or excluded.

Analysis Model 1 uses the largest dataset (with respect to total MV crash count) of all the models considered in the cross-sectional crash analysis. Volume statistics (mean and median) are shown in Table 13, where Vol_1, Vol_2, and Vol_3 are as defined in Figure 29. Total and FI crash statistics are shown in Table 14.

Table 13. Mean and Median Motor-Vehicle Volumes by Intersection Type—Analysis Model 1

Intersection approach type	Number of approaches	Mean MV volumes (24-hr counts)[a]			Median MV volumes (24-hr counts)[a]		
		Vol_1	Vol_2	Vol_3	Vol_1	Vol_2	Vol_3
STR	217	1,435	10,208	36,209	1,091	9,118	30,891
RTL	95	2,274	14,507	47,841	2,169	13,845	50,256
CRT	83	1,799	12,070	42,770	1,581	12,189	42,211

[a] Vol_1, Vol_2, and Vol_3 are as defined in Figure 29.

Table 14. Seven (7)-Year Total and FI Motor-Vehicle Crash Counts by Intersection Approach—Analysis Model 1

Intersection approach type	Number of approaches	7-year total crash counts			7-year FI crash counts		
		Minimum	Maximum	Sum	Minimum	Maximum	Sum
STR	217	0	10	365	0	3	52
RTL	95	0	14	276	0	3	36
CRT	83	0	13	185	0	5	38

The regression results for the total and FI models are summarized in Table 15. These include the regression coefficients [see Equation (1)] and their 90 percent confidence limits. The Type 3 p-value provides the significance level of each parameter in the model; the last column indicates whether the parameter is statistically significant at the 90 percent confidence level.

Table 15. Regression Results for Motor-Vehicle Crash Models—Analysis Model 1

Parameter[a]		Regression coefficients[b]: Estimate	90% lower confidence limit	90% upper confidence limit	Type 3 p-value	Parameter significant at 90% confidence level?
Total motor-vehicle crashes—Analysis Model 1						
Intercept		−13.49	−15.99	−11.01		
Intersection approach type	STR	−0.04	−0.25	0.17	**0.67**	**No**
	RTL	0.07	−0.16	0.29		
	CRT	0				
Vol_1		0.38	0.25	0.51	< .0001	YES
Vol_2		0.15	0.01	0.29	0.09	YES
Vol_3		0.76	0.50	1.03	< .0001	YES
Dispersion		0.35	0.25	0.47		
Fatal-and-injury motor-vehicle crashes—Analysis Model 1						
Intercept		−14.72	−20.21	−9.45		
Intersection approach type	STR	−0.38	−0.79	0.04	**0.26**	**No**
	RTL	−0.39	−0.84	0.06		
	CRT	0				
Vol_1		0.58	0.29	0.87	0.0007	YES
Vol_2		0.12	−0.18	0.44	0.54	No
Vol_3		0.62	0.05	1.20	0.07	YES
Dispersion		0.71	0.25	1.36		

[a] Vol_1, Vol_2, and Vol_3 are as defined in Figure 29.
[b] Using the model form in Equation (1).

Based on this analysis model, the right-turn treatment has no statistically significant effect on total crashes ($p = 0.67$) or FI crashes ($p = 0.26$). The coefficients (third column) for the three types of intersection approaches are to be interpreted as follows:

- The CRT treatment is the base (comparison) treatment in all models and its coefficient is therefore always zero on the log-scale or one on the original scale.
- If the coefficient for either STR or RTL approaches is positive, then approaches with that type of right-turn treatment experience, on average, **higher** crash counts than CRT approaches, all volumes held constant between intersection approach types.
- If the coefficient for either STR or RTL approaches is negative, then approaches with that type of right-turn treatment experience, on average, **lower** crash counts than CRT approaches, all volumes held constant between intersection approach types.

The coefficient estimates corresponding to the intersection approach types shown in Table 15 therefore provide a means for ranking the right-turn treatments with respect to their predicted crash counts (all volumes held constant between intersection approach types): the smallest coefficient of the three corresponds to the lowest predicted crash count. This, however, does not imply statistical significance; the last column in Table 15 provides that information. Because the right-turn treatment for Analysis Model 1 was not statistically significant at the 90 percent confidence level, the NB regression analysis was not followed-up with a direct comparison of CRT approaches to either STR or RTL approaches.

Using Equation (1) and the regression coefficients shown in Table 15, yearly MV crash counts were predicted for all three approach types. To account for the differences in MV volumes among the three intersection approach types (as shown in Table 13), the three models were applied to all three intersection approaches with MV volumes (Vol_1, Vol_2, and Vol_3) set at the observed mean and median volumes for CRT approaches, as shown in Table 13. The predicted average crash frequencies are shown in Table 16 for each approach type using mean and median volumes, respectively.

Table 16. Yearly Motor-Vehicle Crash Predictions—Analysis Model 1

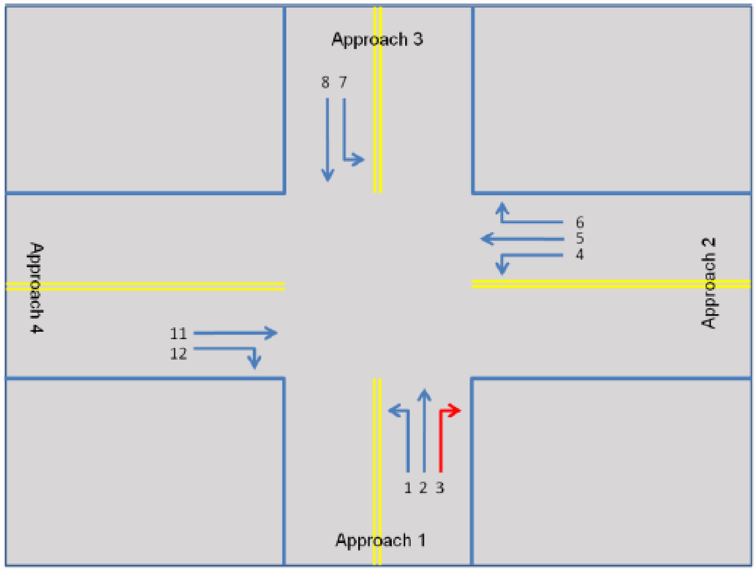
Intersection approach type	Yearly crash predictions per approach	
	At mean CRT volumes	At median CRT volumes
Total motor-vehicle crashes—Analysis Model 1		
STR	0.316	0.298
RTL	0.351	0.331
CRT	0.329	0.310
Fatal-and-injury motor-vehicle crashes—Analysis Model 1		
STR	0.046	0.042
RTL	0.045	0.041
CRT	0.066	0.061

For Analysis Model 1, the right-turn treatment has no statistically significant effect on total crashes or FI crashes. This may be largely due to the fact that all possible maneuvers and impact types, several of which are unlikely to affect right-turn crashes involving Movement 3, have been included in Analysis Model 1.

5.3.2 Analysis Model 2 Results

Analysis Model 2 is similar to Analysis Model 1 with the exception that two turning movements (Movement 9 and 10), which appear to be highly unlikely to conflict with Movement 3, have been omitted from the analysis. Analysis Model 2 includes multiple-vehicle crashes that involve one vehicle making Movement 3 and another vehicle making one of the following movements: 1, 2, 3, 4, 5, 6, 7, 8, 11, or 12. Also, single-vehicle crashes and crashes where the maneuver of the second vehicle was coded as “unknown” or “other” or was left blank have been excluded from the analysis. The layout for this analysis model is presented in Figure 30.

Volume statistics (mean and median) corresponding to Analysis Model 2 are shown in Table 17, where Vol_1, Vol_2, and Vol_3 are defined in Figure 30. Total and FI crash statistics are shown in Table 18. The selection of possible vehicle maneuvers for Analysis Model 2 resulted in a considerably smaller number of crashes than that for Analysis Model 1 (compare to Table 14).



Analysis Model 2 includes multiple-vehicle crashes that involve one vehicle making Movement **3** and another vehicle making one of the following movements: 1, 2, **3**, 4, 5, 6, 7, 8, 11 or 12. The following criteria apply:

- Single-vehicle crashes are *excluded*.
- Collisions involving vehicle movements 9 and 10 are *excluded*.
- Crashes where the maneuver of the second vehicle is coded as "unknown" or "other" or is left blank are *excluded*.
- Pedestrian crashes are *excluded*.

Vehicle maneuvers for crashes included in the analysis					
Vehicle number	1	2			
Approach number	1	1	2	3	4
Turning left		✓	✓	✓	
Making "U" turn		✓	✓	✓	
Going ahead		✓	✓	✓	✓
Slowing or stopping		✓	✓	✓	✓
Overtaking		✓	✓	✓	✓
Changing lanes		✓	✓	✓	✓
Reversing		✓	✓	✓	✓
Stopped		✓	✓	✓	✓
Pulling away from shoulder or curb		✓	✓	✓	✓
Pulling onto from shoulder or curb		✓	✓	✓	✓
Turning right	✓	✓	✓		✓
Merging	✓	✓	✓		✓
Parked					
Disabled					
Blank					
Unknown					
Other					

Volume variables used in modeling	
Vol_1	**3**
Vol_2	1+2
Vol_3	4+5+6+7+8+11+12

Initial impact types included	
Approaching	✓
Angle	✓
Rear end	✓
Sideswipe	✓
Turning movement	✓

Figure 30. Summary of Analysis Model 2 Inputs and Criteria

Table 17. Mean and Median Motor-Vehicle Volumes by Intersection Type—Analysis Model 2

Intersection approach type	Number of approaches	Mean MV volumes (24-hr counts)[a]			Median MV volumes (24-hr counts)[a]		
		Vol_1	Vol_2	Vol_3	Vol_1	Vol_2	Vol_3
STR	217	1,435	10,208	32,647	1,091	9,118	29,215
RTL	95	2,274	14,507	43,124	2,169	13,845	45,493
CRT	83	1,799	12,070	39,288	1,581	12,189	39,023

[a] Vol_1, Vol_2, and Vol_3 are as defined in Figure 30.

Table 18. Seven (7)-Year Total and FI Motor-Vehicle Crash Counts by Intersection Approach—Analysis Model 2

Intersection approach type	Number of approaches	7-yr total crash counts			7-yr FI crash counts		
		Minimum	Maximum	Sum	Minimum	Maximum	Sum
STR	217	0	8	221	0	3	32
RTL	95	0	10	182	0	2	18
CRT	83	0	9	115	0	2	20

The regression results for the total and FI models are summarized in Table 19. Based on this analysis model, the right-turn treatment has no statistically significant effect on total crashes ($p = 0.48$) or FI crashes ($p = 0.39$). Because the right-turn treatment for Analysis Model 2 was not statistically significant at the 90 percent confidence level, the NB regression analysis was not followed-up with a direct comparison of CRT approaches to either STR or RTL approaches.

Using Equation 1 and the regression coefficients shown in Table 19, yearly MV crash counts were predicted for all three approach types. To account for the differences in MV volumes among the three intersection approach types (as shown in Table 17), the three models were applied to all three intersection approaches with MV volumes (Vol_1, Vol_2, and Vol_3) set at the observed mean and median volumes for CRT approaches. The predicted average crash frequencies are shown in Table 20 for each approach type using mean and median volumes, respectively.

For Analysis Model 2, the right-turn treatment has no statistically significant effect on total crashes or FI crashes. Again, this may be largely because there are still several maneuvers and impact types included in the analysis that are not necessarily related to the right-turn movement in question.

Table 19. Regression Results for Motor-Vehicle Crash Models—Analysis Model 2

Parameter[a]		Regression coefficients[b]			Type 3 p-value	Parameter significant at 90% confidence level?
		Estimate	90% Lower confidence limit	90% Upper confidence limit		
Total motor-vehicle crashes—Analysis Model 2						
Intercept		–16.05	–18.97	–13.19		
Intersection approach type	STR	–0.03	–0.27	0.20	**0.48**	**No**
	RTL	0.12	–0.12	0.37		
	CRT	0				
Vol_1		0.42	0.26	0.57	< .0001	YES
Vol_2		0.13	–0.03	0.30	0.18	No
Vol_3		0.96	0.65	1.27	< .0001	YES
Dispersion		0.30	0.18	0.45		
Fatal-and-injury motor-vehicle crashes—Analysis Model 2						
Intercept		–19.42	–26.64	–12.61		
Intersection approach type	STR	–0.18	–0.69	0.34	**0.39**	**No**
	RTL	–0.48	–1.06	0.10		
	CRT	0				
Vol_1		0.56	0.18	0.94	0.01	YES
Vol_2		0.12	–0.25	0.54	0.61	No
Vol_3		1.02	0.27	1.79	0.02	YES
Dispersion		0.49	–0.11	1.48		

[a] Vol_1, Vol_2, and Vol_3 are as defined in Figure 30.
[b] Using the model form in Equation 1.

Table 20. Yearly Motor-Vehicle Crash Predictions—Analysis Model 2

Intersection approach type	Yearly crash predictions per approach: At mean CRT volumes	Yearly crash predictions per approach: At median CRT volumes
Total motor-vehicle crashes—Analysis Model 2		
STR	0.195	0.184
RTL	0.227	0.214
CRT	0.201	0.190
Fatal-and-injury motor-vehicle crashes—Analysis Model 2		
STR	0.029	0.027
RTL	0.021	0.020
CRT	0.034	0.032

5.3.3 Analysis Model 3 Results

Analysis Model 3 focuses on those vehicle maneuvers more likely to conflict with the right-turning vehicle. This analysis includes the right-turn movement (Movement 3) and any other movement that could potentially conflict with the right-turning vehicle, either at the departure end of the right turn (Movements 1 and 2) or as the right-turning vehicle merges into traffic on the cross street (Movements 7 and 11). The layout for this analysis model is presented in Figure 31.

Volume statistics (mean and median) corresponding to Analysis Model 3 are shown in Table 21, where Vol_1, Vol_2, and Vol_3 are defined in Figure 31. Total and FI crash statistics are shown in Table 22. The selection of possible vehicle maneuvers for Analysis Model 3 resulted in a yet smaller number of crashes than that for Analysis Model 2 (compare to Table 18).

Table 21. Mean and Median Motor-Vehicle Volumes by Intersection Type—Analysis Model 3

Intersection approach type	Number of approaches	Mean MV volumes (24-hr counts)[a]			Median MV volumes (24-hr counts)[a]		
		Vol_1	Vol_2	Vol_3	Vol_1	Vol_2	Vol_3
STR	217	1,435	10,208	10,323	1,091	9,118	8,937
RTL	95	2,274	14,507	13,220	2,169	13,845	13,697
CRT	83	1,799	12,070	12,786	1,581	12,189	13,743

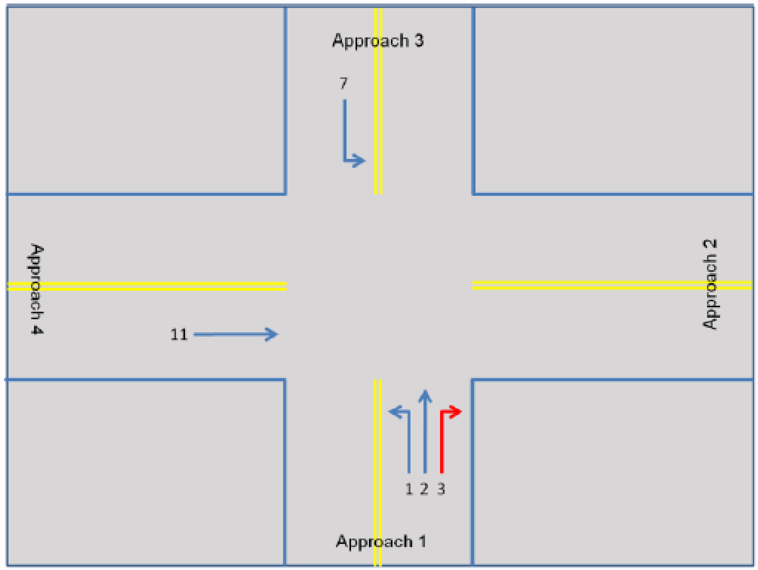
[a] Vol_1, Vol_2, and Vol_3 are as defined in Figure 31.

Table 22. Seven (7)-Year Total and FI Motor-Vehicle Crash Counts by Intersection Approach—Analysis Model 3

Intersection approach type	Number of approaches	7-yr total crash counts			7-yr FI crash counts		
		Minimum	Maximum	Sum	Minimum	Maximum	Sum
STR	217	0	8	172	0	2	20
RTL	95	0	9	154	0	2	17
CRT	83	0	9	86	0	2	14

The regression results for the total and FI models are summarized in Table 23. Based on this analysis model, the right-turn treatment has no statistically significant effect on total crashes ($p = 0.28$) or FI crashes ($p = 1$). Because the right-turn treatment for Analysis Model 3 was not statistically significant at the 90 percent confidence level, the NB regression analysis was not followed-up with a direct comparison of CRT approaches to either STR or RTL approaches.

Using Equation (1) and the regression coefficients shown in Table 23, yearly MV crash counts were predicted for all three approach types. To account for the differences in MV volumes among the three intersection approach types (as shown in Table 21), the three models were applied to all three intersection approaches with MV volumes (Vol_1, Vol_2, and Vol_3) set at the observed mean and median volumes for CRT approaches. The predicted average crash frequencies are shown in Table 24 for each approach type using mean and median volumes, respectively.



Vehicle maneuvers for crashes included in the analysis					
Vehicle number	1	2			
Approach number	1	1	2	3	4
Turning left		✓		✓	
Making "U" turn		✓		✓	
Going ahead		✓			✓
Slowing or stopping		✓			✓
Overtaking		✓			✓
Changing lanes		✓			✓
Reversing		✓			✓
Stopped		✓			✓
Pulling away from shoulder or curb		✓			✓
Pulling onto from shoulder or curb		✓			✓
Turning right	✓	✓			
Merging	✓	✓			
Parked					
Disabled					
Blank					
Unknown					
Other					

Analysis Model 3 includes multiple-vehicle crashes that involve one vehicle making Movement **3** and another vehicle making one of the following movements: 1, 2, **3**, 7, or 11. The following criteria apply:

- Single-vehicle crashes are *excluded*.
- Collisions involving vehicle movements 4, 5, 6, 8, 9, 10 and 12 are *excluded*.
- Crashes where the maneuver of the second vehicle is coded as "unknown" or "other" or is left blank are *excluded*.
- Pedestrian crashes are *excluded*.

Volume variables used in modeling	
Vol_1	**3**
Vol_2	1+2
Vol_3	7+11

Initial impact types included	
Approaching	✓
Angle	✓
Rear end	✓
Sideswipe	✓
Turning movement	✓

Figure 31. Summary of Analysis Model 3 Inputs and Criteria

Table 23. Regression Results for Motor-Vehicle Crash Models—Analysis Model 3

Parameter[a]		Regression coefficients[b] Estimate	90% Lower confidence limit	90% Upper confidence limit	Type 3 p-value	Parameter significant at 90% confidence level?
Total motor-vehicle crashes—Analysis Model 3						
Intercept		−15.01	−17.51	−12.59		
Intersection approach type	STR	0.00	−0.26	0.27	**0.28**	**No**
	RTL	0.21	−0.06	0.48		
	CRT	0				
Vol_1		0.58	0.41	0.76	< .0001	YES
Vol_2		0.38	0.20	0.57	0.0005	YES
Vol_3		0.56	0.37	0.75	< .0001	YES
Dispersion		0.31	0.17	0.48		
Fatal-and-injury motor-vehicle crashes—Analysis Model 3						
Intercept		−5.16	−5.16	−5.16		
Intersection approach type	STR	−0.09	−0.09	−0.09	**1**	**No**
	RTL	−0.08	−0.08	−0.08		
	CRT	0				
Vol_1		0.19	0.19	0.19	1	No
Vol_2		0.02	0.02	0.02	0.02	YES
Vol_3		0.08	0.08	0.08	1	No
Dispersion		−0.50	−0.50	−0.48		

[a] Vol_1, Vol_2, and Vol_3 are as defined in Figure 31.
[b] Using the model form in Equation (1).

Table 24. Yearly Motor-Vehicle Crash Predictions—Analysis Model 3

Intersection approach type	Yearly crash predictions per approach: At mean CRT volumes	At median CRT volumes
Total motor-vehicle crashes—Analysis Model 3		
STR	0.162	0.157
RTL	0.200	0.194
CRT	0.162	0.157
Fatal-and-injury motor-vehicle crashes—Analysis Model 3		
STR	0.054	0.053
RTL	0.055	0.054
CRT	0.059	0.058

For Analysis Model 3, the right-turn treatment has no statistically significant effect on yearly predictions of total or FI crashes. However, while not statistically significant, the yearly total crash predictions tend to show that CRT and STR approaches have similar safety performance (0.162 crashes per year per approach based on mean CRT volumes or 0.157 crashes per year per approach based on median CRT volumes).

5.3.4 Analysis Model 4 Results

Analysis Model 4 focuses on those vehicle maneuvers more likely to conflict with the right-turning vehicle (Movement 3) as it merges into traffic on the cross street (Movements 7 and 11). Thus, Analysis Model 4 includes multiple-vehicle crashes that involve one vehicle making Movement 3 and another vehicle making Movement 7 or 11. The objective of this analysis was to assess whether CRT approaches experience more crashes than RTL or STR approaches as the right-turning vehicle merges with the cross street, particularly since a CRT approach positions the driver at more of a skew angle at the point of the merge. The layout for this analysis model is presented in Figure 32.

Volume statistics (mean and median) corresponding to Analysis Model 4 are shown in Tables 25, where Vol_1 and Vol_3 are defined in Figure 32. Total and FI crash statistics are shown in Table 26. The selection of possible vehicle maneuvers for Analysis Model 4 resulted in a yet smaller number of crashes than that for Analysis Model 3 (compare to Table 22). Note that the 7-year FI crash counts are very low for this scenario; indeed, at most one FI crash occurred at any single approach over the 7-year study period.

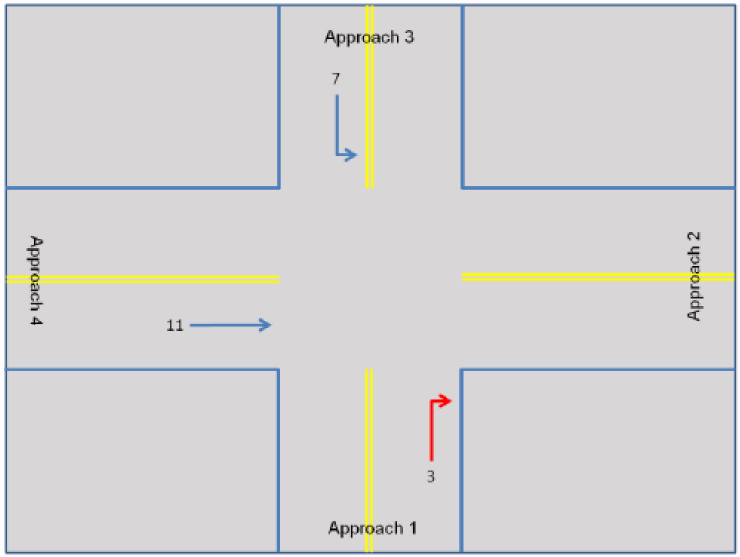
Table 25. Mean and Median Motor-Vehicle Volumes by Intersection Type—Analysis Model 4

Intersection approach type	Number of approaches	Mean MV volumes (24-hr counts)[a]			Median MV volumes (24-hr counts)[a]		
		Vol_1	Vol_2	Vol_3	Vol_1	Vol_2	Vol_3
STR	217	1,435		10,323	1,091		8,937
RTL	95	2,274		13,220	2,169		13,697
CRT	83	1,799		12,786	1,581		13,743

[a] Vol_1 and Vol_3 are as defined in Figure 32.

Table 26. Seven (7)-Year Total and FI Motor-Vehicle Crash Counts by Intersection Approach—Analysis Model 4

Intersection approach type	Number of approaches	7-yr total crash counts			7-yr FI crash counts		
		Minimum	Maximum	Sum	Minimum	Maximum	Sum
STR	217	0	3	56	0	1	7
RTL	95	0	5	75	0	1	7
CRT	83	0	5	41	0	1	6



Analysis Model 4 includes multiple-vehicle crashes that involve one vehicle making Movement 3 and another vehicle making one of the following movements: 3, 7, or 11. The following criteria apply:

- Single-vehicle crashes are *excluded*.
- Collisions involving vehicle movements 1, 2, 4, 5, 6, 8, 9, 10 and 12 are *excluded*.
- Crashes where the maneuver of the second vehicle is coded as "unknown" or "other" or is left blank are *excluded*.
- Pedestrian crashes are *excluded*.

Vehicle maneuvers for crashes included in the analysis

Vehicle number	1	2			
Approach number	1	1	2	3	4
Turning left				✓	
Making "U" turn				✓	
Going ahead					✓
Slowing or stopping					✓
Overtaking					✓
Changing lanes					✓
Reversing					✓
Stopped					✓
Pulling away from shoulder or curb					✓
Pulling onto from shoulder or curb					✓
Turning right	✓	✓			
Merging	✓	✓			
Parked					
Disabled					
Blank					
Unknown					
Other					

Volume variables used in modeling	
Vol_1	3
Vol_2	--
Vol_3	7+11

Initial impact types included	
Approaching	✓
Angle	✓
Rear end	✓
Sideswipe	✓
Turning movement	✓

Figure 32. Summary of Analysis Model 4 Inputs and Criteria

The regression results for the total and FI models are summarized in Table 27. The algorithm to estimate the regression coefficients for the FI crash model did not converge, therefore no model for FI crashes for Analysis Model 4 is available. Based on this analysis model, the right-turn treatment has a statistically significant effect on total crashes (p = 0.01).

Table 27. Regression Results for Motor-Vehicle Crash Models—Analysis Model 4

Parameter[a]		Regression coefficients[b]			Type 3 p-value	Parameter significant at 90% confidence level?
		Estimate	90% Lower confidence limit	90% Upper confidence limit		
Total motor-vehicle crashes—Analysis Model 4						
Intercept		-14.47	-17.69	-11.49		
Intersection approach type	STR	-0.34	-0.71	0.03	**0.01**	**YES**
	RTL	0.25	-0.10	0.62		
	CRT	0	0.00	0.00		
Vol_1		0.83	0.58	1.08	< .0001	YES
Vol_3		0.60	0.31	0.91	0.0004	YES
Dispersion		0.30	0.06	0.63		
Fatal-and-injury motor-vehicle crashes—Analysis Model 4						
No regression model available						

[a] Vol_1 and Vol_3 are as defined in Figure 32.
[b] Using the model form in Equation 1.

For Analysis Model 4, the right-turn treatment was statistically significant at the 90 percent confidence level. In this analysis, CRT approaches have a lower estimate of total crashes than RTL approaches, but a higher estimate than STR approaches.

Since the right-turn treatment for Analysis Model 4 was statistically significant at the 90 percent confidence level, the NB regression analysis was followed-up with a direct comparison of CRT approaches to either STR or RTL approaches; these comparisons are summarized in Table 28 for total crashes. Although the **overall** effect of the right-turn treatment was statistically significant, neither one-to-one comparison was statistically significant at the 90 percent confidence level (p = 0.13 for CRT vs. STR; p = 0.24 for CRT vs. RTL). The second column in Table 28 indicates whether average total crash rate for CRT approaches is lower than that for either of the other two approach types. Each answer is simply based on the comparison of the corresponding parameter estimates shown in Table 27—a lower estimate corresponds to a lower crash rate (this is just a mathematical assessment, not a statistical one).

Table 28. Contrast Results for Motor-Vehicle Crash Models—Analysis Model 4

Comparison	Crash rate lower at CRT?	Chi^2 p-value	Contrast significant at 90% confidence level?
Total motor-vehicle crashes—Analysis Model 4			
CRT vs. STR	No	0.13	No
CRT vs. RTL	Yes	0.24	No
Fatal-and-injury motor-vehicle crashes—Analysis Model 4			
No regression model available			

Using Equation (1) and the regression coefficients shown in Table 27, yearly MV crash counts were predicted for all three approach types. To account for the differences in MV volumes among the three intersection approach types (as shown in Table 27), the three models were applied to all three intersection approaches with MV volumes (Vol_1 and Vol_3) set at the observed mean and median volumes for CRT approaches. The predicted average crash frequencies are shown in Table 29 for each approach type using mean and median volumes, respectively.

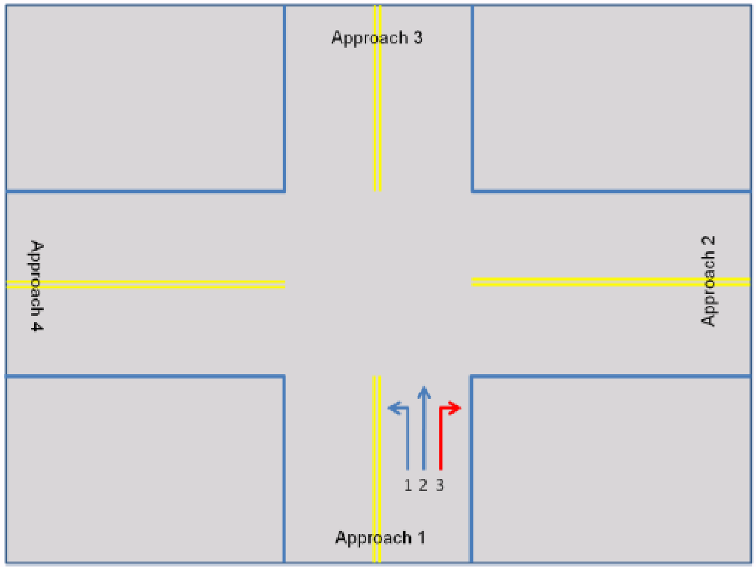
Table 29. Yearly Motor-Vehicle Crash Predictions—Analysis Model 4

Intersection approach type	Yearly crash predictions per approach	
	At mean CRT volumes	At median CRT volumes
Total motor-vehicle crashes—Analysis Model 4		
STR	0.051	0.048
RTL	0.093	0.087
CRT	0.072	0.068
Fatal-and-injury motor-vehicle crashes—Analysis Model 4		
No regression model available		

For Analysis Model 4, the yearly total crash predictions for CRT approaches are lower than the yearly total crash predictions for RTL approaches but higher than for STR approaches.

5.3.5 Analysis Model 5 Results

Analysis Model 5 focuses on those vehicle maneuvers that could potentially conflict with the right-turning vehicle (Movement 3) as it turns *from* the intersection approach (i.e., the departure end). Thus, Analysis Model 5 includes sideswipe and rear-end crashes that involve one vehicle making Movement 3 and another vehicle making Movement 1, 2, or 3. The objective of this analysis was to assess whether CRT approaches experience more crashes at the departure end than RTL or STR approaches. The layout for this analysis model is presented in Figure 33.



Analysis Model 5 includes multiple-vehicle crashes that involve one vehicle making Movement 3 and another vehicle making one of the following movements: 1, 2, or 3. The following criteria apply:

- Single-vehicle crashes are *excluded*.
- Collisions involving vehicle movements 4, 5, 6, 7, 8, 9, 10, 11 and 12 are *excluded.*
- Crashes where the maneuver of the second vehicle is coded as "unknown" or "other" or is left blank are *excluded*.
- Pedestrian crashes are *excluded*.

Vehicle maneuvers for crashes included in the analysis

Vehicle number	1	2			
Approach number	1	1	2	3	4
Turning left		✓			
Making "U" turn		✓			
Going ahead		✓			
Slowing or stopping		✓			
Overtaking		✓			
Changing lanes		✓			
Reversing		✓			
Stopped		✓			
Pulling away from shoulder or curb		✓			
Pulling onto from shoulder or curb		✓			
Turning right	✓	✓			
Merging	✓	✓			
Parked					
Disabled					
Blank					
Unknown					
Other					

Volume variables used in modeling	
Vol_1	3
Vol_2	1+2
Vol_3	--

Initial impact types included	
Approaching	
Angle	
Rear end	✓
Sideswipe	✓
Turning movement	

Figure 33. Summary of Analysis Model 5 Inputs and Criteria

Volume statistics (mean and median) corresponding to Analysis Model 5 are shown in Tables 30, where Vol_1 and Vol_2 are defined in Figure 33. Total and FI crash statistics are shown in Table 31. The selection of possible vehicle maneuvers for Analysis Model 5 resulted in a small number of crashes. **NOTE**: The seven-year FI crash counts are again very low for this scenario; indeed, at most two FI crashes occurred at any single STR or RTL approach over the seven-year study period; at most one FI crashes occurred at any single CRT approach over the same period.

Table 30. Mean and Median Motor-Vehicle Volumes by Intersection Type—Analysis Model 5

Intersection approach type	Number of approaches	Mean MV volumes (24-hr counts)[a]			Median MV volumes (24-hr counts)[a]		
		Vol_1	Vol_2	Vol_3	Vol_1	Vol_2	Vol_3
STR	217	1,435	10,208		1,091	9,118	
RTL	95	2,274	14,507		2,169	13,845	
CRT	83	1,799	12,070		1,581	12,189	

[a] Vol_1 and Vol_2 are as defined in Figure 33.

Table 31. Seven (7)-Year Total and FI Motor-Vehicle Crash Counts by Intersection Approach—Analysis Model 5

Intersection approach type	Number of approaches	7-yr total crash counts			7-yr FI crash counts		
		Minimum	Maximum	Sum	Minimum	Maximum	Sum
STR	217	0	7	74	0	2	12
RTL	95	0	9	50	0	2	12
CRT	83	0	6	49	0	1	8

The regression results for the total and FI models are summarized in Table 32. Based on this analysis model, the right-turn treatment has no statistically significant effect on total crashes ($p = 0.37$) or FI crashes ($p = 1$). Because the right-turn treatment for Analysis Model 5 was not statistically significant at the 90 percent confidence level, the NB regression analysis was not followed-up with a direct comparison of CRT approaches to either STR or RTL approaches.

Using Equation (1) and the regression coefficients shown in Table 32, yearly MV crash counts were predicted for all three approach types. To account for the differences in MV volumes among the three intersection approach types (as shown in Table 30), the three models were applied to all three intersection approaches with MV volumes (Vol_1 and Vol_2) set at the observed mean and median volumes for CRT approaches. The predicted average crash frequencies are shown in Table 33 for each approach type using mean and median volumes, respectively.

For Analysis Model 5, the right-turn treatment has no statistically significant effect on yearly total or FI crash predictions.

Table 32. Regression Results for Motor-Vehicle Crash Models—Analysis Model 5

Parameter[a]		Regression coefficients[b] Estimate	90% Lower confidence limit	90% Upper confidence limit	Type 3 p-value	Parameter significant at 90% confidence level?
Total motor-vehicle crashes—Analysis Model 5						
Intercept		-13.66	-16.86	-10.65		
Intersection approach type	STR	-0.32	-0.73	0.08	**0.37**	**No**
	RTL	-0.32	-0.76	0.13		
	CRT	0				
Vol_1		1.04	0.76	1.33	< .0001	YES
Vol_2		0.36	0.07	0.67	0.04	YES
Dispersion		1.04	0.62	1.61		
Fatal-and-injury motor-vehicle crashes—Analysis Model 5						
Intercept		-4.36	-5.26	-4.35		
Intersection approach type	STR	-0.15	-0.15	0.27	**1**	**No**
	RTL	-0.06	-0.06	-0.05		
	CRT	0				
Vol_1		0.17	0.17	0.17	< .0001	YES
Vol_2		-0.02	-0.02	-0.02	1	No
Dispersion		-0.50	-0.50	-0.46		

[a] Vol_1 and Vol_2 are as defined in Figure 33.
[b] Using the model form in Equation (1).

Table 33. Yearly Motor-Vehicle Crash Predictions—Analysis Model 5

Intersection approach type	Yearly crash predictions per approach: At mean CRT volumes	At median CRT volumes
Total motor-vehicle crashes—Analysis Model 5		
STR	0.060	0.053
RTL	0.061	0.053
CRT	0.084	0.073
Fatal-and-injury motor-vehicle crashes—Analysis Model 5		
STR	0.035	0.034
RTL	0.039	0.038
CRT	0.041	0.040

5.3.6 Analysis Models 6 Results

Analysis Models 6a, 6b, and 6c are similar to Analysis Model 5, except that the left-turn movement (Movement 1) is excluded from the analysis. The analysis is broken into three sub-analyses in order to hone in on certain potential problems (rear-end crashes vs. sideswipe crashes, crashes between a right-turning vehicle and a through vehicle vs. crashes between two right-turning vehicles, etc). The three sub-analyses are:

- Analysis Model 6a focuses on rear-end and sideswipe crashes that involve one vehicle making Movement 3 and another vehicle making either Movement 2 or 3.
- Analysis Model 6b focuses exclusively on rear-end crashes that involve one vehicle making Movement 3 and another vehicle making either Movement 2 or 3.
- Analysis Model 6c focuses exclusively on rear-end crashes that involve two right-turning vehicles (Movement 3).

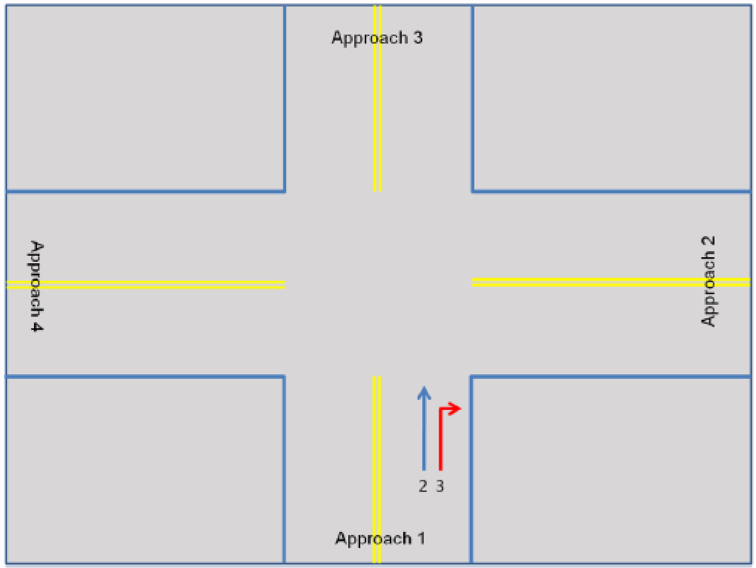
The layout for Analysis Models 6a, 6b, and 6c is presented in Figure 34.

Volume statistics (mean and median) corresponding to Analysis Model 6 are shown in Tables 34, where Vol_1 and Vol_2 are defined in Figure 34. Total and FI crash statistics are shown in Table 35. The selection of possible vehicle maneuvers for Analysis Model 6 resulted in a small number of crashes. **NOTE:** The 7 year FI crash counts are again very low for this scenario; indeed, at most two FI crashes occurred at any single STR or RTL approach over the 7 year study period; at most one FI crashes occurred at any single CRT approach over the same period.

Table 34. Mean and Median Motor-Vehicle Volumes by Intersection Type—Analysis Model 6

Analysis model	Intersection approach type	Number of approaches	Mean MV volumes (24-hr counts)[a]			Median MV volumes (24-hr counts)[a]		
			Vol_1	Vol_2	Vol_3	Vol_1	Vol_2	Vol_3
6a or 6b	STR	217	1,435	8,841		1,091	7,965	
	RTL	95	2,274	12,215		2,169	11,564	
	CRT	83	1,799	9,407		1,581	8,691	
6c	STR	217	1,435			1,091		
	RTL	95	2,274			2,169		
	CRT	83	1,799			1,581		

[a] Vol_1 and Vol_2 are as defined in Figure 34.



Analysis Models 6a, 6b, and 6c include multiple-vehicle crashes that involve one vehicle making Movement **3** and another vehicle making one of the following movements: 2 or **3**. The following criteria apply:

- Single-vehicle crashes are *excluded.*
- Collisions involving vehicle movements 1, 4, 5, 6, 7, 8, 9, 10, 11 and 12 are *excluded.*
- Crashes where the maneuver of the second vehicle is coded as "unknown" or "other" or is left blank are *excluded*.
- Pedestrian crashes are *excluded*.

Vehicle maneuvers for crashes included in the analysis					
Vehicle number	1	2			
Approach number	1	1	2	3	4
Turning left					
Making "U" turn					
Going ahead		✓			
Slowing or stopping		✓			
Overtaking		✓			
Changing lanes		✓			
Reversing		✓			
Stopped		✓			
Pulling away from shoulder or curb		✓			
Pulling onto from shoulder or curb		✓			
Turning right	✓	✓			
Merging	✓	✓			
Parked					
Disabled					
Blank					
Unknown					
Other					

Volume variables used in modeling

Model	6a	6b	6c
Vol_1	**3**	**3**	**3**
Vol_2	2	2	--
Vol_3	--	--	--

Initial impact types included

Model	6a	6b	6c
Approaching			
Angle			
Rear end	✓	✓	✓
Sideswipe	✓		
Turning movement			

Figure 34. Summary of Analysis Model 6 Inputs and Criteria

Table 35. Seven (7)-Year Total and FI Motor-Vehicle Crash Counts by Intersection Approach—Analysis Model 6

Analysis model	Intersection approach type	Number of approaches	7-yr total crash counts			7-yr FI crash counts		
			Minimum	Maximum	Sum	Minimum	Maximum	Sum
6a (rear-end and sideswipe crashes)	STR	217	0	7	71	0	2	12
	RTL	95	0	9	50	0	2	12
	CRT	83	0	6	48	0	1	8
6b or 6c (rear-end crashes only)	STR	217	0	7	51	0	2	10
	RTL	95	0	7	37	0	2	12
	CRT	83	0	6	42	0	1	8

The regression results for the total and FI models are summarized in Table 36. Based on this analysis model, the right-turn treatment has no statistically significant effect on *total* crashes ($p = 0.34$ for Model 6a; $p = 0.15$ for Model 6b; $p = 0.30$ for Model 6c). However, the right-turn treatment has a statistically significant effect on FI crashes for all analysis models ($p < = 0.001$).

Table 36. Regression Results for Motor-Vehicle Crash Models—Analysis Model 6

Parameter[a]		Regression coefficients[b] Estimate	90% Lower confidence limit	90% Upper confidence limit	Type 3 p-value	Parameter significant at 90% confidence level?
Total motor-vehicle crashes—Analysis Model 6a						
Intercept		-13.42	-16.36	-10.69		
Intersection approach type	STR	-0.36	-0.77	0.06	**0.34**	**No**
	RTL	-0.32	-0.77	0.14		
	CRT	0				
Vol_1		1.13	0.84	1.42	< .0001	YES
Vol_2		0.27	0.05	0.51	0.05	YES
Dispersion		1.08	0.65	1.67		
Fatal-and-injury motor-vehicle crashes—Analysis Model 6a						
Intercept		-17.26	-23.21	-12.11		
Intersection approach type	STR	-0.25	-1.00	0.53	**< .0001**	**YES**
	RTL	-0.09	-0.84	0.70		
	CRT	0				
Vol_1		1.47	0.94	2.04	< .0001	YES
Vol_2		0.20	-0.17	0.68	0.40	No
Dispersion		-0.13	-0.50	1.46		

Table 36. Regression Results for Motor-Vehicle Crash Models—Analysis Model 6 (Continued)

Parameter[a]		Regression coefficients[b] Estimate	90% Lower confidence limit	90% Upper confidence limit	Type 3 p-value	Parameter significant at 90% confidence level?
Total motor-vehicle crashes—Analysis Model 6b						
Intercept		-16.28	-19.98	-12.89		
Intersection approach type	STR	-0.53	-1.00	-0.06	**0.15**	**No**
	RTL	-0.49	-1.00	0.03		
	CRT	0				
Vol_1		1.35	1.02	1.71	< .0001	YES
Vol_2		0.38	0.11	0.67	0.02	YES
Dispersion		1.30	0.75	2.09		
Fatal-and-injury motor-vehicle crashes—Analysis Model 6b						
Intercept		-17.60	-23.93	-12.16		
Intersection approach type	STR	-0.42	-1.21	0.40	**< .0001**	**YES**
	RTL	-0.09	-0.84	0.71		
	CRT	0				
Vol_1		1.53	0.98	2.14	< .0001	YES
Vol_2		0.18	-0.20	0.68	0.46	No
Dispersion		-0.05	-0.50	1.68		
Total motor-vehicle crashes—Analysis Model 6c						
Intercept		-13.40	-16.20	-10.81		
Intersection approach type	STR	–0.44	-0.90	0.03	**0.30**	**No**
	RTL	-0.35	-0.86	0.17		
	CRT	0				
Vol_1		1.41	1.08	1.77	< .0001	YES
Dispersion		1.36	0.78	2.17		
Fatal-and-injury motor-vehicle crashes—Level 6c						
Intercept		-16.12	-20.94	-11.79		
Intersection approach type	STR	-0.38	–1.17	0.43	**< .0001**	**YES**
	RTL	-0.03	-0.76	0.76		
	CRT	0				
Vol_1		1.55	1.01	2.16	< .0001	YES
Dispersion		-0.08	-0.50	1.59		

[a] Vol_1 and Vol_2 are as defined in Figure 34.
[b] Using the model form in Equation 1.

Because the right-turn treatment for Analysis Models 6a, 6b, and 6c for FI crashes was statistically significant at the 90 percent confidence level, the NB regression analysis was followed-up with a direct comparison of CRT approaches to either STR or RTL approaches; these comparisons are summarized in Table 37 for FI crashes and show that:

- Although the overall effect of the right-turn treatment was statistically significant (for FI crashes) in Analysis Model 6a, neither one-to-one comparison was statistically significant at the 90 percent confidence level (p = 0.59 for CRT vs. STR; p = 0.84 for CRT vs. RTL).
- Similarly for Analysis Model 6b, neither one-to-one comparison was statistically significant at the 90 percent confidence level (p = 0.39 for CRT vs. STR; p = 0.85 for CRT vs. RTL).
- Similarly for Analysis Model 6c, neither one-to-one comparison was statistically significant at the 90 percent confidence level (p = 0.43 for CRT vs. STR; p = 0.95 for CRT vs. RTL).

Table 37. Contrast Results for Motor-Vehicle Crash Models—Analysis Models 6

Comparison	Crash rate lower CRT?	Chi^2 p-value	Contrast significant at 90% confidence level?
Total motor-vehicle crashes—Analysis Model 6a			
Overall effect of intersection approach type is not statistically significant			
Fatal-and-injury motor-vehicle crashes—Analysis Model 6a			
CRT vs. STR	No	0.59	No
CRT vs. RTL	No	0.84	No
Total motor-vehicle crashes—Analysis Model 6b			
Overall effect of intersection approach type is not statistically significant			
Fatal-and-injury motor-vehicle crashes—Analysis Model 6b			
CRT vs. STR	No	0.39	No
CRT vs. RTL	No	0.85	No
Total motor-vehicle crashes—Analysis Model 6c			
Overall effect of intersection approach type is not statistically significant			
Fatal-and-injury motor-vehicle crashes—Analysis Model 6c			
CRT vs. STR	No	0.43	No
CRT vs. RTL	No	0.95	No

Using Equation (1) and the regression coefficients shown in Table 36, yearly MV crash counts were predicted for all three approach types for each analysis approach. To account for the differences in MV volumes among the three intersection approach types (as shown in Table 34), the three models were applied to all three intersection approaches with MV volumes (Vol_1 and Vol_2 or Vol_1 only) set at the observed mean and median volumes for CRT approaches. The predicted average crash frequencies are shown in Table 38 for each approach type using mean and median volumes, respectively.

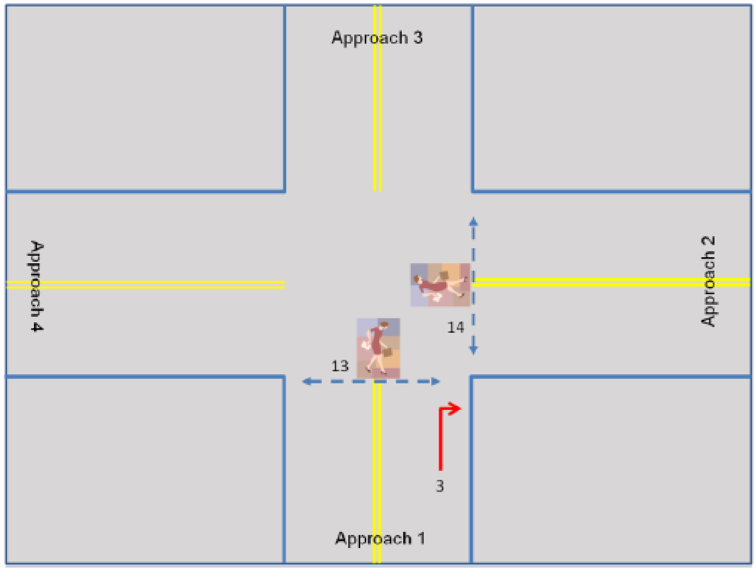
Table 38. Yearly Motor-Vehicle Crash Predictions—Analysis Models 6

Intersection approach type	Yearly crash predictions per approach	
	At mean CRT volumes	At median CRT volumes
Total motor-vehicle crashes—Analysis Model 6a		
STR	0.057	0.048
RTL	0.059	0.050
CRT	0.081	0.069
Fatal-and-injury motor-vehicle crashes—Analysis Model 6a		
STR	0.010	0.008
RTL	0.011	0.009
CRT	0.012	0.010
Total motor-vehicle crashes—Analysis Model 6b		
STR	0.039	0.032
RTL	0.041	0.033
CRT	0.066	0.054
Fatal-and-injury motor-vehicle crashes—Analysis Model 6b		
STR	0.008	0.006
RTL	0.011	0.009
CRT	0.012	0.010
Total motor-vehicle crashes—Analysis Model 6c		
STR	0.039	0.033
RTL	0.043	0.036
CRT	0.061	0.051
Fatal-and-injury motor-vehicle crashes—Analysis Model 6c		
STR	0.008	0.006
RTL	0.011	0.009
CRT	0.011	0.009

While the overall analysis of treatment type suggests that CRT approaches may experience more rear-end and sideswipe crashes between the right-turning vehicle and either (1) a through vehicle or (2) another right-turning vehicle than RTL or STR approaches (Analysis Model 6a), neither of the one-to-one comparisons was statistically significant. This is true for Analysis Models 6b and 6c as well.

5.3.7 Analysis Models 7 Results

Analysis Model 7 focuses on crashes between right-turning vehicles (Movement 3) and pedestrians, and includes the two pedestrian maneuvers/crossings that would potentially conflict with a right-turning vehicle. Figure 35 illustrates the right-turn movement and the two conflicting



Vehicle maneuvers for crashes included in the analysis	Vehicle	Pedestrian
Turning right	✓	
Merging	✓	
Crossing Approach 1		✓
Crossing Approach 2		✓

Volume variables used in modeling	
Vol_1	**3**
Vol_2	--
Vol_3	13+14

Initial impact types included
Pedestrian crashes only

Analysis Model 7 includes only pedestrian crashes that involve one vehicle making Movement **3**. Crashes may involve additional vehicles making any of the other possible maneuvers from any of the vehicle movement locations. The following criteria apply:

- Crashes must include a vehicle making Movement **3**.
- Crashes must include a pedestrian crossing Approach 1 or Approach 2.

Figure 35. Summary of Analysis Model 7 Inputs and Criteria

pedestrian movements of interest. Movement 13 consists of the pedestrian crossing the approach that the right-turning vehicle turns *from* (in this case, Approach 1); Movement 14 consists of the pedestrian crossing the approach that the right-turning vehicle turns *into* (in this case, Approach 2).

Volume statistics (mean and median) corresponding to Analysis Model 7 are shown in Tables 39, where Vol_1 and Vol_3 are defined in Figure 35. Total and FI pedestrian crash statistics are shown in Table 40. **NOTE**: The difference between total and FI pedestrian crashes is minor, as expected, since pedestrian crashes are almost all FI crashes.

Table 39. Mean and Median Motor-Vehicle and Pedestrian Volumes by Intersection Type—Analysis Model 7

Intersection approach type	Number of approaches	Mean volumes (24-hr counts)[a]			Median volumes (24-hr counts)[a]		
		Vol_1 (motor vehicle)	Vol_2	Vol_3 (pedestrian)	Vol_1 (motor vehicle)	Vol_2	Vol_3 (pedestrian)
STR	217	1,435		2,077	1,091		1,133
RTL	95	2,274		1,120	2,169		775
CRT	83	1,799		510	1,581		277

[a] Vol_1 and Vol_3 are as defined in Figure 35.

Table 40. Seven (7)-Year Total and FI Pedestrian Counts by Intersection Approach—Analysis Model 7

Intersection approach type	Number of approaches	7-yr total crash counts			7-yr FI crash counts		
		Minimum	Maximum	Sum	Minimum	Maximum	Sum
STR	217	0	4	51	0	4	49
RTL	95	0	3	45	0	3	44
CRT	83	0	2	12	0	2	11

The regression results for the total and FI models are summarized in Table 41. Based on this analysis model, the right-turn treatment has a statistically significant effect on total crashes ($p = 0.05$) and on FI crashes ($p = 0.04$).

The right-turn treatment for Analysis Model 7 was statistically significant at the 90 percent confidence level for both total and FI pedestrian crashes ($p = 0.05$ and 0.04, respectively). Therefore, the NB regression analysis was followed-up with a direct comparison of CRT approaches to either STR or RTL approaches; these comparisons are summarized in Table 42 for total and FI pedestrian crashes and show that although the overall effect of the right-turn treatment was statistically significant:

- The comparison between CRT and STR approaches was **not** statistically significant at the 90 percent confidence level ($p = 0.95$ for total crashes; $p = 0.86$ for FI crashes).
- The comparison between CRT and RTL approaches was statistically significant at the 90 percent confidence level ($p = 0.10$ for total crashes; $p = 0.07$ for FI crashes).

Table 41. Regression Results for Pedestrian Crash Models—Analysis Model 7

Parameter[a]		Regression coefficients[b] Estimate	90% Lower confidence limit	90% Upper confidence limit	Type 3 p-value	Parameter significant at 90% confidence level?
Total pedestrian crashes—Analysis Model 7						
Intercept		–12.13	–14.96	–9.49		
Intersection approach type	STR	0.02	–0.55	0.64	**0.05**	**YES**
	RTL	0.57	0.02	1.18		
	CRT	0				
Vol_1		0.71	0.40	1.02	0.0001	YES
Vol_3		0.50	0.33	0.67	< .0001	YES
Dispersion		0.31	–0.06	0.86		
Fatal-and-injury pedestrian crashes—Analysis Model 7						
Intercept		–11.94	–14.83	–9.25		
Intersection approach type	STR	0.07	–0.53	0.71	**0.04**	**YES**
	RTL	0.65	0.07	1.28		
	CRT	0				
Vol_1		0.68	0.36	0.99	0.0003	YES
Vol_3		0.50	0.33	0.68	< .0001	YES
Dispersion		0.38	–0.03	0.98		

[a] Vol_1 and Vol_3 are as defined in Figure 35.
[b] Using the model form in Equation (2).

Table 42. Contrast Results for Pedestrian Models—Analysis Model 7

Comparison	Crash rate lower at channelized RTL?	Chi^2 p-value	Contrast significant at 90% confidence level?
Total pedestrian crashes—Analysis Model 7			
CRT vs. STR	Yes	0.95	No
CRT vs. RTL	Yes	0.10	**YES**
Fatal-and-injury pedestrian crashes—Analysis Model 7			
CRT vs. STR	Yes	0.86	No
CRT vs. RTL	Yes	0.07	**YES**

Using Equation (2) and the regression coefficients shown in Table 41, yearly pedestrian crash counts were predicted for all three approach types for each analysis approach. To account for the substantial differences in MV and pedestrian volumes, respectively, among the three intersection approach types (as shown in Table 39), the three models were applied to all three intersection approaches with MV and pedestrian volumes (Vol_1 and Vol_3) set at the observed mean and median volumes for CRT approaches. The predicted average crash frequencies are shown in Table 43 for each approach type using mean and median volumes, respectively.

Table 43. Yearly Pedestrian Crash Predictions—Analysis Model 7

Intersection approach type	Yearly crash predictions per approach	
	At mean CRT volumes	At median CRT volumes
Total pedestrian crashes—Analysis Model 7		
STR	0.025	0.017
RTL	0.043	0.029
CRT	0.024	0.016
Fatal-and-injury pedestrian crashes—Analysis Model 7		
STR	0.024	0.016
RTL	0.043	0.029
CRT	0.023	0.015

The yearly pedestrian crash predictions for CRT and STR approaches are similar (0.024 total crashes per CRT approach vs. 0.025 total crashes per STR approach; 0.023 FI crashes per CRT approach vs. 0.024 FI crashes per STR approach). These comparisons also hold when the predictions are made based on median CRT volumes. The yearly pedestrian crash prediction for RTL approaches is approximately 70 to 80 percent higher than for the other two types of right-turn treatments. This suggests that CRT approaches do not experience a particular safety problem with respect to pedestrians and, in fact, may have fewer pedestrian safety problems than RTL approaches.

5.4 Summary of Safety Analysis

A cross-sectional safety analysis was conducted to determine the safety performance of channelized right-turn lanes. An overall comparison was performed of the safety performance of the following types of intersection approaches:

- Intersection approaches with channelized right-turn lanes (CRT approaches)
- Intersection approaches with conventional right-turn lanes (RTL approaches)
- Intersection approaches with shared through/right-turn lanes (STR approaches)

A multi-tiered analysis approach was conducted in which all movements were initially included in the analysis, and then each subsequent analysis became more focused on those movements more likely to conflict with the right-turn vehicle in question. In all, nine different analysis models were investigated; four of them are of interest and are highlighted next.

- Analysis Model 3 focused on those vehicle maneuvers more likely to conflict with the right-turning vehicle, either at the departure end of the right turn or as the right-turning vehicle merges into traffic on the cross street. While the right-turn treatment had no statistically significant effect on total or FI MV crashes, the yearly *total* crash predictions showed that CRT and STR approaches have similar safety performance

(0.162 total crashes per year, on average, for both approach types), while the crash frequencies for RTL approaches were slightly higher (0.2 total crashes per year, on average, per approach). However, this observation is not statistically significant.

- Analysis Model 4 assessed whether CRT approaches experience more crashes than RTL or STR approaches as the right-turning vehicle merges with the cross street, particularly since the CRT approach positions the driver at a higher skew angle at the point of the merge. Based on this analysis model, the right-turn treatment was statistically significant at the 90 percent confidence level; CRT approaches had a lower estimate of total crash frequency (0.072 MVcrashes per year per approach) than RTL approaches (0.093 MV crashes per year per approach) but a higher estimate than STR approaches (0.051 MV crashes per year per approach). While the overall effect of right-turn treatments was statistically significant, the comparisons between the individual right-turn treatment types were not. This suggests that the three right-turn treatments may differ in safety performance as the right-turning vehicle merges with the cross street, but this is not conclusively established.
- Analysis Model 6 focused exclusively on rear-end and sideswipe crashes between the right-turning vehicle (Movement 3) and either another right-turning vehicle or a through vehicle on the same intersection approach. Based on this analysis model, the right-turn treatment had no statistically significant effect on *total* crashes. For FI crashes, CRT approaches had a slightly higher estimate than RTL or STR approaches, but the differences were very small—for example, 0.012 vs. 0.011 vs. 0.010 FI MV crashes per year per CRT, RTL, and STR approach, respectively. Furthermore, when the analysis was followed-up with direct one-to-one comparison of CRT approaches to either STR or RTL approaches, neither of the comparisons was statistically significant at the 90 percent confidence level.
- Analysis Model 7 focused on crashes between right-turning vehicles and pedestrians, and included the two pedestrian maneuvers/crossings that would potentially conflict with a right-turning vehicle. Based on this analysis model, the right-turn treatment had a statistically significant effect on total and FI crashes. The yearly pedestrian crash predictions for CRT and STR approaches were similar (0.024 total crashes per CRT approach vs. 0.025 total crashes per STR approach; 0.023 FI crashes per CRT approach vs. 0.024 FI crashes per STR approach). The yearly pedestrian crash prediction for RTL approaches was approximately 70 to 80 percent higher than for the other two types of right-turn treatments. This suggests that CRT and STR have similar pedestrian safety performance, while RTL approaches have more pedestrian crashes, on average, than either CRT or STR approaches.

Chapter 6.
Interpretation of Results and Design Guidance

This chapter presents the interpretation of the research results and provides a basis for the design guidance presented in the guidelines in Appendix A. This guidance compares approaches with channelized right-turn lanes (CRT), shared through/right-turn lanes (SRT), and conventional right-turn lanes (RTL). These configurations are illustrated in Figure 36.

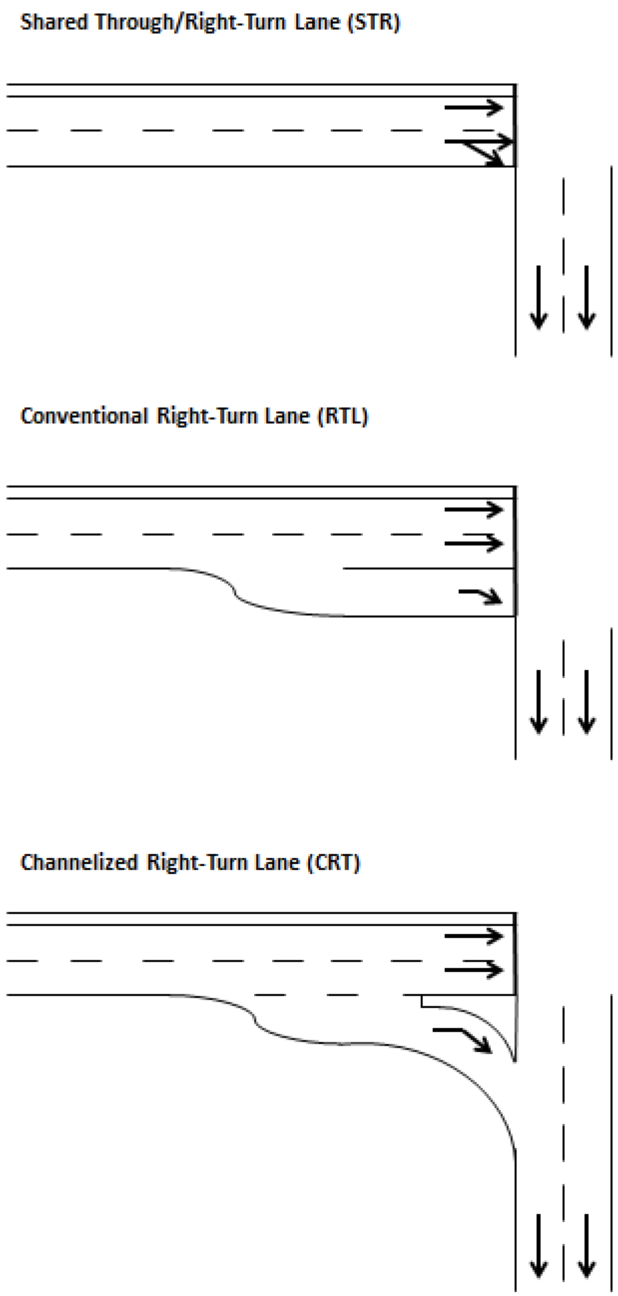


Figure 36. Illustration of Three Right-Turn Treatment Types—STR, RTL, and CRT.

6.1 Application of Channelized Right-Turn Lanes

The research results indicate that channelized right-turn lanes have a definite role in improving operations and safety at intersections. However, to achieve these benefits they should have consistent design and traffic control and should be used at appropriate locations.

Results of the observational field studies in Chapter 3 of this report suggest that, overall, pedestrians do not have difficulty crossing channelized right-turn lanes. Most pedestrians cross in the crosswalk and obey pedestrian signals. Most motorists yield to pedestrians once they are in the crosswalk of a channelized right-turn lane, either by stopping or reducing their speed. Fewer motorists in channelized right-turn lanes yield to pedestrians waiting at the curb to cross, although such failure to yield is typical of most pedestrian crossings and is not unique to channelized right-turn lanes. When stopped in a queue, motorists keep the crosswalk open to pedestrians. Avoidance maneuvers, either by a pedestrian or a motorist, were observed in less than 1 percent of the pedestrian crossings.

The traffic operational analysis in Chapter 4 of this report found that channelized right-turn lanes with yield control reduce right-turn delay to vehicles by 25 to 75 percent in comparison to intersection approaches with conventional right-turn lanes. This advantage in delay reduction was observed over the full range of vehicle and pedestrian volumes considered. Vehicle delay increased proportionally faster with increasing pedestrian crossing volume for channelized right-turn lanes than for conventional right-turn lanes, but the vehicle delay for channelized right-turn lanes was always lower than for conventional right-turn lanes.

Where a signal is provided for pedestrians to cross a channelized right-turn lane on a cycle coordinated with the primary signal at the intersection, vehicle delay with the channelized right-turn lane is, generally, greater than the vehicle delay for both conventional right-turn lanes and yield-controlled channelized right-turn lanes. For the configuration with a coordinated signal, the vehicle delay is independent of the pedestrian volume because the signal phase for crossing the channelized right-turn lane is called every cycle when the primary signal changes. This effect can be reduced in instances where pedestrian crossing times are dictating signal timing by providing a pedestrian-actuated signal for crossing the channelized right-turn lane; with an actuated signal, vehicle delay would be expected to increase proportionally with pedestrian crossing volume.

Chapter 5 of this report presents an analysis of total crashes, rear-end crashes, sideswipe crashes, and merging crashes, for three right-turn treatment types—channelized right-turn lanes, conventional right-turn lanes, and shared through/right-turn lanes. No difference in the frequency of motor-vehicle crashes was found between channelized right-turn lanes and the other right-turn treatments.

Pedestrian crash frequencies for CRT and STR approaches were very similar; pedestrian crash frequencies for RTL approaches were approximately 70 to 80 percent higher than CRT and RTL approaches, for average levels of pedestrian crossing volume. Thus, the results indicate that CRT and STR approaches have similar pedestrian safety performance, while RTL approaches have substantially more pedestrian crashes than either CRT or STR approaches. This is likely because RTL approaches have longer pedestrian crossing distances on the through roadway than CRT or STR approaches with similar overall cross sections, because pedestrians on an RTL approach must cross not only the through lanes but also the right-turn lane. A further advantage of CRT approaches is that they have a refuge island for pedestrians, providing the opportunity for crossing the intersection in a two-step process. In addition, those pedestrians that cross two legs of an intersection with a channelized right-turn lane can complete their crossing without the need to cross the channelized right-turn lane. This eliminates a conflict with right-turning traffic that would occur for the other intersection types.

The finding that CRT approaches have similar pedestrian crash frequencies to STR approaches and substantially lower pedestrian crash frequencies than RTL approaches must be considered in light of current highway agency practices for using channelized right-turn lanes. Most highway agencies choose to provide channelized right-turn lanes for locations with lower pedestrian volumes than intersections in general. For example, at the Toronto intersections evaluated in Chapter 5, the average pedestrian crossing volume was 510 pedestrians per day for CRT approaches; 1,120 pedestrians per day for RTL approaches; and 2,077 pedestrians per day for STR approaches. While the findings reported above were normalized for pedestrian volume, the general highway agency practice of using channelized right-turn lanes at intersections with lower pedestrian volumes suggests that this is a reasonable approach, and that caution should be exercised in using channelized right-turn lanes where pedestrian crossing volumes are high. For example, most channelized right-turn lanes in the Toronto database had pedestrian crossing volumes under 1,000 pedestrians per day.

6.2 Design Issues Related to Channelized Right-Turn Lanes

Crosswalk Location

A majority of the sites (nearly 70 percent) evaluated in the observational studies, presented in Chapter 3 of this report, had marked crosswalks located near the center of the channelized right-turn lane; only about 30 percent of crosswalks were located at the upstream or downstream end of the channelized right-turn lane. The highway agency survey conducted in NCHRP Project 3-72 (*3*) found that highway agencies prefer a crosswalk location near the center of a channelized right-turn lane; over 70 percent of highway agencies reported in the survey that their practice was to place crosswalks near the center of channelized right-turn lanes.

There has been little research that evaluates how the crosswalk location affects crossings by pedestrians with vision impairment in terms of their ability to identify the appropriate time to cross or efficiently locate the crosswalk. While research would be desirable to provide more concrete recommendations, orientation and mobility (O&M) specialists, who teach pedestrians with vision impairment how to better traverse intersections, recommend that consistency of crosswalk location is important to pedestrians with vision impairment. Such consistency would make it easier for O&M specialists to describe a typical channelized right-turn lane to pedestrians with vision impairment and teach procedures for crossing it.

There is no strong technical basis for recommending one crosswalk location over another, other than the need for consistency. However, consistency in locating crosswalks is important, especially to pedestrians with vision impairment, and current practice shows a clear preference for crosswalk locations near the center of a channelized right-turn lane. And, a crosswalk location at the center of the channelized right-turn lane moves vehicle-pedestrian conflicts away from both the diverge maneuver at the upstream end of the channelized right-turn lane and, especially, from the merge maneuver at the downstream end of the channelized right-turn lane. The only potential exception to a center crosswalk location for channelized right-turn lanes is that, where STOP sign or traffic signal control is provided on the channelized right-turn lane, the crosswalk should be located beyond the stop line. In addition, at locations where the channelized right-turn lane intersects the cross street at nearly a right angle, the stop line and crosswalk may be better placed at the downstream end of the channelized right-turn lane, depending on the island size and location of sidewalk approaches. To summarize the recommended guidance for the placement of crosswalks at channelized right-turn lanes:

- Where the entry to the cross street at the downstream end of the channelized right-turn lane has yield control or no control, place the crosswalk near the center of the channelized right-turn lane.
- Where the channelized right-turn lane has STOP sign control or traffic signal control, place the crosswalk immediately downstream of the stop bar, where possible. Where the channelized right-turn roadway intersects with the cross street at nearly a right angle, the stop bar and crosswalk can be placed at the downstream end of the channelized right-turn roadway.

Special Crosswalk Signing and Marking

Seven of the observational field study sites (see Chapter 3 of this report) included special crosswalk signing and marking treatments. An informal comparison of pedestrian and motorist behavior was made between the sites with special crosswalk signing and marking and the other observational field study sites. The comparison suggested that the additional signage and pedestrian crosswalk treatments may improve the motorist yield behavior and pedestrian use of the crosswalk. For example, the yield behavior of motorists yielding to pedestrians waiting at the curb was slightly better (47 percent vs. 40 percent) at sites with special crosswalk treatments. This suggests that additional emphasis on signing or other treatments may be needed to increase yielding for pedestrians waiting at the curb.

Enhanced features of crosswalk signing and marking that are desirable include:

- Use of a raised crosswalk to improve visibility of crosswalk for motorists and to better define crosswalk boundaries for pedestrians (raised crosswalks are particularly helpful to pedestrians with vision impairment).
- 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).

Island Type

The channelizing island that defines a channelized right-turn lane, 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. O&M specialists have a strong preference for raised islands with "cut-through" pedestrian paths, which provide better guidance and information about the location of the island for pedestrians with vision impairment than painted islands.

Radius of Turning Roadway

The traffic operational analysis in Chapter 4 of this report found that increasing the radius of a channelized right-turn roadway reduces right-turn delay by approximately 10 to 20 percent for each 8-km/h (5-mi/h) increase in turning speed. Larger delay reductions generally occur when conflicting traffic volumes on the cross street are lower. However, vehicle delay should not be the only consideration when selecting an appropriate radius. Larger radii generally encourage higher turning speeds, and previous research (*15*) has shown that higher speeds can result in a decrease in yielding to pedestrians by motorists. Thus, smaller radii may be more appropriate at locations where pedestrians are anticipated.

Angle of Intersection with Cross Street

The alignment of a channelized right-turn lane and the angle between the channelized right-turn roadway and the cross street can be designed in two different ways (as illustrated in Figure 9 in Chapter 2):

- A flat-angle entry to the cross street
- A nearly-right-angle entry to the cross street

The two designs shown in Figure 9 differ in the shape of the island that creates the channelized right-turn lane. The flat-angle entry design has an island that is typically shaped like an equilateral triangle (often with one curved side), while the nearly-right-angle design is typically shaped like an isosceles triangle. The flat-angle entry design is appropriate for use in channelized right-turn lanes with either yield control or no control for vehicles at the entry to the cross street. The nearly-right-angle entry design can be used with STOP sign control or traffic signal control for vehicles at the entry to the cross street; yield control can also be used with this design where the angle of entry and sight distance along the cross street are appropriate.

Acceleration Lanes

Acceleration lanes at the downstream end of a channelized right-turn lane provide an opportunity for vehicles to complete the right-turn maneuver unimpeded and then accelerate parallel to the cross-street traffic prior to merging. The traffic operational analysis in Chapter 4 of this report found that the addition of an acceleration lane can reduce the right-turn delay by 65 to 85 percent, depending on the conflicting through traffic volume, and may be considered where right-turn delay is a particular problem. Acceleration lanes are only desirable where there are no driveways or other access points on the cross street within or close to the acceleration lane. In addition, channelized right-turn lanes with acceleration lanes at their downstream end appear to be very difficult for pedestrians with vision impairment to cross. Therefore, the use of acceleration lanes at the downstream end of a channelized right-turn lane should generally be reserved for locations where no pedestrians or very few pedestrians are present. Typically, these would be locations without sidewalks or pedestrian crossings; at such locations, the reduction in vehicle delay resulting from addition of an acceleration lane becomes very desirable.

Traffic Control

Channelized right-turn lanes with signals tied to the signal cycle of the primary intersection consistently experience more delay to right-turning vehicles than yield-controlled channelized right-turn lanes. If signalization of the right-turn movement is used, a conventional right-turn lane configuration (including right-turn on red) generally performs better than signalization of the channelized right-turn lane. However, at signalized channelized right-turn lanes, it is common for traffic engineers to provide extra green time to the right-turn movement without increasing cycle length by overlapping the right turn with the cross street left turn. Figure 37 illustrates the concept of a right-turn overlap. A potential drawback of the right-turn overlap phasing is that U-turns cannot be permitted from the cross-street left-turn lane, as they may conflict with right-turning vehicles. Thus, use of an overlap phase, or other method of providing additional green time to right-turning vehicles, can substantially reduce the delay for a signalized channelized right-turn lane, but may result in other impacts to intersection operations, such as the need to restrict U-turn maneuvers.

Where a signal is provided for pedestrians to cross a channelized right-turn lane, a pedestrian-actuated signal should be considered. This can reduce vehicle delay because the phase for crossing the channelized right-turn lane is called only when pedestrians are present.

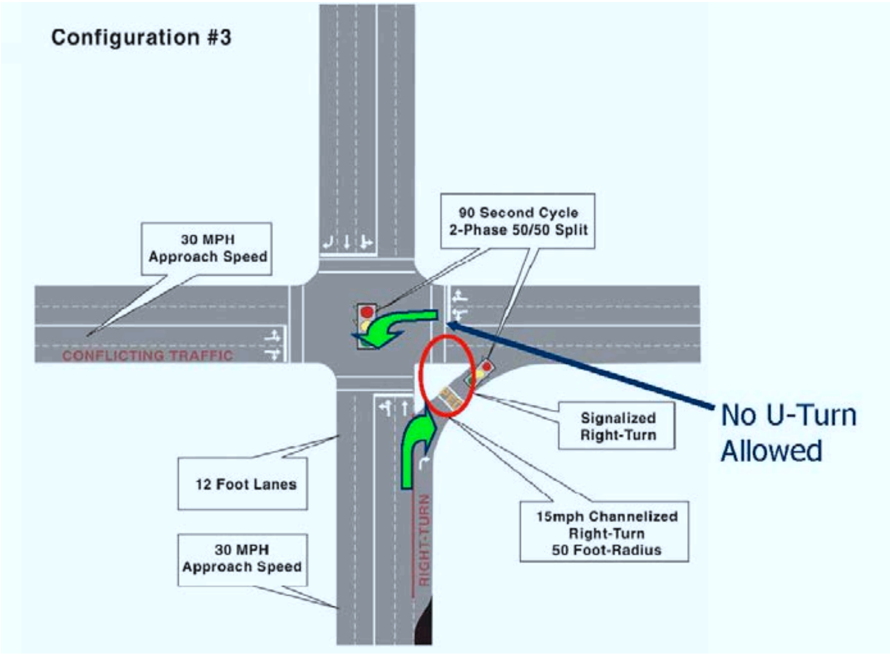


Figure 37. Right-Turn Overlap

Chapter 7. Conclusions and Recommendations

This chapter presents the conclusions and recommendations based on the results of the research.

7.1 Conclusions

The following conclusions are based on field observational studies of vehicle and pedestrian interactions at channelized right-turn lanes, interviews with orientation and mobility (O&M) specialists, traffic operational analyses of channelized right-turn lanes conducted with VISSIM, and safety analyses of channelized right-turn lanes:

- A majority of the sites (nearly 70 percent) had marked crosswalks located near the center of the channelized right-turn lane; only about 30 percent of crosswalks were located at the upstream or downstream end of the channelized right-turn lane. The highway agency survey conducted in NCHRP Project 3-72 (*3*) found that highway agencies prefer a crosswalk location near the center of a channelized right-turn lane; over 70 percent of highway agencies reported in the survey that their practice was to place crosswalks near the center of channelized right-turn lanes.
- Pedestrians did not appear to have any particular difficulty crossing channelized right-turn lanes. Most pedestrians crossed in the crosswalk (75 percent) and, where pedestrian signals were present, most pedestrians crossed during the pedestrian crossing phase (72 percent). The pedestrians who crossed outside the crosswalk generally did so when no vehicular traffic was present and this behavior did not cause any traffic conflicts. Avoidance maneuvers by a pedestrian or motorist appear to be relatively rare, and were observed in less than 1 percent of the pedestrian crossings.
- Nearly all motorists (over 96 percent) yielded to pedestrians in the crosswalk, or were unaffected by the pedestrian crossing (i.e., the pedestrian crossed without substantially impacting the vehicle's speed). The observed yield rate was somewhat lower (approximately 40 percent) for pedestrians waiting at the curb. The failure of vehicles to yield to pedestrians waiting to cross at a marked crosswalk is not unique to channelized right-turn lanes, but is a general problem at pedestrian crosswalks. The yield behavior of motorists was slightly better (47 percent vs. 40 percent) at sites with special crosswalk treatments (e.g., raised crosswalk, pavement markings, signing). This may indicate that additional emphasis on signing or other treatments may be needed to increase yielding for pedestrians waiting at the curb.
- There has been little research that evaluates how the crosswalk location affects crossings by pedestrians with vision impairment in terms of their ability to identify the appropriate time to cross of efficiently locate the crosswalk. O&M specialists recommend that consistency of crosswalk location and traffic control is important to pedestrians with vision impairment. They also have a strong preference for raised islands with "cut-

through" pedestrian paths, which provide better guidance and information for pedestrians with vision impairment than do painted islands.

- Channelized right-turn lanes with yield control were shown to reduce right-turn delay to vehicles by 25 to 75 percent in comparison to intersection approaches with conventional right-turn lanes. High pedestrian volumes increase right-turn delay by approximately 60 percent on a yield-controlled channelized right-turn lane.
- The addition of an acceleration lane at the downstream end of a channelized right-turn lane can substantially reduce the right-turn delay (by 65 to 85 percent) depending on the conflicting traffic volume on the cross street. However, channelized right-turn lanes with acceleration lanes appear to be very difficult for pedestrians with vision impairment to cross due to vehicle speeds and lack of yielding by motorists.
- Increasing the radius of a channelized right-turn roadway can reduce right-turn delay by approximately 10 to 20 percent for each 8-km/h (5-mi/h) increase in turning speed. However, in previous research (*15*), higher speeds have been shown to result in a decrease in yielding to pedestrians by motorists.
- For channelized right-turn lanes with signal control, use of an overlap phase, or other method of providing additional green time to right-turning vehicles, can substantially reduce the delay for a signalized channelized right-turn lane. However, this may result in other impacts to intersection operations, such as restricting U-turn maneuvers.
- Intersection approaches with channelized right-turn lanes appear to have similar motor-vehicle safety performance as approaches with conventional right-turn lanes or shared through/right-turn lanes. This was found to be the case both at the downstream end of the channelized right-turn lane (where the right-turning vehicle merges with the cross street) as well as at the upstream end of the channelized right-turn lane (where the right-turning vehicle begins the right-turn maneuver).
- Intersection approaches with channelized right-turn lanes appear to have similar pedestrian safety performance as approaches with shared through/right-turn lanes. Intersection approaches with conventional right-turn lanes have substantially more pedestrian crashes (approximately 70 to 80 percent more) than approaches with channelized right-turn lanes or shared/through right-turn lanes.

7.2 Recommendations

The following recommendations were developed in the research:

- Channelized right-turn lanes have a definite role in improving operations and safety at intersections. However, to achieve these benefits, they should have consistent design and traffic control and should be used at appropriate locations.
- There has been little research that evaluates how the crosswalk location affects crossings by pedestrians with vision impairment, and more research would be desirable to provide more concrete recommendations.

- Since consistency in locating crosswalks is important and since current practice shows a clear preference for crosswalk locations near the center of a channelized right-turn lane, design guidance should recommend placing crosswalks near the center of the channelized right-turn lane for channelized right-turn lanes with yield control or no control at the entry to the cross street.
- Where the channelized right-turn lane has STOP sign control or traffic signal control, the crosswalk should be placed immediately downstream of the stop bar. If the channelized right-turn roadway intersects with the cross street at nearly a right angle, the stop bar and crosswalk can be placed at the downstream end of the channelized right-turn roadway.
- Raised islands should be considered because they serve as a refuge area so that pedestrians may cross the street in two stages. Raised islands with "cut-through" also provide better guidance for pedestrians with vision impairment than painted islands.
- Channelized right-turn lanes with acceleration lanes appear to be very difficult for pedestrians with vision impairment to cross. Therefore, the use of acceleration lanes at the downstream end of a channelized right-turn lane should generally be reserved for locations where no pedestrians or very few pedestrians are present. Typically, these would be locations without sidewalks or pedestrian crossings; at such locations, the reduction in vehicle delay resulting from addition of an acceleration lane becomes very desirable.
- Where a signal is provided for pedestrians to cross a channelized right-turn lane, a pedestrian-actuated signal should be considered. This can reduce vehicle delay because the phase for crossing the channelized right-turn lane is called only when pedestrians are present.
- Use of an overlap phase (or other method of providing additional green time to right-turning vehicles) should be considered as it can substantially reduce delay at channelized right-turn lanes with signals tied to the signal cycle of the primary intersection. However, consideration should be given to other possible impacts to intersection operations, such as restricting U-turn maneuvers.

The general highway agency practice of using channelized right-turn lanes at intersections with lower pedestrian volumes suggests that this is a reasonable approach, and that caution should be exercised in using channelized right-turn lanes where pedestrian crossing volumes are high (e.g., over 1,000 pedestrians per day). This guidance is based on the 85th percentile pedestrian volume—1,000 pedestrians per day—in the Toronto intersection database that was used for the safety evaluation. While channelized right-turn lanes may be suitable for higher pedestrian volumes, the research cannot predict the safety performance of channelized right-turn lanes with pedestrian volumes beyond the range evaluated in the research.

Chapter 8. References

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Appendix A

Design Guide for Channelized Right-Turn Lanes

Chapter 1
Introduction

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-turn lanes in all quadrants of the intersection, channelized right-turn lanes may be appropriate in some quadrants, but not in others, depending on intersection geometry and traffic demands.

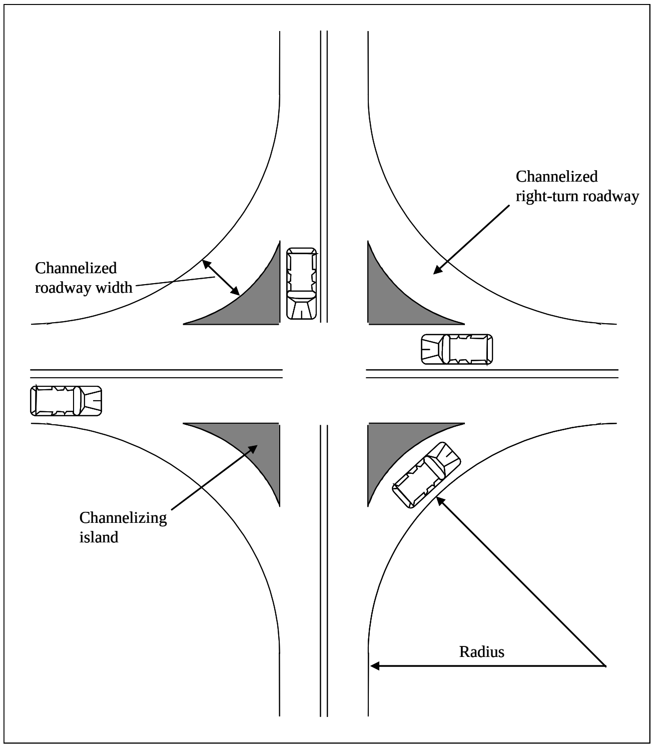


Figure 1. Typical Intersection With Channelized Right-Turn Lanes

The primary reasons for providing a channelized right-turn lane are (*1*):

- 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

Chapter 2
Consideration of User Types

Many transportation agencies use channelized right-turn lanes to improve operations at intersections, although there may be advantages and disadvantages of channelized right-turn lanes for different roadway user types including motor vehicles, pedestrians, and bicyclists.

Motor Vehicles

The primary traffic operational reasons for providing channelized right-turn lanes are to increase vehicular capacity at an intersection, reduce delay to drivers by allowing them to turn at higher speeds, and reduce unnecessary stops. Channelized right-turn lanes appear to provide a net reduction in motor vehicle delay at intersections where they are installed. A yield-controlled channelized right-turn lane can reduce right-turn delay by 25 to 75 percent in comparison to intersection approaches with conventional right-turn lanes (*2*). This advantage in delay reduction would like be observed at channelized right-turn lanes with no traffic control on the right-turn roadway.

It is generally accepted that channelized right-turn lanes improve safety for motor vehicles at intersections where they are used, but there have been concerns that channelized right-turn lanes may experience a higher proportion of rear-end crashes than other right-turn treatments. Recent research (*2*) assessed whether channelized right-turn lanes experience more crashes than intersection approaches with conventional right-turn lanes or shared through/right-turn lanes. Research results found that any difference in motor-vehicle safety performance between the three right-turn treatments was not conclusively established.

At intersections with substantial truck volumes, channelized right-turn lanes permit the use of large curb return radii to accommodate large trucks, without unnecessarily increasing the intersection pavement area and the pedestrian crossing distance.

Pedestrians

A key concern with channelized right-turn lanes has been 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 or the placement of pedestrian crosswalks or pedestrian signals on channelized right-turn lanes may violate driver expectancy. For most pedestrians, crossing the channelized right-turn roadway may be a relatively easy task because such roadways are not very wide and because traffic is approaching from a single direction. However, pedestrians with vision impairment may have difficulty detecting approaching traffic because (a) right-turning vehicles are traveling a curved rather than a straight path; (b) there is not a systematic stopping and starting of traffic, as there would be at a conventional signal- or stop-controlled intersection; and (c) the traffic sounds from the major streets may mask the sound of traffic on the right-turn roadway.

Despite these potential problems, channelized right-turn lanes also provide advantages for pedestrians. The provision of a channelized right-turn lane, while making it necessary for pedestrians to cross two roadways, often reduces the pedestrian crossing distance. Furthermore the channelizing island, particularly when bounded by raised curbs, serves as a refuge area for pedestrians, and improves safety by allowing pedestrians to cross the street in two stages.

Bicyclists

There may be an inherent risk to bicyclists at channelized right-turn lanes 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 on crash history are available to support this presumption. However, similar conflicts between through bicyclists and right-turn vehicles are present at conventional intersections as well.

Chapter 3
Traffic Operational and Safety Considerations for Channelized Right-Turn Lanes

Channelized right-turn lanes have a definite role in improving traffic operations and safety at intersections. Specific traffic operational and safety considerations related to channelized right-turn lanes are discussed below.

Traffic Operational Considerations

Channelized right-turn lanes can play a key role in reducing right-turn delay to vehicles. Channelized right-turn roadways may have no control or may be controlled by stop signs, yield signs, or signals. In comparison to intersection approaches with conventional right-turn lanes, channelized right-turn lanes with *yield* control can reduce right-turn delay to vehicles by 25 to 75 percent (*2*). This advantage in delay reduction has been observed for pedestrian crossing volumes up to 200 ped/h. Similar delay reductions would likely be observed for channelized right-turn lanes with *no* traffic control.

Right-turn delay at *signalized* channelized right-turn lanes is generally higher than at yield-controlled channelized right-turn lanes, and is typically higher than or similar to the right-turn delay at conventional right-turn lanes at signalized intersections where right-turn-on-red (RTOR) operation is permitted. At signalized channelized right-turn lanes, it is common for traffic engineers to provide extra green time to the right-turn movement without increasing cycle length by overlapping the right turn with the cross street left turn. Figure 2 illustrates the concept of a right-turn overlap. A potential drawback of the right-turn overlap phasing is that U-turns cannot be permitted from the cross-street left-turn lane, as they may conflict with right-turning vehicles. The elimination of the U-turn can be a significant issue in states where U-turns are allowed at all intersections and in areas that have median access control and U-turns are the primary means of providing left-turn access to businesses. Thus, use of an overlap phase or other methods of providing additional green time to right-turning vehicles can substantially reduce the delay for a signalized channelized right-turn lane, but may result in other impacts to intersection operations.

Where a signal is provided for pedestrians to cross a channelized right-turn lane on a cycle coordinated with the primary signal at the intersection, vehicle delay with the channelized right-turn lane is generally greater than vehicle delay for conventional right-turn lanes and for yield-controlled channelized right-turn lanes. The vehicle delay is independent of the pedestrian volume because the phase for crossing the channelized right-turn lane can be called every cycle in conjunction with the cross-street signal phase. A disadvantage of providing a pedestrian signal is that a pedestrian must wait for the pedestrian crossing phase to cross the channelized right-turn lane and then wait again for the pedestrian crossing phase of the primary intersection to cross the major or cross street. However, pedestrian signals are very important to pedestrians with vision impairment who cross at a channelized right-turn lane. Provision of a pedestrian-actuated signal should be considered.

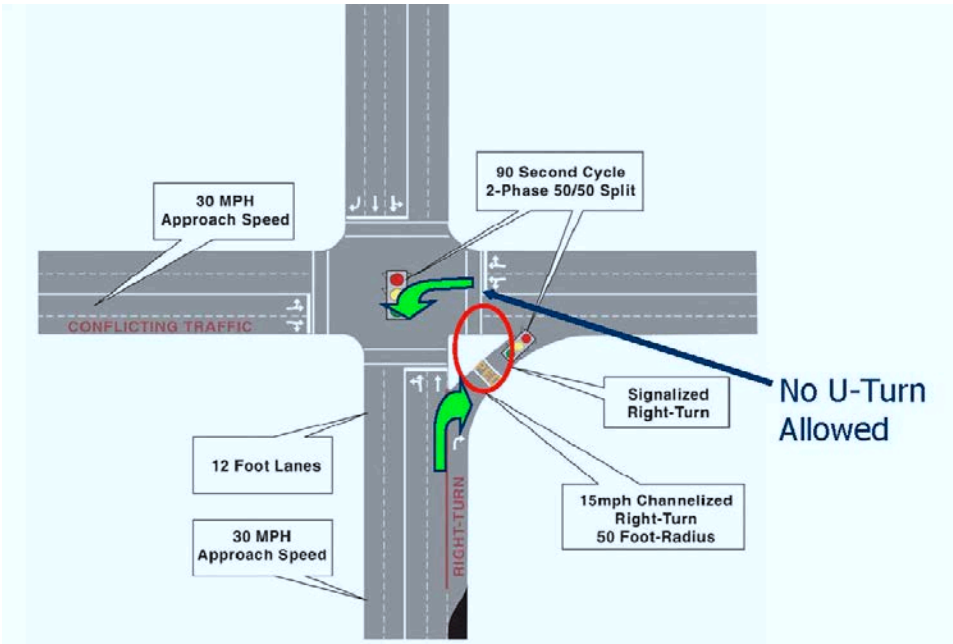


Figure 2. Right-Turn Overlap

Traffic Safety Issues

It is generally accepted that channelized right-turn lanes improve safety for motor vehicles, but there have been concerns about the safety of channelized right-turn lanes for pedestrians. Recent research (*2*) evaluated seven years of motor-vehicle and pedestrian crash and volume data from nearly 400 four-leg signalized intersection approaches in Toronto, Ontario, Canada. The Toronto data represented a unique resource because they included both vehicle turning-movement volumes and pedestrian crossing volumes by intersection approach, as well as crash data that could be classified by intersection approach and turning movement. The results of this research provide insights into the safety of motor vehicles and pedestrians at channelized right-turn lanes.

Potts et al. (*2*) assessed whether channelized right-turn lanes experience more motor-vehicle crashes than other right-turn treatments, such as conventional right-turn lanes or shared through/right-turn lanes. The research results found that any difference between the three right-turn treatment types was not conclusively established. Concerns have been raised that channelized right-turn lanes may experience a higher proportion of rear-end crashes, particularly at the downstream end of a channelized right-turn lane as vehicles merge into cross-street traffic. The same research (*2*) compared rear-end crash experience at channelized right-turn lanes to that of conventional right-turn lanes and shared through/right-turn lanes and found no difference between the right-turn treatments that could be conclusively established.

A key concern with channelized right-turn lanes has been pedestrian safety as pedestrians cross the right-turn roadway. Specifically, there have been concerns that the driver's attention may be focused on cross-street traffic and that the placement of pedestrian crosswalks or pedestrian signals on channelized right-turn lanes may violate driver expectancy. Research results *(2)* showed that channelized right-turn lane approaches and approaches with shared through/right-turn lanes have similar pedestrian crash frequencies, while conventional right-turn lane approaches have substantially more (70 to 80 percent) pedestrian crashes than either of the other two right-turn treatments, for average levels of pedestrian crossing volumes. This is likely because conventional right-turn lane approaches have longer pedestrian crossing distances. A further advantage of channelized right-turn lanes is that they have a refuge island for pedestrians, providing the opportunity for crossing the intersection in two stages. In addition, those pedestrians that cross two legs of an intersection with a channelized right-turn lane can complete their crossing without the need to cross the channelized right-turn lane. This eliminates a conflict with right-turning traffic that would occur with the other intersection types.

Most highway agencies choose to provide channelized right-turn lanes for locations with lower pedestrian volumes than intersections in general. For example, at the intersection considered in a safety evaluation by Potts et al. (*2*), the average pedestrian crossing volume was 510 pedestrians per day for channelized right-turn lane approaches; 1,120 pedestrians per day for conventional right-turn lane approaches; and 2,077 pedestrians per day for shared through/right-turn lane approaches. While the findings reported by Potts et al. were normalized for pedestrian volume, the general highway agency practice of using channelized right-turn lanes at intersections with lower pedestrian volumes suggests that this is a reasonable approach. The findings (*2*) are based on a database with an 85th percentile pedestrian volume of 1,000 pedestrians per day. Therefore, caution should be exercised in using channelized right-turn lanes where pedestrian crossing volumes are high (i.e., greater than 1,000 ped/day).

For most pedestrians, crossing the channelized right-turn roadway can be a relatively easy task because such roadways are not very wide and because traffic is approaching from a single direction. However, pedestrians with vision impairment may have difficulty detecting approaching traffic. Certain design considerations at channelized right-turn lanes may better facilitate the safety crossing of channelized right-turn lanes by pedestrians with vision impairment. These design considerations are discussed in Chapter 4.

Chapter 4
Design Issues Related to Channelized Right-Turn Lanes

The AASHTO *Policy on Geometric Design of Highways and Streets* (*1*), 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* (*2*). Recent research (*3*) provides additional guidance on various design issues for channelized right turns.

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

- Crosswalk location
- Special crosswalk signing and marking
- Island type
- Radius of turning roadway
- Angle of intersection with cross street
- Deceleration and acceleration lanes
- Traffic control
- Bicycle treatments

Each of these issues is addressed below.

Crosswalk Location

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. 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.

A majority of the sites (nearly 70 percent) evaluated by Potts et al. (*3*) had marked crosswalks located near the center of the channelized right-turn lane; only about 30 percent of crosswalks were located at the upstream or downstream end of the channelized right-turn lane. The highway agency survey conducted in NCHRP Project 3-72 (*4*) found that highway agencies prefer a crosswalk location near the center of a channelized right-turn lane; over 70 percent of highway agencies reported in the survey that their practice was to place crosswalks near the center of channelized right-turn lanes.

There has been little research that evaluates how the crosswalk location affects crossings by pedestrians with vision impairment in terms of their ability to identify the appropriate time to cross or efficiently locate the crosswalk. While further research would be desirable to provide more complete recommendations based on field observations of pedestrians with vision impairment, orientation and mobility (O&M) specialists, who teach pedestrians with vision impairment how to better traverse intersections recommend that consistency of crosswalk location is important. Such a consistency would make it easier for O&M specialists to describe a typical channelized right-turn lane to pedestrians with vision impairment and teach procedures for crossing such lanes.

There is no strong technical basis for recommending one crosswalk location over another, other than the need for consistency. However, consistency in locating crosswalks is important, especially to pedestrians with vision impairment, and current practice shows a clear preference for crosswalk locations near the center of a channelized right-turn lane. And, a crosswalk location at the center of the channelized right-turn lane moves vehicle-pedestrian conflicts away from both the diverge maneuver at the upstream end of the channelized right-turn lane and, especially, from the merge maneuver at the downstream end of the channelized right-turn lane. The only potential exception to a center crosswalk location for channelized right-turn lanes is that, where STOP sign or traffic signal control is provided on the channelized right-turn roadway, the crosswalk should be located beyond the stop line. In addition, at locations where the channelized right-turn lane intersects the cross street at nearly a right angle, the stop line and crosswalk may be better placed at the downstream end of the channelized right-turn lane, depending on the island size and location of sidewalk approaches. To summarize the recommended guidance for the placement of crosswalks at channelized right-turn lanes:

- Where the entry to the cross street at the downstream end of the channelized right-turn lane has yield control or no control, place the crosswalk near the center of the channelized right-turn lane.
- Where the channelized right-turn lane has STOP sign control or traffic signal control, place the crosswalk immediately downstream of the stop bar, where possible. Where the channelized right-turn roadway intersects with the cross street at nearly a right angle, the stop bar and crosswalk can be placed at the downstream end of the channelized right-turn roadway.

Special Crosswalk Signing and Marking

Marked crosswalks are the primary means of indicating the presence of a pedestrian crossing. However, drivers do not always yield the right-of-way to pedestrians simply because they are in a crosswalk. Other special crosswalk signing and marking treatments have been considered for use at pedestrian crossings on channelized right-turn roadways to enhance crossing safety for pedestrians, in general, and for pedestrians with vision impairment. These include:

- Use of a raised crosswalk to improve visibility of crosswalk for motorists and to better define crosswalk boundaries for pedestrians (Raised crosswalks are particularly helpful to pedestrians with vision impairment)
- Addition of reflective 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)

None of these traffic control approaches has been evaluated to prove its effectiveness for pedestrian crossings on channelized right-turn roadways. However, an informal comparison (*3*) of pedestrian and motorist behavior between observational field study sites with and without special crosswalk signing and marking (i.e., raised crosswalks with contrast pavement markings and additional signing) suggested that the additional signing and pedestrian crosswalk treatments may improve the motorist yield behavior and pedestrian use of the crosswalk. For example, the percentage of motorists yielding to pedestrians waiting at the curb was slightly better (47 percent vs. 40 percent) at sites with special crosswalk treatments. This suggests that additional emphasis on signing or other treatments may be needed to increase yielding for pedestrians waiting at the curb.

Island Type

A channelized right-turn lane 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, 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. 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-turn lanes typically serve all three functions.

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. Curbed islands can improve the safety for pedestrians by allowing them to cross the street in two stages. Orientation and mobility (O&M) specialists have a strong preference for raised islands with "cut-through" pedestrian paths because they provide better guidance and information about the location of the island for pedestrians with vision impairment than painted islands. Where curb ramps are provided, 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 with vision impairment.

Radius of Turning Roadway

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. Such criteria are established in current design policy, but the needs of pedestrians and trucks are in conflict in setting such criteria. For example, large turning radii better accommodate large trucks negotiating through right-turn maneuvers, but may result in higher turning speeds on the right-turn roadway as pedestrians are crossing. On the other hand, 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.

Reduction of delay to turning vehicles is a key reason for providing a channelized right-turn lane, and recent research (*3*) found that increasing the radius of a channelized right-turn roadway reduces right-turn delay by approximately 10 to 20 percent for each 8-km/h (5-mi/h) increase in turning speed. Where right-turn volumes are high and pedestrian and bicycle volumes are relatively low, capacity considerations may dictate the use of larger radii, which enable higher-speed, higher-volume turns. However, small corner radii, which promote low-speed right turns, are appropriate where such turns regularly conflict with pedestrians, as higher speeds have been shown to result in a decrease in yielding to pedestrians by motorists.

Angle of Intersection with Cross Street

The alignment of a channelized right-turn lane and the angle between the channelized right-turn roadway and the cross street can be designed in two different ways (as illustrated in Figure 3):

- A flat-angle entry to the cross street
- A nearly-right-angle entry to the cross street

The two designs shown in Figure 3 differ in the shape of the island that creates the channelized right-turn lane. The flat-angle entry design has an island that is typically shaped like an equilateral triangle (often with one curved side), while the nearly-right-angle design is typically shaped like an isosceles triangle. The flat-angle entry design is appropriate for use in channelized right-turn lanes with either yield control or no control, such locations with an acceleration lane, for vehicles at the entry to the cross street. The nearly-right-angle entry design can be used with STOP sign control or traffic signal control for vehicles at the entry to the cross street; yield control can also be used with this design where the angle of entry and sight distance along the cross street are appropriate.

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. Substantial deceleration or acceleration that takes place directly on the through traveled way may disrupt the flow of through traffic and increase the potential for

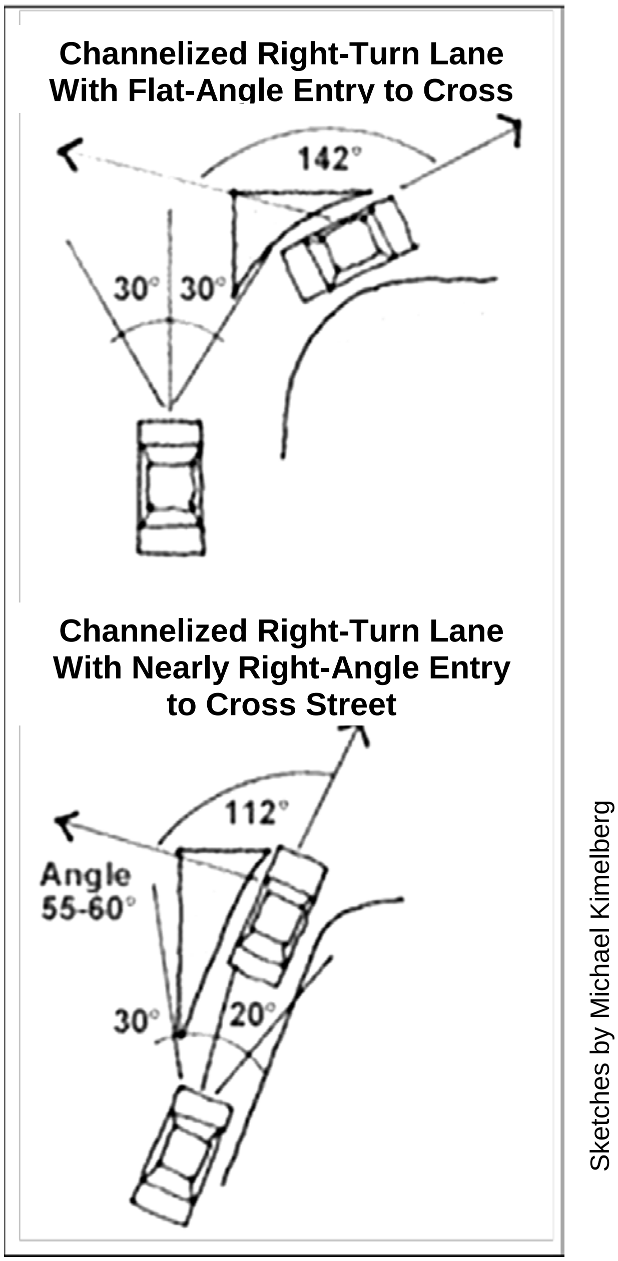


Figure 3. Typical Channelized Right-Turn Lanes With Differing Entry Angles to the Cross Street [Adapted From (*5*)]

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 4 shows the typical use of deceleration and acceleration lanes in conjunction with channelized right-turns lanes.

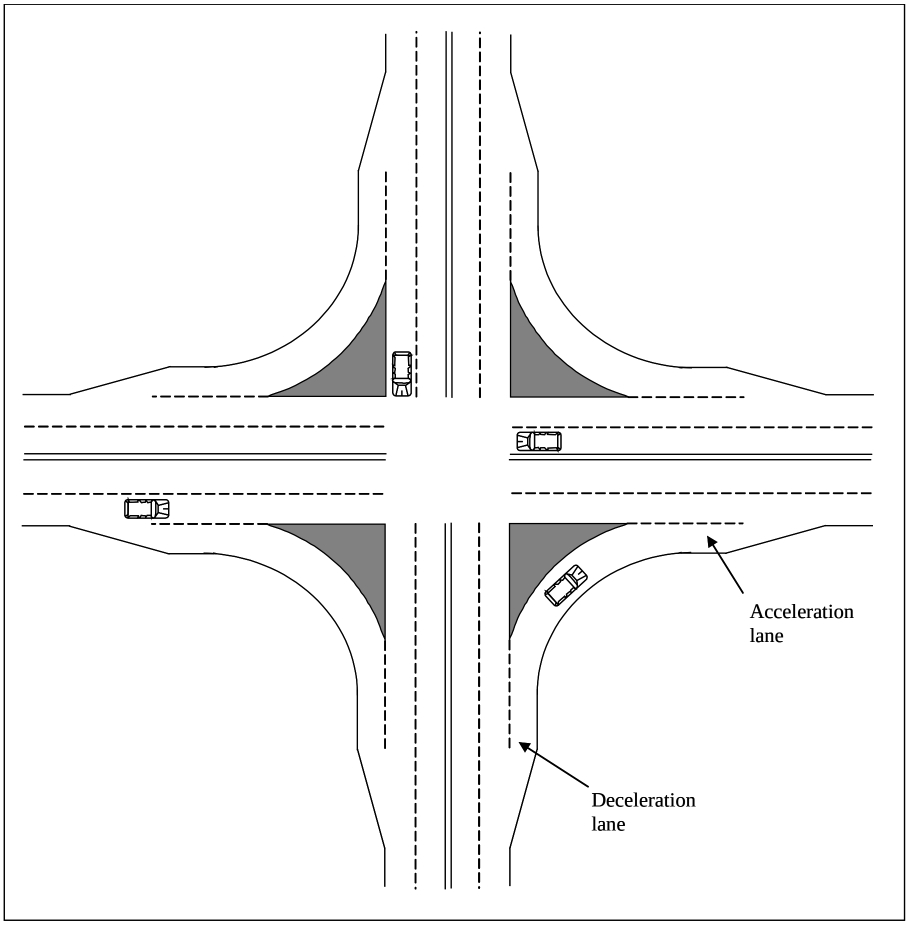


Figure 4. Channelized Right-Turn Lanes With Deceleration And Acceleration Lanes.

There are no generally established criteria concerning where deceleration and acceleration lanes should be provided in conjunction with channelized right-turn lanes. The AASHTO *Green Book* (*1*) 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.

Deceleration Lanes

Right-turn deceleration lanes provide one or more of the following functions (*6*):

- 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 lane provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway.

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. The addition of an acceleration lane at the downstream end of a channelized right-turn lane can reduce the right-turn delay by 65 to 85 percent, depending on the conflicting through traffic volume, and may be considered where right-turn delay is a particular problem. Channelized right-turn lanes with acceleration lanes appear to be very difficult for pedestrians with vision impairment to cross. Therefore, the use of acceleration lanes at the downstream end of a channelized right-turn lane should generally be reserved for locations where no pedestrians or very few pedestrians are present. Typically, these would be locations without sidewalks or pedestrian crossings; at such locations, the reduction in vehicle delay resulting from addition of an acceleration lane becomes very desirable.

Traffic Control

Channelized right-turn lanes 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.

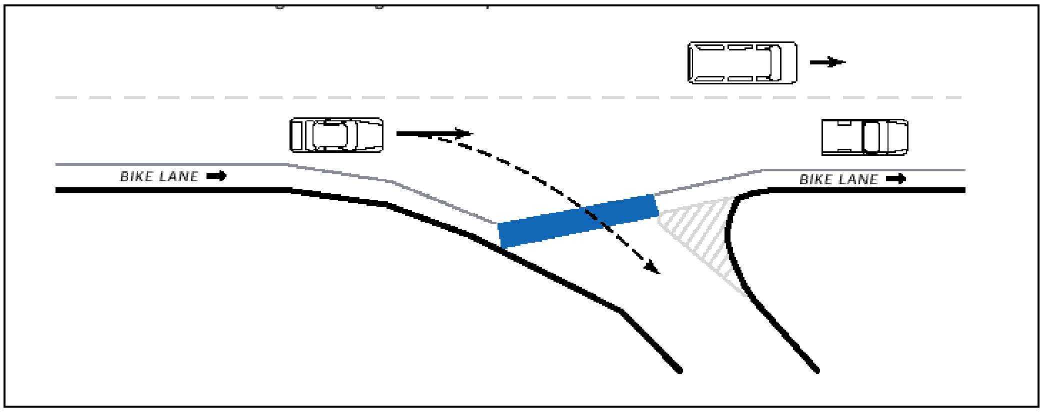
The primary traffic control decision for a channelized right-turn roadway concerns the type of traffic control device to be provided at the downstream end of the right-turn roadway, where it enters the cross street. Traffic control alternatives include no control, yield control, stop control, and signal control. Recent research (*3*) found that signalized channelized right-turn lanes consistently experience more delay to right-turning vehicles than yield-controlled channelized right-turn lanes. Use of an overlap phase, as discussed in Chapter 3 and illustrated in Figure 2 of this Guide, can substantially reduce the delay for a signalized channelized right-turn lane, but may result in other impacts to intersection operations, such as the need to restrict U-turn maneuvers.

Pedestrian signals can be used at pedestrian crossings on channelized right-turn roadways to enhance crossing safety for pedestrians, particularly for pedestrians with vision impairment. Where a signal is provided for pedestrians to cross a channelized right-turn lane, a pedestrian-actuated signal should be considered. Actuation reduces vehicle delay for other movements because the phase associated to crossing the channelized right-turn lane is called only when pedestrians or adequate vehicular demand is present.

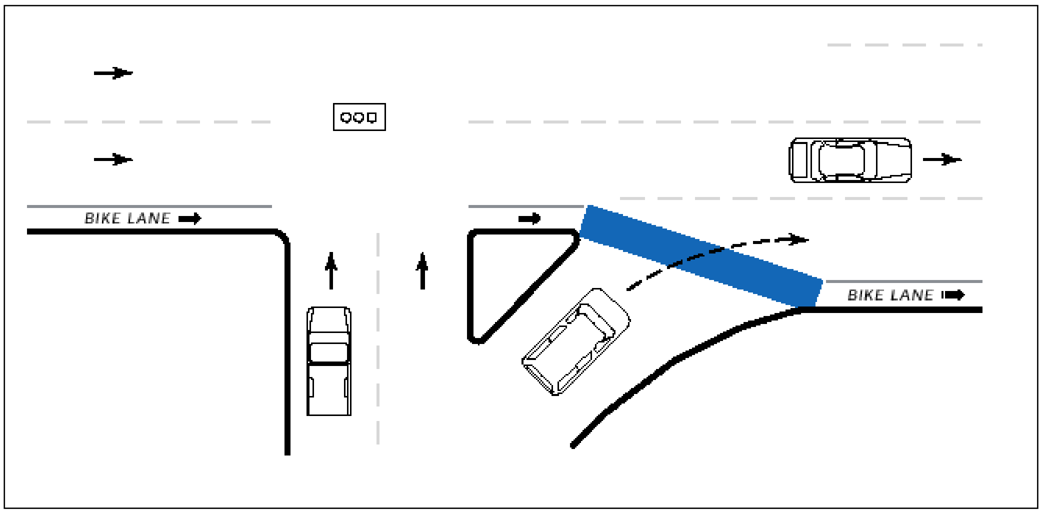
Bicycle Treatments

There is a potential risk to bicyclists at channelized right-turn lanes because motor vehicles entering the channelized right-turn roadway must weave across the path of bicycles traveling straight through the intersection. However, 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 at three-leg intersections where there is no leg to the right on a given approach.

Highway agencies may want to consider using special pavement markings and signing, such as those illustrated in Figures 5 and 6, to highlight a preferred bicycle path through channelized right-turn lanes and to increase motorist awareness of bicyclists at channelized right-turn lanes. Hunter et al. conducted a before-after evaluation of the blue pavement markings and signing in Figures 5 and 6 and found that they resulted in an increase in motorists yielding to bicyclists and an increase in bicyclists following the marked path. Overall, the treatment appeared to result in a heightened awareness on the part of both bicyclists and motorists.



a. At entrance to channelized right-turn roadway



b. At exit of channelized right-turn roadway

Figure 5. Blue Pavement Marking Treatment at Channelized Right-Turn Lane (*7*)

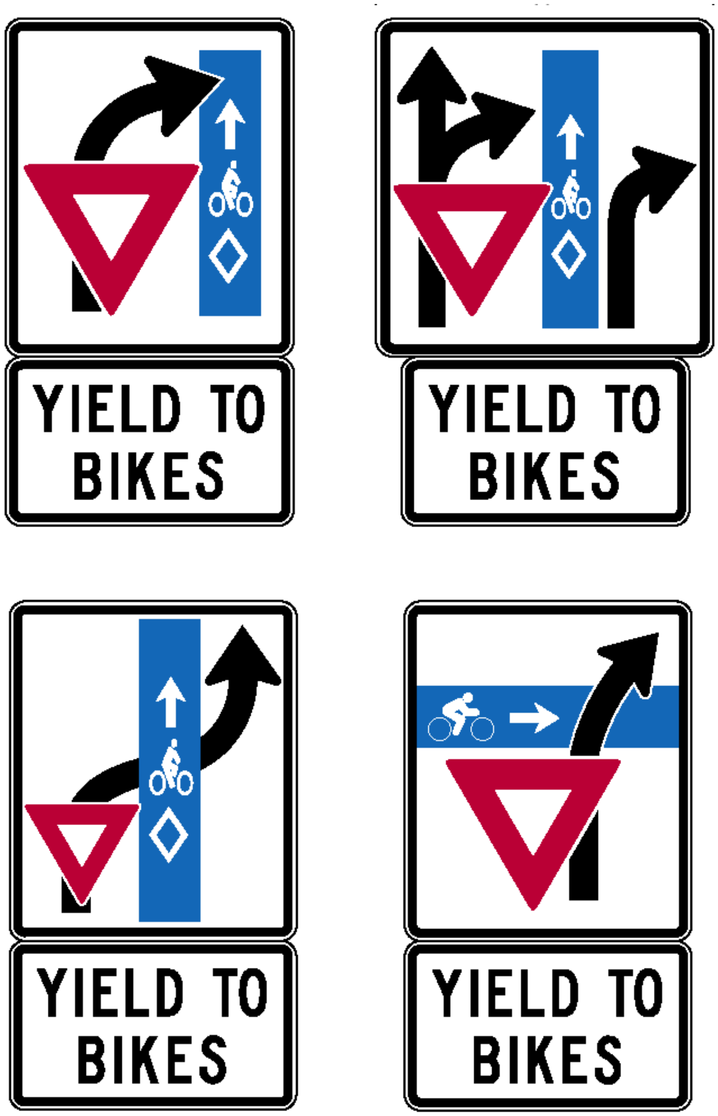


Figure 6. Signs Used in Oregon Blue Bike Lane Program (*7*)

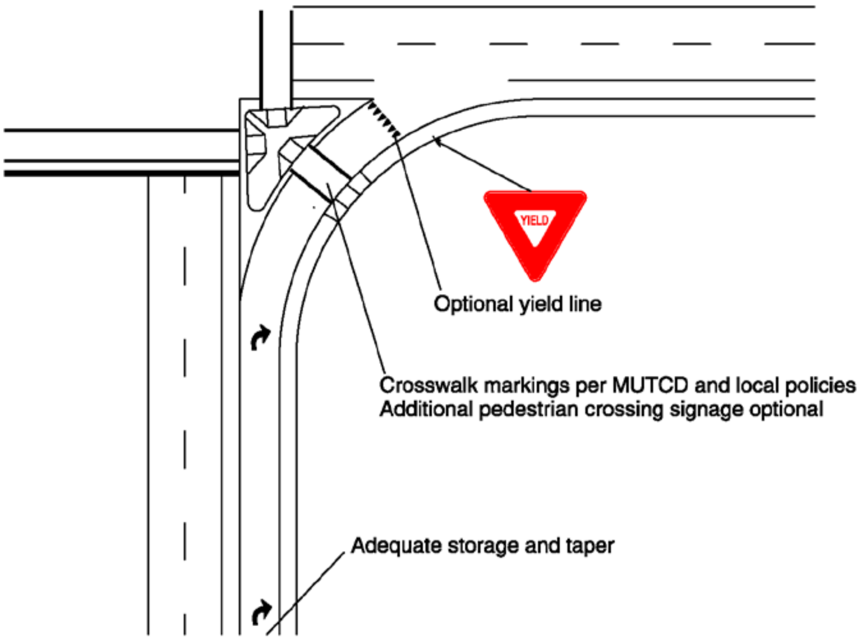
Chapter 5
Typical Channelized Right-Turn Lane Designs

This chapter presents diagrams of the following four typical channelized right-turn lane designs:

- Channelized right-turn lane with center crosswalk and yield control
- Channelized right-turn lane with center crosswalk, acceleration lane, and no control
- Channelized right-turn lane with center crosswalk and stop control
- Channelized right-turn lane with center crosswalk, signal control, and pedestrian signal

Advantages and disadvantages of each design are presented below each diagram.

Channelized Right-Turn Lane With Center Crosswalk and Yield Control



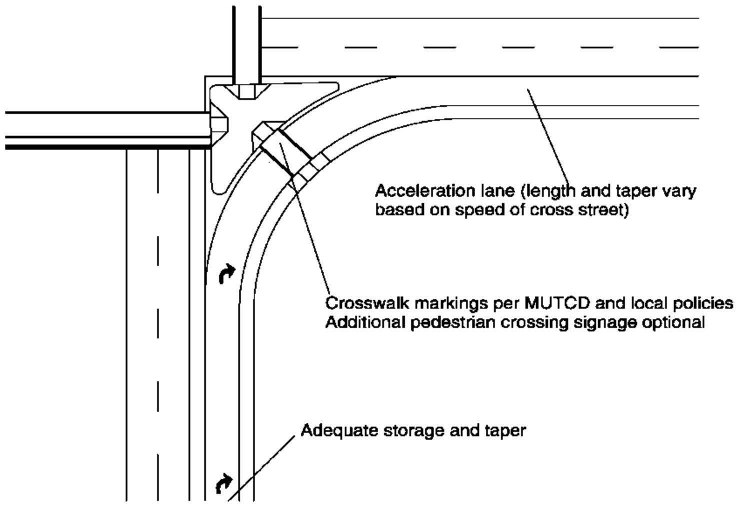
Advantages

- Channelized right-turn lanes with yield control have been shown to reduce right-turn delay to vehicles by 25 to 75 percent in comparison to intersection approaches with conventional right-turn lanes.
- Channelized right-turn lanes generally result in reduced pedestrian crossing distances and exposure.
- Shorter signal phase times (of primary signal) are possible due to shorter pedestrian crossing distance.
- A consistent practice of placing the crosswalk near the center of the channelized right-turn lane would be beneficial to pedestrians with vision impairment, particularly if accompanied by a raised island with a cut-through path.
- The addition of a deceleration lane at the approach to a channelized right-turn lane provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway.

Disadvantages

- The lack of a pedestrian signal can be especially challenging for pedestrians with vision impairment.
- Potential for queued vehicles to stack across the crosswalk.
- Channelized right-turn lanes generally have a greater intersection influence area in which driveways would need to be restricted.

Channelized Right-Turn Lane With Center Crosswalk, Acceleration Lane, and No Control



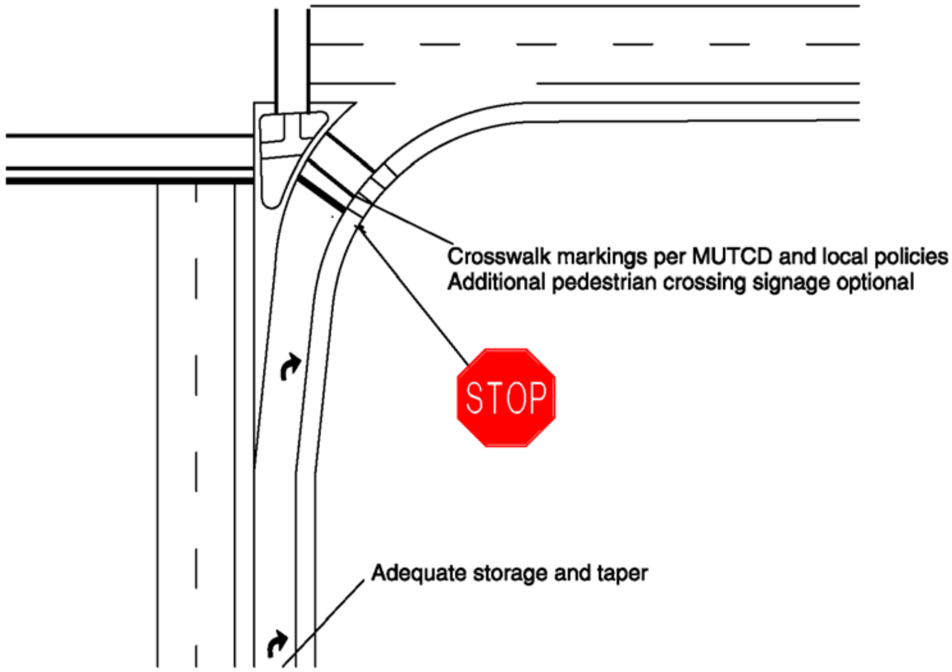
Advantages

- The addition of an acceleration lane can reduce the right-turn delay by 65 to 85 percent, depending on the conflicting traffic volume on the cross street.
- The addition of an acceleration lane may allow motorists to focus on the crosswalk area prior to having to address the task of merging with the cross-street traffic.
- Channelized right-turn lanes generally result in reduced pedestrian crossing distance and exposure.
- Shorter signal phase times (of primary signal) are possible due to shorter pedestrian crossing distances.
- A consistent practice of placing the crosswalk near the center of the channelized right-turn lane would be beneficial to pedestrians with vision impairment, particularly if accompanied by a raised island with a cut-through path.
- The addition of a deceleration lane at the approach to a channelized right-turn lane provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway.

Disadvantages

- The addition of an acceleration lane to a channelized right-turn lane makes crossing very challenging for pedestrians with vision impairment.
- High-speed merging and weaving maneuvers may be challenging for bicyclists traveling on the cross street.
- Higher turning speeds may be a disadvantage for pedestrian crossings.
- The lack of a pedestrian signal can be especially challenging for pedestrians with vision impairment.
- Channelized right-turn lanes generally have a greater intersection influence area in which driveways would need to be restricted.

Channelized Right-Turn Lane with Center Crosswalk and STOP Control



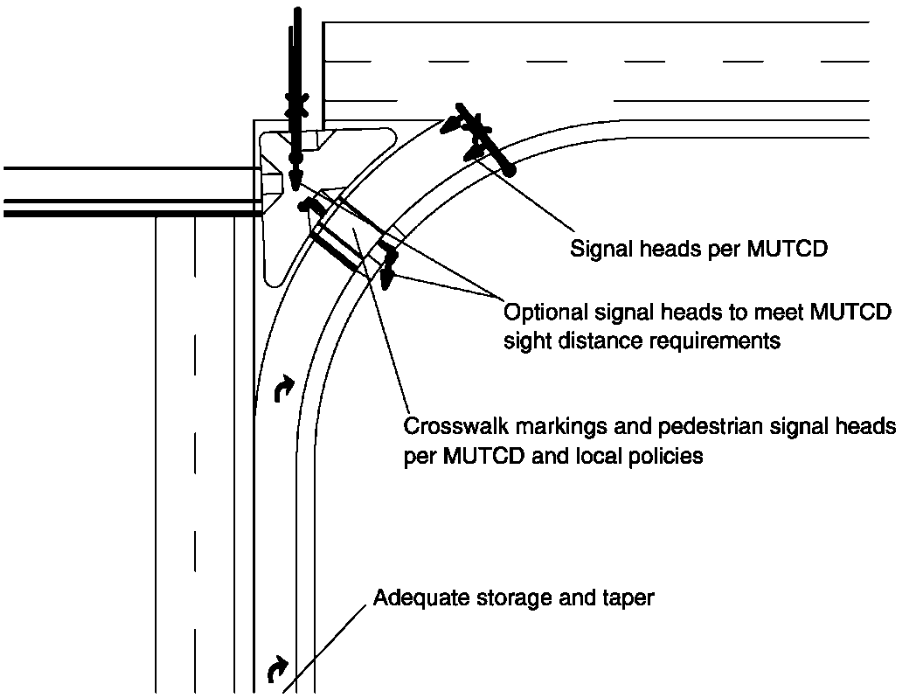
Advantages

- Providing a STOP sign on the channelized right-turn lane may provide more crossing opportunities for pedestrians than yield control. The crosswalk should be placed immediately downstream of the stop line, where possible.
- Consideration should be given to designing the channelized right-turn roadway such that it intersects with the cross street at nearly a right angle. This provides the driver with less of a skew angle when searching for gaps in cross-street traffic.
- A consistent practice of placing the crosswalk near the center of the channelized right-turn lane would be beneficial to pedestrians with vision impairment, particularly if accompanied by a raised island with a cut-through path. However, where the channelized right-turn roadway intersects with the cross street at nearly a right angle, the stop line and crosswalk can be placed at the downstream end of the channelized right-turn roadway.
- The addition of a deceleration lane at the approach to a channelized right-turn lane provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway.

Disadvantages

- STOP control results in increased delay for right-turning vehicles than yield control.
- There is a greater potential for longer right-turn queues with STOP control than with yield control.
- The lack of a pedestrian signal can be especially challenging for pedestrians with vision impairment.
- Channelized right-turn lanes generally have a greater intersection influence area in which driveways would need to be restricted.

Channelized Right-Turn Lane With Center Crosswalk and Signal Control and Pedestrian Signal



Advantages

- Providing a signal on the channelized right-turn lane may provide more crossing opportunities for pedestrians than STOP or yield control, particularly at locations with high right-turn volumes and pedestrian volumes.
- Provision of a pedestrian signal is especially beneficial pedestrians with vision impairment but may make crossing easier for all pedestrians.
- Ability to install dual right-turn lanes to increase capacity without impacting the pedestrian crossing distance for the intersection legs and the associated pedestrian crossing times in the traffic signal timing.
- Channelized right-turn lanes generally result in reduced pedestrian crossing distances and exposure.
- Shorter signal phase times (of primary signal) are possible due to shorter pedestrian crossing distance.
- A consistent practice of placing the crosswalk near the center of the channelized right-turn lane would be beneficial to pedestrians with vision impairment, particularly if accompanied by a raised island with a cut-through path.
- The addition of a deceleration lane at the approach to a channelized right-turn lane provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway.

Disadvantages

- Signal control results in increased delay for right-turning vehicles than STOP or yield control, particularly when RTOR is not permitted.
- Some pedestrians will likely cross against the pedestrian signal.
- There is an additional cost of installing the traffic signal equipment for the channelized right-turn movement.
- Channelized right-turn lanes generally have a greater intersection influence area in which driveways would need to be restricted.

References

1. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets*, 2004.
2. American Association of State Highway and Transportation Officials, *Guide for Planning, Design, and Operation of Pedestrian Facilities*, 2004.
3. Potts, I. B., D. W. Harwood, K. M. Bauer, D. K. Gilmore, J. M. Hutton, D. J. Torbic, J. F. Ringert, A. Daleiden, and J. M. Barlow, "Design Guidance for Channelized Right-Turn Lanes," Final Report, NCHRP Project 3-89, Midwest Research Institute, July 2011.
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5. Zegeer, C. V., C. Seiderman, P. Lagerwey, M. Cynecki, M. Ronkin, and B. Schneider, *Pedestrian Facilities Users Guide: Providing Safety and Mobility*, Report No. FHWA-RD-01-102, Federal Highway Administration, March 2002.
6. Neuman, T. R., *NCHRP Report 279: Intersection Channelization Design Guide*, TRB, National Research Council, Washington, D.C., 1985.
7. Hunter, W. W., D. L. Harkey, J. R. Stewart, and M. L. Birk, *Evaluation of the Blue Bike Lane Treatment Used in Bicycle/Motor Vehicle Conflict Areas in Portland, Oregon*, Report No. FHWA-RD-00-150, Federal Highway Administration, August 2000.

Appendix B

Revised Text on Channelized Right-Turn Lanes for the AASHTO *Green Book*

This appendix presents revised text on channelized right-turn lanes for consideration by AASHTO for potential inclusion in a future edition of the AASHTO *Policy on Geometric Design of Highways and Streets* (*1*), commonly known as the *Green Book.* The first page of text should replace the discussion in Chapter 9 in the section entitled "Types and Examples of Intersections," subsection "General Considerations," that appears on Page 558 of the 2004 *Green Book*. On this first page of text, modified text is shown in a bold font. It is not intended that this bold font should be used in the *Green Book*.

The subsequent pages of text should be inserted in Chapter 9 as a new subsection under "Types of Turning Roadways," which begins on Page 583 of the 2004 *Green Book*. The recommended title of this new subsection is "Channelized Right-Turn Lanes." The new subsection could potentially be inserted before the subsection on "Minimum Edge-of-Traveled-Way Designs." This text is entirely new, so no bold font is used to identify changes.

The research team recommends that the term "free-flow right turns" be replaced with the term "channelized right-turn lanes" throughout Chapter 9 of the *Green Book.*

The *Green Book* is currently in the publication process for a major update. If this update is complete, this page in the revised final report for Project 3-89 will be updated accordingly.

Types and Examples of Intersections

General Considerations

The basic types of intersections are the three-leg or T, the four-leg, and the multileg. At each particular location, the intersection type is determined primarily by the number of intersecting legs, the topography, the character of the intersecting highways, the traffic volumes, patterns, and speeds, and the desired type of operation.

Any of the basic intersection types can vary greatly in scope, shape, and degree of channelization. Once the intersection type is established, the design controls and criteria discussed in Chapter 2 and the elements of intersection design presented in Chapter 3, as well as in this chapter, should be applied to arrive at a suitable geometric plan. In this section each type of intersection is discussed separately, and likely variations of each are shown. It is not practical to show all possible variations, but those presented are sufficient to illustrate the general application of intersection design. Many other variations of types and treatment may be found in the NCHRP Report 279, *Intersection Channelization Design Guide* (2), which shows detailed examples that are not included in this policy.

Although many of the intersection design examples are located in urban areas, the principles involved apply equally to design in rural areas. Some minor design variations occur with different kinds of traffic control, but all of the intersection types shown lend themselves to cautionary or non-stop control, stop control for minor approaches, four-way stop control, and both fixed-time and traffic-actuated signal control. Right turns without stop or yield control are sometimes provided at channelized intersections. Such **channelized right-turn lanes** should be used only where an adequate merge is provided. Where motor vehicle conflicts with pedestrians or bicyclists are anticipated, provisions for pedestrians and bicycle movements must be considered in the design. **Channelized right-turn lanes have a definite role in improving operations and safety at intersections. However, at locations with high pedestrian volumes,** the use of **channelized right-turn lanes** should be considered only where significant traffic capacity or safety problems may occur without them and adequate pedestrian crossings can be provided.

Simple intersections are presented first, followed by more complex types, some of which are special adaptations. In addition, conditions for which each intersection type may be suited are discussed below.

Channelized Right-Turn Lanes

Channelized right-turn lanes have a definite role in improving operations and safety at intersections. However, to achieve these benefits they should have consistent design and traffic control and should be used at appropriate locations.

Crosswalk Location

A pedestrian crosswalk could potentially be placed at any location along a channelized right-turn roadway (e.g., upstream, center, or downstream). 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.

A majority of the sites (nearly 70 percent) evaluated by Potts et al. (*2*) had marked crosswalks located near the center of the channelized right-turn lane; only about 30 percent of crosswalks were located at the upstream or downstream end of the channelized right-turn lane. The highway agency survey conducted in NCHRP Project 3-72 (*3*) found that highway agencies prefer a crosswalk location near the center of a channelized right-turn lane; over 70 percent of highway agencies reported in the survey that their practice was to place crosswalks near the center of channelized right-turn lanes.

Consistency of crosswalk location at channelized right-turn lanes is important to pedestrians with vision impairment, and current highway agency practice indicates a preference for crosswalk locations near the center of a channelized right-turn lane. And, a crosswalk location at the center of the channelized right-turn lane moves vehicle-pedestrian conflicts away from both the diverge maneuver at the upstream end of the channelized right-turn lane and, especially, from the merge maneuver at the downstream end of the channelized right-turn lane. The only potential exception to a center crosswalk location for channelized right-turn lanes is that where STOP sign or traffic signal control is provided at the entry to the cross street, the crosswalk should be located beyond the stop line at that point. To summarize the recommended guidance for the placement of crosswalks at channelized right-turn lanes:

- Where the entry to the cross street at the downstream end of the channelized right-turn lane has yield control or no control, place the crosswalk near the center of the channelized right-turn lane.
- Where the entry to the cross street at the downstream end of the channelized right-turn lane has STOP sign control or traffic signal control, place the crosswalk immediately downstream of the stop bar, where possible. Where the channelized right-turn roadway intersects with the cross street at nearly a right angle, the stop bar and crosswalk can be placed at the downstream end of the channelized right-turn roadway.

Special Crosswalk Signing and Marking

Marked crosswalks are the primary means of indicating the presence of a pedestrian crossing. However, drivers do not always yield the right-of-way to pedestrians simply because they are in a crosswalk. Other special crosswalk signing and marking treatments have been considered for use at pedestrian crossings on channelized right-turn roadways to enhance crossing safety for pedestrians, in general, and for pedestrians with vision impairment. These include:

- Use of a crosswalk to improve visibility of crosswalk for motorists and to better define crosswalk boundaries for pedestrians (Raised crosswalks are particularly helpful to pedestrians with vision impairment)
- 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)

Additional signing and pedestrian crosswalk treatments may improve the motorist yield behavior and pedestrian use of the crosswalk.

Island Type

A channelized right-turn lane 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, 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. 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-turn lanes typically serve all three functions.

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. Curbed islands can improve the safety for pedestrians by allowing them to cross the street in two stages. Raised islands with “cut-through” pedestrian paths are important to pedestrians with vision impairment because they provide better guidance and information about the location of the island than painted islands. Where curb ramps are provided, 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 with vision impairment.

Radius of Turning Roadway

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. Channelized right-turn lanes provide one method for accommodating larger turning radii without widening the major-street pedestrian crossings and without increasing the intersection pavement area. Where right-turn volumes are high and pedestrian and bicycle volumes are relatively low, capacity considerations may dictate the use of larger radii, which enable higher-speed, higher-volume turns. However, small turning radii, which promote low-speed right turns, are appropriate where such turns regularly conflict with pedestrians, as higher speeds have been shown to result in a decrease in yielding to pedestrians by motorists.

Angle of Intersection With Cross Street

The alignment of a channelized right-turn lane and the angle between the channelized right-turn roadway and the cross street can be designed in two different ways:

- A flat-angle entry to the cross street
- A nearly-right-angle entry to the cross street

The two designs differ in the shape of the island that creates the channelized right-turn lane. The flat-angle entry design has an island that is typically shaped like an equilateral triangle (often with one curved side), while the nearly-right-angle design is typically shaped like an isosceles triangle. The flat-angle entry design is appropriate for use in channelized right-turn lanes with either yield control or no control for vehicles at the entry to the cross street. The nearly-right-angle entry design can be used with STOP sign control or traffic signal control for vehicles at the entry to the cross street; yield control can also be used with this design where the angle of entry and sight distance along the cross street are appropriate.

Deceleration Lanes

Drivers making a right-turn maneuver at an intersection are usually required to reduce speed before turning. Significant deceleration 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 in the through travel lanes, deceleration lanes should be considered.

Right-turn deceleration lanes provide one or more of the following functions (*4*):

- 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 lane provides an opportunity for motorists to safely slow down prior to reaching the crosswalk area at the turning roadway.

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. Channelized right-turn lanes with acceleration lanes appear to be very difficult for pedestrians with vision impairment to cross. Therefore, the use of acceleration lanes at the downstream end of a channelized right-turn lane should generally be reserved for locations where no pedestrians or very few pedestrians are present. Typically, these would be locations without sidewalks or pedestrian crossings; at such locations, the reduction in vehicle delay resulting from addition of an acceleration lane becomes very desirable.

Pedestrian Signals

Pedestrian signals can be used at pedestrian crossings on channelized right-turn roadways to enhance crossing safety for pedestrians, particularly for pedestrians with vision impairment. Where a signal is provided for pedestrians to cross a channelized right-turn lane, a pedestrian-actuated signal should be considered.

References

1. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets*, 2004.
2. Potts, I. B., D. W. Harwood, K. M. Bauer, D. K. Gilmore, J. M. Hutton, D. J. Torbic, J. F. Ringert, A. Daleiden, and J. M. Barlow, *NCHRP Web-Only Document 208: Design Guidance for Channelized Right-Turn Lanes*, Transportation Research Board of the National Academies, Washington, D.C., 2011.
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