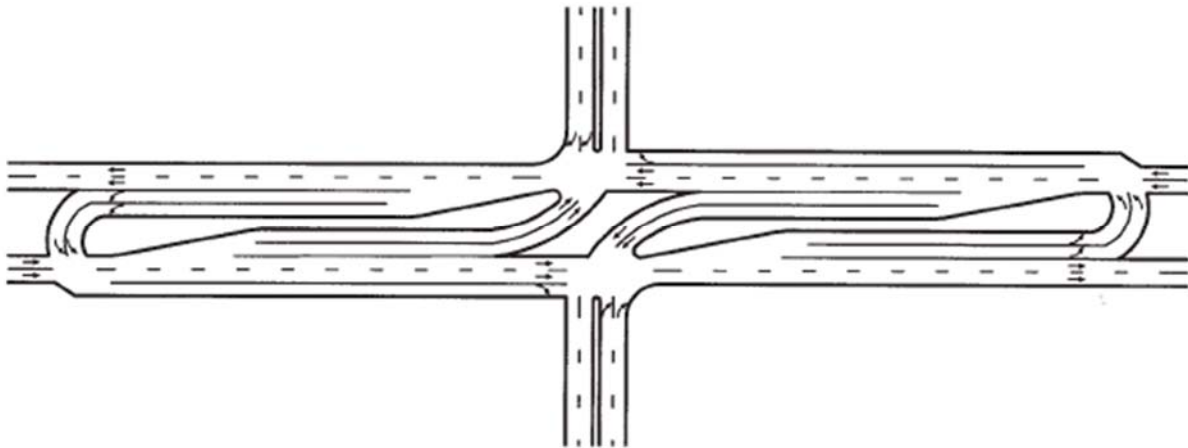


Best Practices for the Design and Operation of Reduced Conflict Intersections



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Table of Contents

INTRODUCTION.....	5
Purpose.....	5
Definition.....	5
Advantages	6
Disadvantages	6
Applications.....	7
DESIGN ELEMENTS.....	9
Roadway Design	9
Main Intersection Design.....	9
Left Turn (J-Turn) Crossover Design	9
Treatment of Minor Street Right Turn Lanes	11
Right Turn (Minor to Major) Acceleration Lanes.....	13
Curb Type	14
Median U-Turn Crossover Design.....	14
Crossover Spacing.....	14
U-Turn Crossover Design	15
U-Turn Lane Design.....	19
U-Turn Crossover Acceleration Lanes.....	21
Pedestrian and Bicycle Accommodations	22
Pedestrian Crossings.....	22
Bicycle Crossings.....	25
Pavement Markings and Signing.....	27
Pavement Markings.....	27
Signing.....	29
Signal and Lighting Design.....	34
Signal Warrants for U-Turns.....	34
Flashing Yellow Arrows for U-Turns and Left Turns	35
Lighting Design.....	35
Signal Pole Placement	36
Signal Operations	39
Signal Phasing and Ring Structure	39
Signal Coordination	40
Number of Controllers	41
Right Turn on Red and Left Turn on Red.....	44
Maintenance	45
Snow Removal	45

SAFETY	46
Conflict Points.....	46
Crash Types.....	46
Crash Modification Factor.....	47
SPECIAL USER CONSIDERATIONS	47
Transit	47
Emergency Vehicles	50
REFERENCES.....	51

Figures

Figure 1: Vehicular Movements at an Intersection with U-Turn Roadways for Indirect Left Turns	5
Figure 2: Feasible Demands for RCIs	8
Figure 3: Left Turn Design Recommendations for a Reduced Conflict Intersection	10
Figure 4: Example of Channelized Right Turn Lanes at an RCI in San Antonio, Texas.....	12
Figure 5: Spacing Consideration for a Minor Street Through or Left Movement	15
Figure 6: Example Plan of a Median U-Turn Crossover.....	17
Figure 7: Loon at a U-Turn Crossover with Two U-Turn Lanes.....	18
Figure 8: RCI with Back-to-Back U-Turn Lane Design	20
Figure 9: RCI with U-Turn Lanes Extended to the Main Intersection	21
Figure 10: "Z" Pedestrian Crossing Treatment at an RCI.....	23
Figure 11: Offset Approach RCI Pedestrian Crossing.....	24
Figure 12: Pedestrian Crossing at a Signalized U-Turn Crossover.....	24
Figure 13: Pedestrian Crossing at a Three-Approach RCI.....	25
Figure 14: Bicycle Lane Configuration on the Major Approach at an RCI	26
Figure 15: Bicycle Route Options for the Minor Street of an RCI	26
Figure 16: NCDOT Example Pavement Marking Plan at an RCI	27
Figure 17: Typical Pavement Marking at a Single-Lane Median U-Turn Crossover.....	28
Figure 18: Pavement Marking Standard at a Dual-Lane Median U-Turn Crossover	28
Figure 19: Median U-Turn Crossover Design with a Separating Striped Median	29
Figure 20: Example Signing Plan from a Signalized RCI in Maryland.....	31
Figure 21: Guide Signs for Median U-Turn Crossovers from Maryland (Left) and Texas (Right)	32
Figure 22: Overhead Signing on the Minor Street (Evans Rd) Approaching the Major Street (US-281)	33
Figure 23: Recommended Signage at the Left Turn (J-Turn) Intersection of an RCI	33
Figure 24: Recommended Signage at the Median U-Turn Crossover Intersection of an RCI	34
Figure 25: Example Street Lamp Placement at an RCI.....	35
Figure 26: Possible Signal Pole Locations at an RCI.....	37

Figure 27: Signal Pole Locations at an RCI on US-17 in North Carolina.....	37
Figure 28: Signal Pole Locations at an RCI on US-17 in North Carolina.....	38
Figure 29: Median U-Turn Crossover Signal Pole Locations at an RCI in North Carolina.....	38
Figure 30: Signal Pole Locations on the Minor Approaches of an RCI on US-17 in North Carolina.....	39
Figure 31: Two-Phase Signal Phasing at the Main Intersection of an RCI.....	40
Figure 32: Example of Bidirectional Progression on an RCI Arterial	41
Figure 33: Signalized RCI with Four Separate Signal Controllers.....	42
Figure 34: Signalized RCI with Three Separate Signal Controllers.....	42
Figure 35: Signalized RCI with Two Separate Signal Controllers.....	43
Figure 36: Signalized RCI with One Signal Controller.....	44
Figure 37: Conflict Points at an RCI from the FHWA	46
Figure 38: Potential Bus Stop Locations at an RCI	48
Figure 39: Potential Bus Stop Locations on the Minor and Major Streets of an RCI	49
Figure 40: RCI Major Street Bus Stop Location Options between U-Turn Crossovers	49

Tables

Table 1: Advantages and Disadvantages of Reduced Conflict Intersections	6
Table 2: Recommended Crossover Spacing from Various Agencies.....	14
Table 3: AASHTO Minimum Median Widths for U-Turns	16
Table 4: Conflict Point Comparison between an RCI and Conventional Intersection.....	46

INTRODUCTION

PURPOSE

Kimley-Horn, under contract with the Minnesota Department of Transportation (MnDOT), has conducted a review of guidance documentation on the design and operation of Reduced Conflict Intersections (RCIs), with a particular focus on signal-controlled RCIs. In addition to synthesizing information from a variety of sources, MnDOT also interviewed representatives from the Texas Department of Transportation (TxDOT) and the North Carolina Department of Transportation (NCDOT)—the two states with the most implemented signalized RCIs in the United States at this time. This document summarizes the findings of this literature review, and is intended to be used as a working best practices guidance document for the design and operation of signalized RCIs in Minnesota.

DEFINITION

The Federal Highway Administration (FHWA) and many state Departments of Transportation are in support of and advocating for the implementation of innovative intersection designs. Innovative intersection designs move vehicles more safely and efficiently than a conventional at-grade intersection, and are much less costly than grade separation.

A reduced conflict intersection, also referred to as a Restricted Crossing U-Turn intersection (RCUT), J-turn intersection, superstreet, or synchronized street is a form of innovative alternative intersection design that displaces left turn and through movements from the minor intersecting roadway. Rather than stopping the mainline to allow minor street traffic to cross, minor street traffic is routed to a downstream intersection where they make a U-turn. **Figure 1** illustrates the vehicle paths allowed at an RCI.

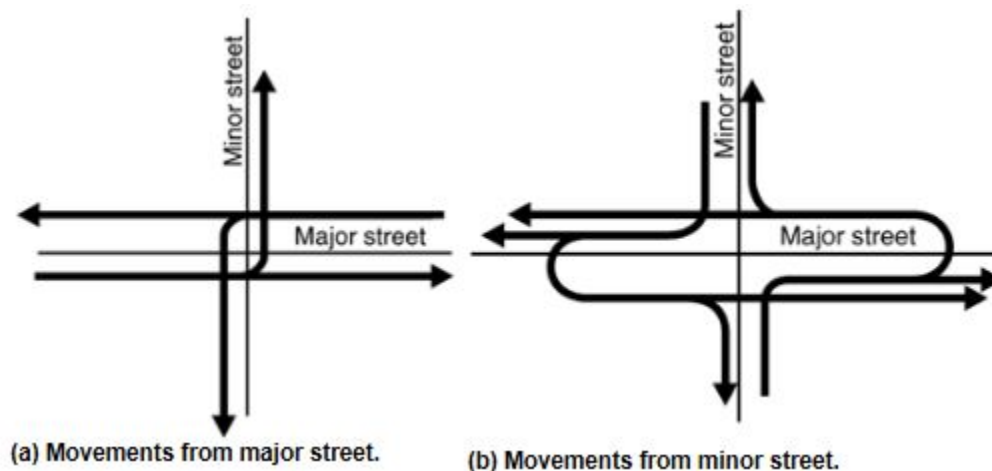


Figure 1: Vehicular Movements at an Intersection with U-Turn Roadways for Indirect Left Turns

Source: FHWA¹

When implemented in appropriate settings, RCIs can provide a variety of safety and operational benefits over conventional intersection configurations. Several key advantages and disadvantages of the intersection treatment include:

Advantages

- Reduction in the number of vehicle-vehicle conflict points at the intersection, which reduces the crash potential.
- Less severe crash types compared to those at the conflict points of a conventional intersection.
- Delay reduction for the major street movements through the use of two rather than four phase signal control, as well as independent control in each direction, which allows for greater optimization.
- Cost-effective design compared to grade separation, with fewer construction impacts, that can typically be implemented a fraction of the time.

Disadvantages

- Introduction of mainline weaving movements on high speed roadways.
- Creation of indirect minor street movements, which have the potential to increase travel time and distance for minor street movements.
- Longer pedestrian paths and two-stage pedestrian crossings may increase crossing times for pedestrians and introduce way-finding challenges; however, if wide medians already exist, two-stage pedestrian crossings are likely already required.
- Indirect movements may increase time needed to access local businesses, or create the perception of increased access time.
- Lack of driver familiarity may require investments in public education and outreach.

The Federal Highway Administration (FHWA) has developed a more comprehensive list of advantages and disadvantages, as provided in **Table 1**.

Table 1: Advantages and Disadvantages of Reduced Conflict Intersections

	Advantages	Disadvantages
Non-motorized users	• Reduces conflicts between vehicles and pedestrians for most crossing movements • Creates shorter pedestrian crossing distance for some movements • Creates opportunities to install mid-block signalized crossings in many places along an arterial	• Increases conflicts between vehicles and pedestrians for some crossing movements • Creates longer pedestrian crossing distances for some movements, which could add delay and reduce convenience • Requires pedestrians to cross in two stages in some cases, which could add delay and reduce convenience • Overall pedestrian wayfinding may require additional signs and other features to create appropriate crossings for pedestrians of all abilities • Provisions for bicycle facilities may be very different from conventional intersections, and may result in reduced convenience
Safety	• At rural four-lane sites, reduces crashes, injuries, and fatalities • Reduces turning and angle crashes • Reduces vehicle-pedestrian conflict points	• Increases sideswipe crashes • Increases travel distances which could lead to more crashes that are related to distance traveled, such as animal and run-off-road crashes

	Advantages	Disadvantages
Operations	• Creates the possibility for the largest possible progression bands in both directions of the arterial at any speed with any signal spacing • Provides potential to reduce overall travel time at signalized sites • Provides potential to reduce delay and travel time for arterial through traffic at signalized sites • Provides potential for shorter signal cycle lengths • Allows larger portion of signal cycle to be allocated to the arterial through movement • Reduces the need for signalization of intersections along rural, high-speed, divided highways	• Increases travel distance (and potentially travel time) for minor street left turn and through movements • Experiences a firm capacity • Creates potential for spillback out of crossover storage lane • Minor street left turn and through drivers must make unusual maneuvers and may need additional guidance
Access Management	• Provides multiple driveway or side street locations along the RCUT corridor • Signals for driveways or side streets may be installed without introducing significant extra delay for arterial through movement • Allows flexibility for crossover locations to accommodate adjacent driveways and side streets • Does not require frontage roads	• Does not allow driveway or side street near entrance to U-turn crossover • Landowners will not have driveways with direct left turns out of their properties
Traffic Calming	• Two-way progression capabilities provide the opportunity to set any progression speed (even low speed) • Provides an additional barrier to fast minor street through traffic across arterial	• The additional barrier to direct minor street through traffic across arterial could be a concern for communities that straddle the arterial and desire direct vehicle connections
Space	• The greater arterial throughput creates possibility to reduce the basic number of through lanes on the arterial and achieve similar service levels	• May require additional right-of-way for loons or wider medians
Maintenance	• Less queuing on the arterial may reduce pavement rutting and wear	• When signalized, there are more signal controllers and cabinets than a comparable conventional intersection • There are more signs than a comparable conventional intersection • If designed with a larger median, there is more to maintain than a comparable conventional intersection • More pavement to maintain in U-turn crossovers and loons
Aesthetics	• Median and islands provide opportunity for landscaping	

Source: FHWA¹

APPLICATIONS

While RCIs have the potential to provide many benefits as an intersection treatment, these benefits may only be realized when applied to roadways with particular characteristics. Under certain volume conditions, the RCI intersection becomes less efficient than a conventional intersection (intersections with high minor street through and left turn demand, for example). RCI design will be most effective at intersections with at least one of the following attributes:

- Intersections where side-street left turn and through volumes are relatively low and the left turn volumes from the major road are high; the ratio of minor road total volume to total intersection volume should be less than or equal to 0.20.²
- On a major highway where the integrity of the through route needs to be maintained with more green time than a conventional signalized intersection can provide.³
- Areas where median widths are greater than 40 feet; for narrower medians, loons, or bulb-outs on the shoulders need to be constructed to allow all vehicles to perform U-turns.⁴
- Intersections with a high number of far-side right-angle crashes²

Figure 2 provides a nomograph with guidance on the feasible demand conditions for which a signalized RCI is appropriate:

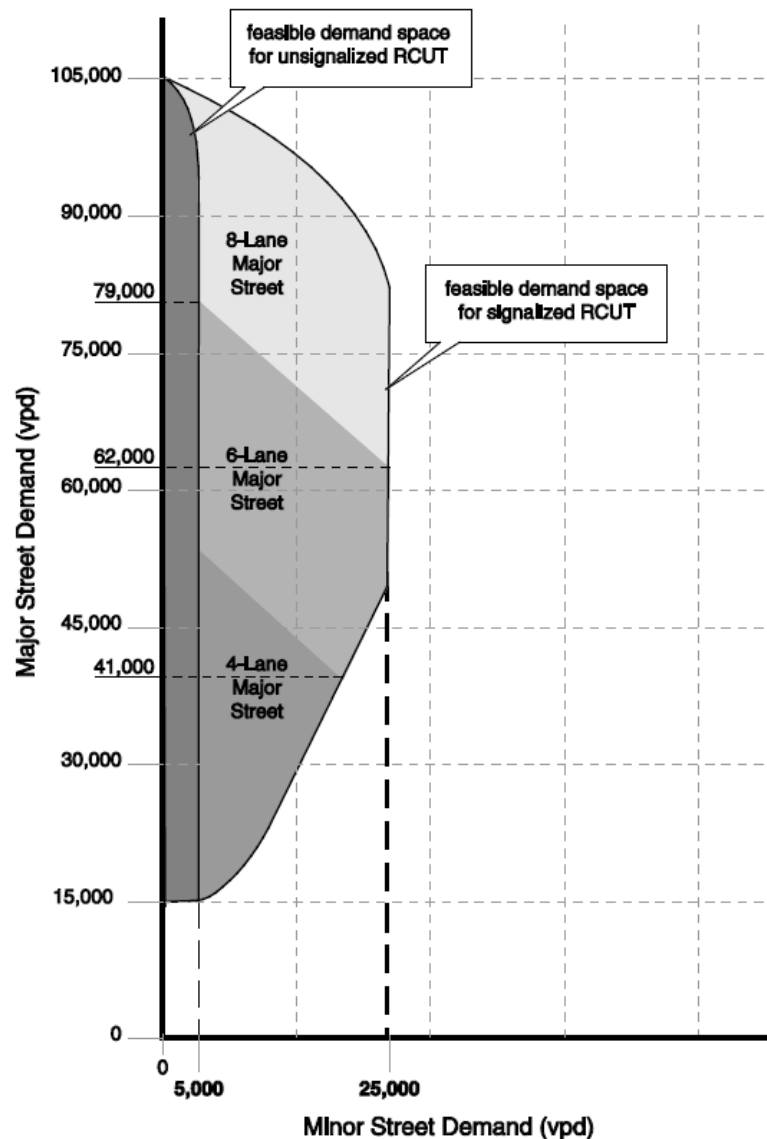


Figure 2: Feasible Demands for RCIs

Source: FHWA¹

DESIGN ELEMENTS

The following section provides guidance on the design and operation of reduced conflict intersections. Topics covered include roadway design, pavement marking and signing, signal and lighting design, signal operations, and maintenance.

ROADWAY DESIGN

MAIN INTERSECTION DESIGN

The unique geometry of reduced conflict intersections requires specific design guidance; some of which is not covered in the standard roadway design manuals such as the American Association of State Highway and Transportation Officials (AASHTO) Green Book and the Manual on Uniform Traffic Control Devices (MUTCD). The following sections provide guidance on the design of the main intersection of an RCI.

Left Turn (J-Turn) Crossover Design

The following guidance for the design of the left turn (J-turn) movement at the main intersection of an RCI is provided by the Federal Highway Administration (FHWA).

At a four-approach RCUT intersection, each left turn crossover serves just one movement (a major street left turn), while each U-turn crossover serves two movements (minor street left turn and through movements). Therefore, it is possible that the left turn crossovers can serve traffic efficiently with only one lane each while the U-turn crossovers have two lanes each. Left turn crossovers can range from one to three lanes wide.¹

Figure 3 shows the detailed design recommendations for the left turn movements at an RCI from the North Carolina DOT.

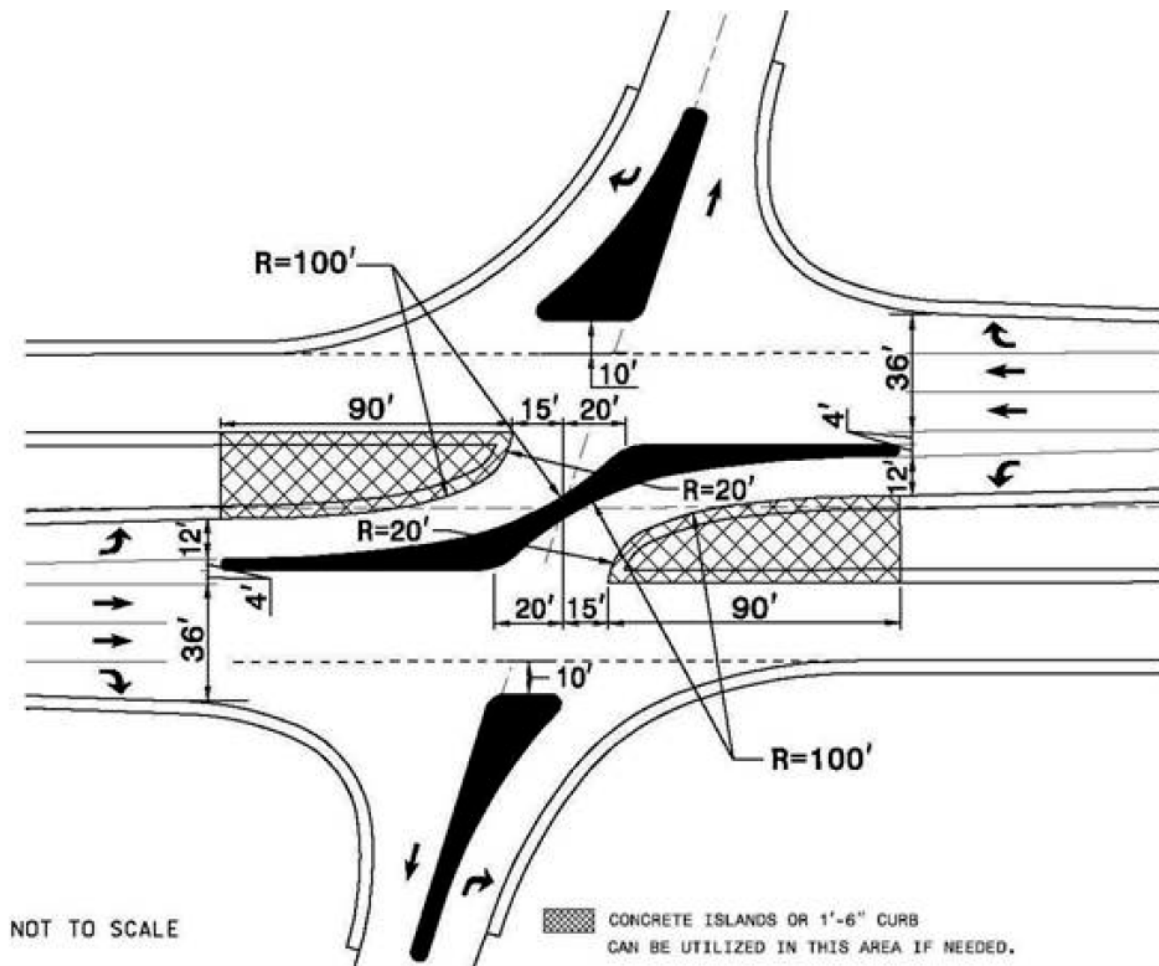


Figure 3: Left Turn Design Recommendations for a Reduced Conflict Intersection

Source: North Carolina DOT⁵

The following guidance on the design of the left turn (J-turn) at an RCI is provided by the North Carolina DOT (NCDOT) and the FHWA, in reference to **Figure 3**.

[The figure] shows the NCDOT design for a 46-ft median with 4-ft paved shoulders (median and outside) assuming a 55 mi/h posted speed. When other median widths, paved shoulders, and posted speeds are used, engineering judgment should be used to establish appropriate geometry.⁶

A pedestrian refuge area should be provided in the middle of the channelizing island to allow for crosswalks or the future addition of crosswalks.¹

Drivers can violate the traffic control devices at RCUT intersections in rural areas by making direct left turns from the minor street. Curbs on the median islands can discourage wrong-way movements. Aligning the minor street approach toward the intended turn direction, as shown [the figure] above, can encourage vehicles to turn right and discourage wrong-way movements. Typically, the design speed of the left turn crossovers is 15 to 20 mph.¹

In order to accommodate a pedestrian crosswalk through the center channelizing island at an RCI, the channelizing island must be designed with adequate width. Based on general design guidelines in Minnesota, this should include a pedestrian crosswalk of at least six feet, and should provide at least six feet of clearance on each side of the crosswalk. This equates to a minimum channelizing island width of 18 feet at an RCI.

The number of turn lanes should be determined for a specific intersection based on the turning movement volumes at the intersection. Turn lane needs depend on multiple factors, including traffic volumes, crossover spacing, and traffic signal timing. An operational analysis should be performed to determine the number and length of turn lanes required for the specific conditions. The North Carolina DOT recommends that a minimum length of 575 feet should be used for all left turn lanes, including the taper length and full storage length. The Mississippi DOT recommends that exclusive left turn lanes on the main roadway should be a minimum of 250 feet with a minimum of a 150-foot taper. However, if the median width is less than 64 feet, the Mississippi DOT advises that a minimum taper length of 75 feet is acceptable if the 150-foot taper is not achievable.

Standard practice in Minnesota for left turn lane design applies for the left turn lane at an RCI. This includes a typical turn lane length of 300 feet of full width lane, plus an additional 180-foot taper sections (based on a 1:15 taper from 12-foot-wide lane), plus additional length needed for downgrades. The total length of the turn lane can also be based on the sum of the turn lane storage length, deceleration length, taper length, and extra length provided to account for downgrade.⁷ MnDOT recommends designing turn lanes based on traffic capacity and required storage lengths, and does not recommend turn lanes greater than 500 feet at RCIs unless justified by traffic capacity.

Treatment of Minor Street Right Turn Lanes

The minor street left turn and through movements at an RCI are converted into right turning movements. Resultantly, the design of the minor street right turn lanes must be sufficient to accommodate all traffic from the minor street. In practice, minor streets at existing signalized RCIs can have single, dual, or triple right turn lanes from the minor streets, though guidance states that minor streets at RCIs can be up to four through lanes wide. The number of turn lanes should be determined for a specific intersection based on the turning movement volumes at that intersection.

At the minor street approaches it is recommended to design channelized right turn lanes to prevent wrong-way maneuvers. There may need to be an increase in the distance to the U-turn maneuver if the right turn is channelized. Additionally, if multiple right turn lanes are provided from the minor street, channelization of one or two (depending on the number of turn lanes) of these lanes to direct them into the U-turn lane is an option. **Figure 4** shows an RCI with the inside two right turn lanes channelized and striped into specific receiving lanes in San Antonio, Texas. The dotted line extensions into specific lanes may help guide turning vehicles into the appropriate lane and reduce initial driver confusion and downstream lane changes. However, such specific guidance may also create imbalanced lane utilization, thus slightly reducing capacity compared to less specific lane guidance.

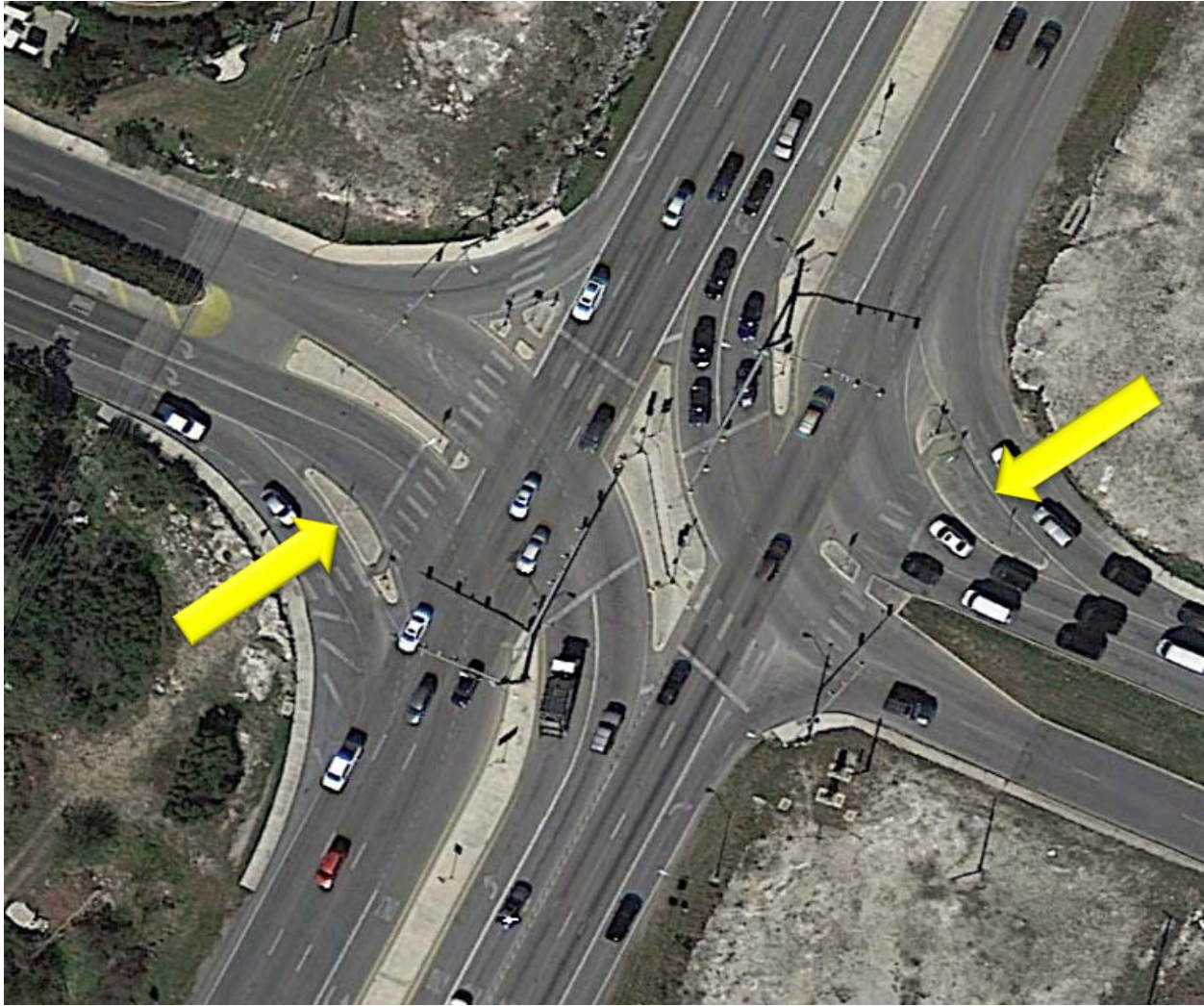


Figure 4: Example of Channelized Right Turn Lanes at an RCI in San Antonio, Texas

Source: Google Earth⁸

The FHWA provides the following guidance on right turn treatment at RCIs:

In most cases, the minor street approach to a RCUT intersection will have a median dividing the two directions of travel. As with any street or channelization separating oncoming movements, medians on the minor street help drivers to avoid head-on conflicts and discourage wrong-way maneuvers. Minor street medians should be a minimum of 6 feet wide. Three options exist for channelizing minor street traffic:

- No channelizing island
- A channelizing island (or channelizing end treatment on a median) separating all of the right turn lanes from the minor street lanes leaving the intersection
- A channelizing island separating minor street right turns that remain on the major street from minor street right turns that subsequently make a U-turn on the major street (i.e. the redirected movements).

The advantages and disadvantages of right turn channelization on the minor street at an RCI intersection are described below:

Advantages

- Guides drivers more firmly, likely reducing sideswipe conflicts during the turn
- Shortens pedestrian crossing distances to a refuge
- Reduces the paved surface area
- Provides the opportunity for a lane addition and a free right turn (merge), reducing delay for that maneuver

Disadvantages

- Requires pedestrians to cross more vehicle pathways, with the right turns moving faster and/or freely; uncontrolled right turns are more difficult to navigate for visually-impaired pedestrians
- Creates potential for uneven lane utilization on the minor street
- Requires drivers on the minor street to select a lane earlier
- Increases right-of-way to accommodate the channelization

There are multiple ways to treat the RCUT intersection's minor street approach depending upon the storage bay length to the U-turn crossover. One option is to align the curve leading out of the minor street to continue directly into the storage bay for the U-turn crossover. The other option is to align it to the major street through lanes, with the U-turn crossover storage bay taper beginning further downstream. If the U-turn crossover storage bay needs to extend all the way back to the minor street, the first option aligning the turn directly into the bay for minor street vehicles is preferred.

Source: FHWA¹

If channelization is provided on the minor street approach, advanced signing should be provided to help guide vehicles to the appropriate lane. More on signing is provided in the Signing and Pavement Markings section of this document.

Right Turn (Minor to Major) Acceleration Lanes

A study was performed at an unsignalized RCI in Missouri to evaluate the performance of multiple aspects of RCIs. As part of this study, the researchers analyzed the utilization of two types of acceleration lanes at RCIs. The findings of the study showed that the utilization of acceleration lanes beginning at the minor road, to be used by minor road vehicles for turning right and getting up to speed to merge into the major road varied based on the destination of the vehicle using it.

In general, the results showed that U-turning vehicles typically used a small portion of the acceleration lane before changing lanes to move to the U-turn lane, while non U-turning vehicles tended to use a larger portion of the acceleration lane to get up to speed.⁹

Based on a review of the existing signalized RCIs in the U.S., provided in **Appendix A**, acceleration lanes from the minor road to the major road are not common practice for signalized RCIs.

Curb Type

Curb can be used to help guide pedestrians through the unconventional pedestrian crossings in an RCI. To help pedestrians locate and traverse the crosswalk in the proper locations, curbs, railings, or landscaping can be used at the main intersection.

Curb design inside the main intersections should take into consideration the design speed of the roadway and the need for emergency vehicles to mount the curb in order to make through and left turning movements from the minor street. Designers should design the center median with mountable curbing. Additionally, the inside curb at the U-turn intersections should be designed with mountable curbing to accommodate oversized vehicles.

As previously mentioned, if traffic violations such as drivers making direct left turns from the minor street is of concern, curbs on the median islands can discourage wrong-way movements.

MEDIAN U-TURN CROSSOVER DESIGN

Guidance for the design of median U-turns is provided in the AASHTO Green Book. The following sections provide guidance for the design of median U-turn crossovers and U-turn storage lanes.

Crossover Spacing

At a signalized RCI where the main intersection and the two U-turn intersections are controlled by traffic signals, specific guidance for the optimal distance of the U-turn signal from the main intersection signal is provided by multiple sources. **Table 2** shows the minimum and maximum recommended distances between traffic signals at a signalized RCI, according to various entities.

Table 2: Recommended Crossover Spacing from Various Agencies

	Minimum	Maximum
AASHTO*	400 ft	600 ft
TRB Access Management Manual	660 ft	1,320 ft
North Carolina	800 ft	1,000 ft
Michigan	560 ft	760 ft
Oregon	990 ft	1,320 ft
Missouri**	600 ft	1,000 ft

* Based on signalized intersection treatment

** Specific location to be determined via capacity analysis

Source: Mississippi DOT²

The spacing from the main intersection to the U-turn crossover varies in practice. The following guidance on crossover spacing is provided by the FHWA:

Several factors should be considered when selecting the appropriate spacing from a main intersection to a U-turn crossover. Longer spacing between the main intersection and crossovers decreases spillback probabilities, providing more time and space for drivers to maneuver into the proper lane and read and respond to highway signs. Shorter spacing between the main intersection and crossovers translates to shorter driving distances and travel times for the minor

street left turn and through vehicle travel times, which are a strong measure of operational effectiveness.^{6, 1}

The distance between the main intersection and the U-turn crossover must be considered for both directions of travel on the major crossroad. The distance for right turning vehicles (with a destination to the minor street or left on the major street) from the minor crossroad to move from the right side of the major crossroad after completing their right turn to the left side prior to the deceleration lane must also be considered.¹

The concept explained in the above paragraph is illustrated in **Figure 5**.

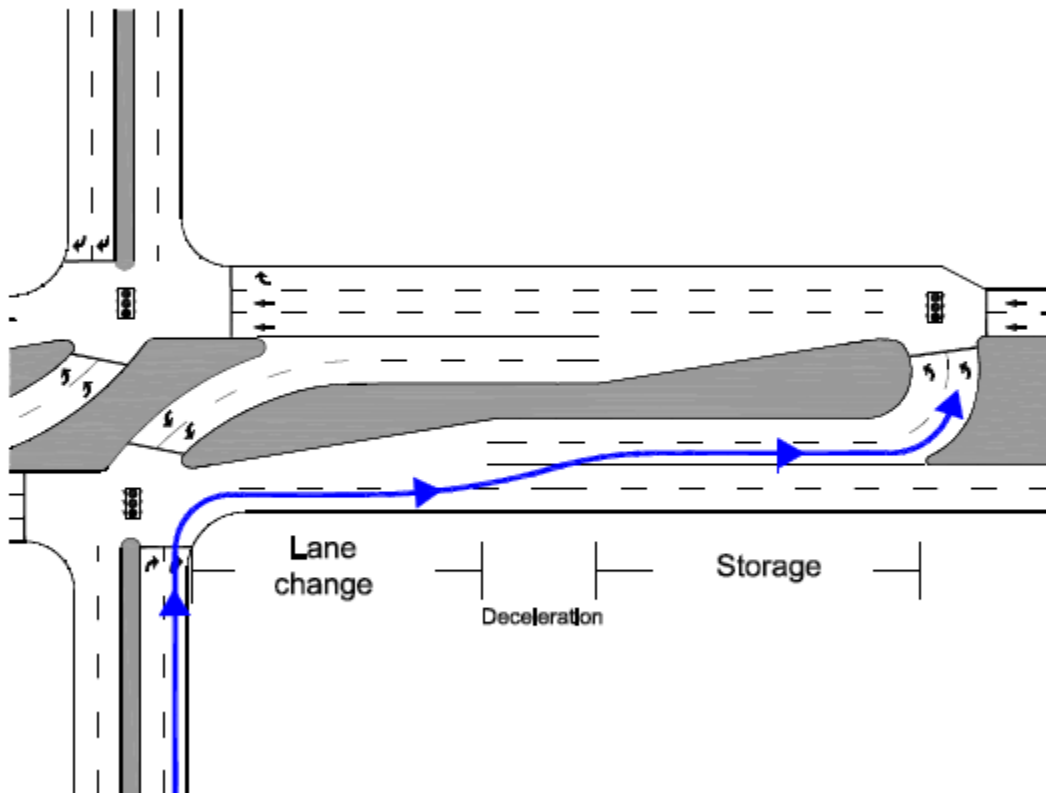


Figure 5: Spacing Consideration for a Minor Street Through or Left Movement

Source: FHWA¹

U-Turn Crossover Design

Proper design of the U-turn crossover is crucial to allow large vehicles to make the U-turn with adequate pavement and without creating conflicts with other vehicles. Trucks should be the main consideration of the designer when designing the median U-turn crossover portion of an RCI. For intersections with inadequate median width for heavy vehicles to maneuver the U-turn, loons should be installed in order to provide adequate turning radii for trucks and the proper space for tracking for both the front and rear ends of the truck. The FHWA provides the following guidance on U-turn crossover design:

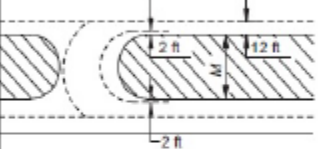
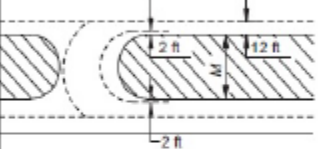
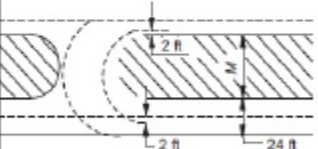
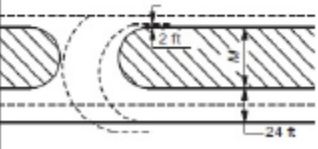
Designers may use one-lane or two-lane crossovers for U-turns depending on traffic volume demands and the number of receiving lanes. AASHTO's Green Book and the [Michigan DOT] Geometric Design Guide 670 provide U-turn crossover design details for MUTs that also apply to RCUT intersections.⁶

Turning Radii and Approach Angle of U-turn

The radii of turning movements affect saturation flow rates. The smaller the radius, the slower the vehicle makes the turn and the lower the saturation flow rate. RCUT intersections with narrow medians and no ability for U-turning vehicles to turn onto a shoulder may result in low saturation flow rates. However, small turning radii may benefit crossing pedestrians.¹

Table 3 provides the recommended minimum median widths for U-turn crossovers as recommended by AASHTO.

Table 3: AASHTO Minimum Median Widths for U-Turns

U.S. Customary		M—Minimum Width of Median (m) for Design Vehicle						
Type of Maneuver		P	WB-40	SU-30	BUS	SU-40	WB-62	WB-67
		Length of Design Vehicle (ft)						
		19	50	30	40	40	63	68
Inner Lane to Inner Lane		30	61	63	63	76	69	69
Inner Lane to Outer Lane		18	49	51	51	64	57	57
Inner Lane to Shoulder		8	39	41	41	54	47	47

Source: AASHTO Green Book¹⁰

Dual U-turn lanes can be implemented if vehicle demand supports it. Dual-lane U-turns are often designed so that a large truck's swept path would use both lanes. If a high percentage or number of heavy vehicles is anticipated, dual U-turn lanes can be designed to accommodate large trucks and buses in both lanes side by side, simultaneously. The size of the U-turn crossover could be reduced if large vehicles were limited to one lane by signing and regulation, eliminating the possibility of two large vehicles using the crossover at the same time.¹

The North Carolina DOT provides an example plan for a median U-turn crossover with a loon in their Roadway Design Manual, shown in **Figure 6**. This example shows a design for a 46-foot median with 4-

foot paved shoulders (median and outside) assuming a 55 mph posted speed. The bulb outs were designed to accommodate a WB-50 heavy vehicle.

MnDOT provides the following guidance for large vehicle consideration in regard to the median U-turn crossover design:

The design vehicle for an RCUT intersection will normally be a WB-62 and WB-67. In corridors with heavy tandem axle truck traffic (e.g. farm grain trucks) consider a wider path comparable to a SU-40. Depending on the nature of the facility or highway corridor, consideration should be given for transit, emergency vehicles, freight, and potentially oversize and overweight (OSOW) vehicles.

In MnDOT's experience, a 47-foot median width is sufficient to accommodate a WB-62 or WB-67 design vehicle without the need for a bump-out.

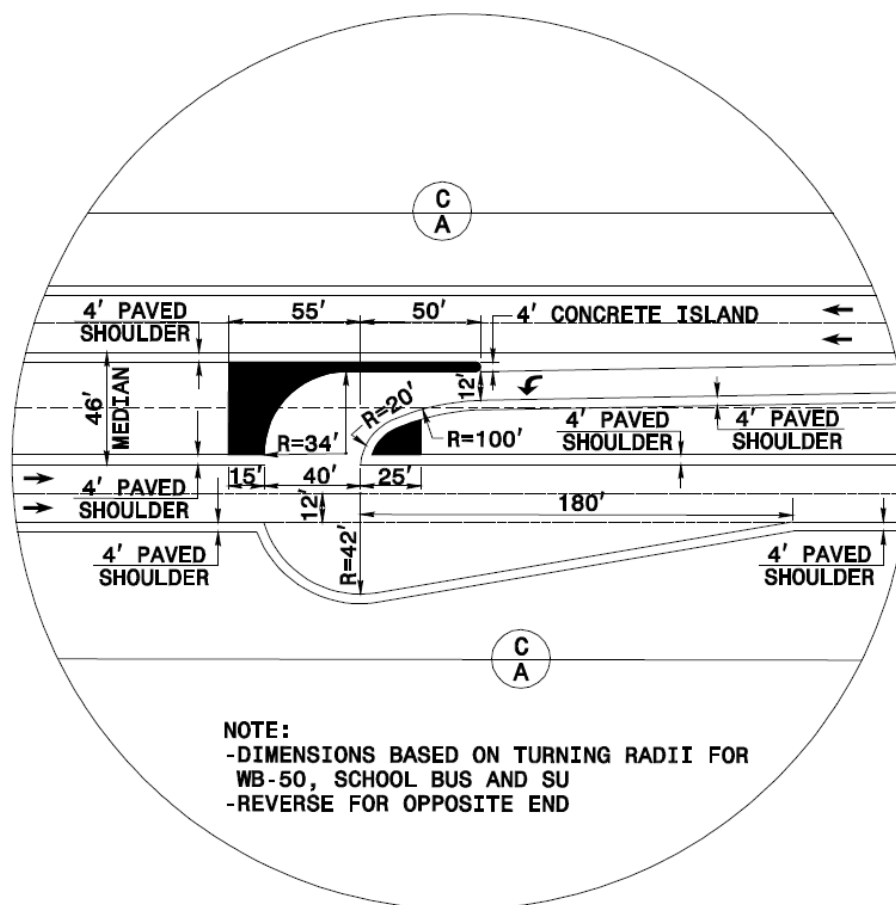


Figure 6: Example Plan of a Median U-Turn Crossover

Source: NCDOT⁵

A loon pavement treatment is required when the center median width is not adequate to accommodate vehicles making the U-turn. For medians with a width less than 64 feet, a 10-foot loon is recommended.

Figure 7 illustrates heavy vehicles traversing a U-turn crossover that uses a loon in order to allow the outside vehicle to complete its turning movement with adequate pavement and without creating a conflict with the inside turning vehicle.

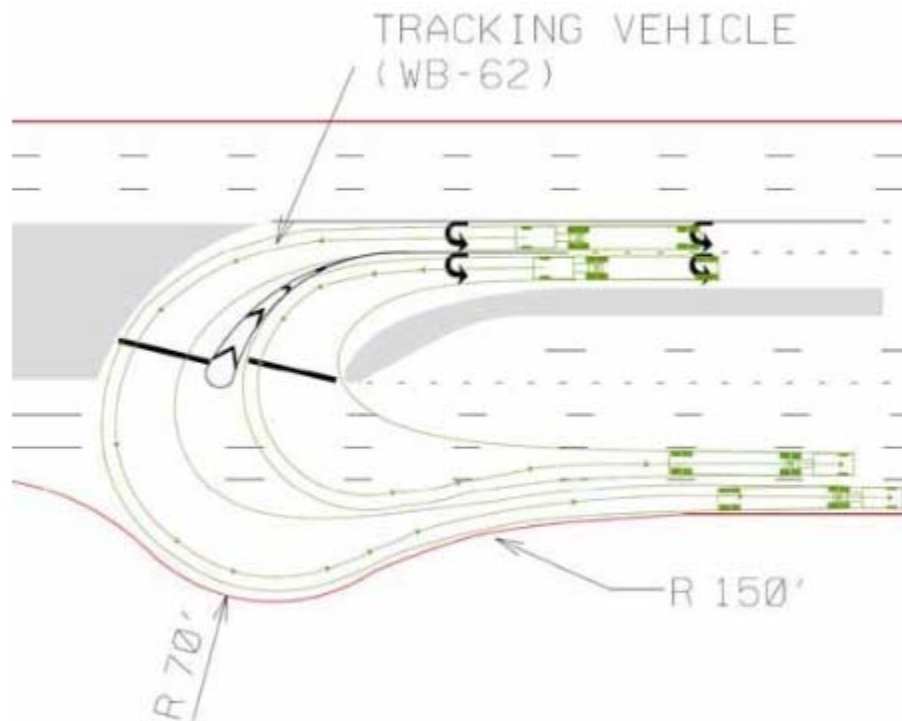


Figure 7: Loon at a U-Turn Crossover with Two U-Turn Lanes

Source: FHWA⁶

The U-turn portion of an RCI replicates that of the Median U-Turn Intersection Treatment (MUTIT) design, used commonly in Michigan. The following findings about the use of loons in MUTITs is provided by the FHWA:

- Consistent placement of advance warning signs preceding the indirect median crossover and associated loon assisted driver expectancy when using MUTITs.
- Proper design of U turns for the appropriate design vehicle was essential to ensure safe traffic operation at the loons.
- At signalized median crossovers, the clearance intervals should account for the extra travel time required for drivers to travel through the loon.
- Suboptimal gap acceptance for U-turn maneuvers and driver confusion were two issues for loons either tapered into downstream right turn lanes or for situations where right turn lanes were located within approximately 45.7 m (150 ft) downstream of the loon. However, the placement of a loon and consecutive right turn lane was recommended for major roads with MUTITs and high U-turning volumes at the median crossover.
- Minimal differences were found between the travel times for commercial and passenger vehicles at MUTIT sites with signalized median crossovers. At unsignalized median crossovers, commercial vehicles were forced to wait for larger gaps in the conflicting traffic stream to complete their U-turn maneuvers.

- Several crashes involved commercial vehicles parked or backing within the median crossovers. Inadequate storage in the left lane preceding the median crossover due to the parked commercial vehicles caused spillback into through lanes. Commercial vehicles parked in the loon presented challenges for larger commercial vehicles executing U turns.
- A majority of the crashes at the loons were fixed-object crashes or sideswipe crashes. The objects most commonly hit were delineator posts, signposts (in the median and along the mainline), and spot locations of guardrail. A majority of the sideswipe crashes involved vehicles merging into traffic from the loon, or mainline traffic attempting to use the right turn lane.
- The study recommended a minimum 1.82-m (6-ft) auxiliary shoulder, with a 0.91-m (3-ft) paved area to provide the additional width necessary to ensure that the required pavement width will not be destroyed by U-turning vehicles that require the entire width of the loon. The study also recommended placement of short curves at both ends of the tapered section of the loon to assist the driver through the loon and U-turn maneuver.

Source: FHWA¹¹

U-Turn Lane Design

The U-turns at an RCI require exclusive deceleration/storage lanes. The Mississippi DOT recommends that the storage lane should be a minimum of 250 feet in length with a 150-foot taper, however the actual storage length will vary based on the demands at the subject intersection. Dual U-turn lanes may be used if demand supports it. U-turn storage length should be designed to accommodate the 95th percentile queue of U-turning vehicles. Additionally, a 1:15 taper should be provided based on MnDOT turn lane design guidelines.

Depending on the available median width, the U-turn storage lane(s) can be designed to be back-to-back with the opposing roadway left turn lane (for narrower medians) as shown in **Figure 8**.

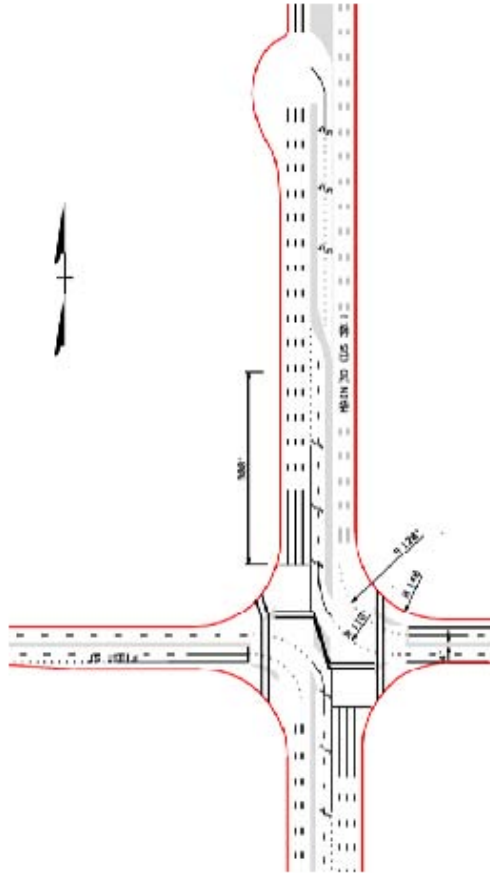


Figure 8: RCI with Back-to-Back U-Turn Lane Design

Source: FHWA⁶

Alternatively, if the median width is adequate, the U-turn storage lane can be designed to extend all the way back to the main intersection. If multiple right turn lanes are present on the minor street, extending the U-turn lane to the main intersection allows for the inside minor street right turn lane to be striped directly into the U-turn lane. If possible, this treatment is preferred. **Figure 9** illustrates this configuration.

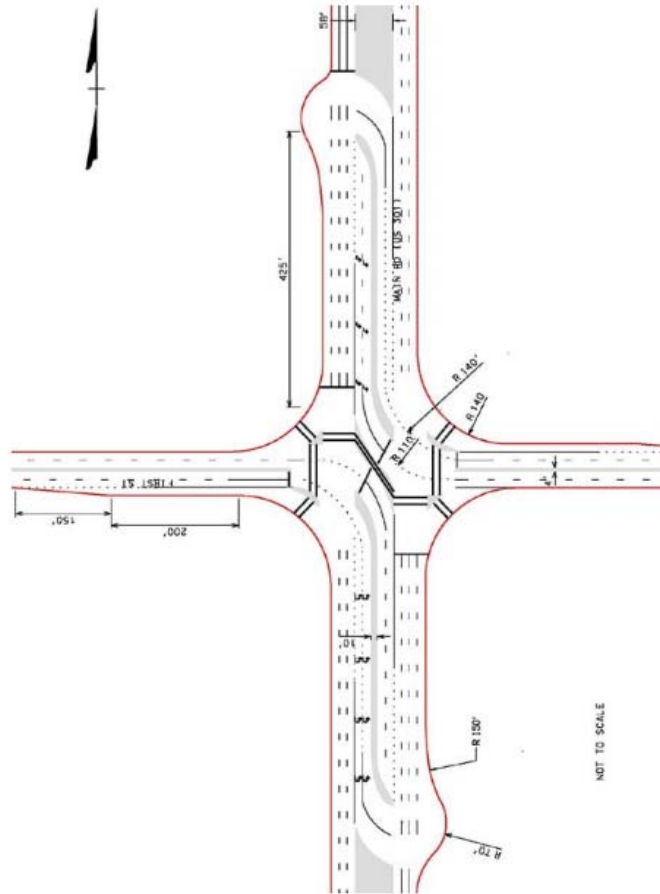


Figure 9: RCI with U-Turn Lanes Extended to the Main Intersection

Source: FHWA⁶

U-Turn Crossover Acceleration Lanes

The following guidance on the application of acceleration lanes is provided by the FHWA:

RCUT intersections with stop signs or signals controlling the minor street and crossovers do not create weaving movements on the major street. Instead, drivers must wait for an acceptable gap or a green signal. In contrast, RCUT intersections with acceleration lanes and merges at the minor street and the U-turn crossovers do create weaving movements. A minor street left turning or through driver emerging from the minor street will, in effect, have to make a two-sided weave right to left. A minor street through driver emerging from the U-turn crossover will have to make a two-sided weave left to right. To minimize the risks in those two-sided weaving maneuvers, the crossover can be located far enough away from the minor street to create acceptable weaving operations; this distance is up to one-half (0.5) mile at some RCUT intersections with merges. The AASHTO Green Book contains recommendations on acceleration and deceleration lane lengths appropriate to RCUT intersections with merges. Heavy vehicles and uphill grades influence crossover distances and lane lengths, and required associated appropriate traffic control devices.¹

A study was performed at an unsignalized RCI in Missouri to evaluate the performance of multiple aspects of RCIs. As part of this study, the researchers analyzed the utilization of two types of acceleration lanes at RCIs. The findings of the study showed that the utilization of acceleration lanes beginning at the U-turn crossover, to be used by U-turning vehicles for getting up to speed to merge into the major road, varied based on the destination of the vehicles using it.

In general, the results showed that vehicles exiting to the minor road used a small portion of the acceleration lane before changing lanes to move to the mainline lane, and all U-turning vehicles used

Based on a review of the existing signalized RCIs in the U.S., provided in **Appendix A**, acceleration lanes from the U-turn lanes onto the mainline are not common practice for signalized RCIs. None of the 27 signalized RCIs reviewed included this type of acceleration lane.

PEDESTRIAN AND BICYCLE ACCOMMODATIONS

Pedestrians and cyclists must be taken into consideration when planning for and designing an RCI. Due to the unique crossing configurations for pedestrians and cyclists at an RCI, proper crossing design and wayfinding is crucial to prevent confusion and promote safe crossing. This section provides guidance on how to design pedestrian and bicycle crossings at an RCI.

Pedestrian Crossings

The unique geometry at reduced conflict intersections presents unfamiliar conditions to new pedestrian users. In order to minimize confusion, both the intersection's geometry and traffic control should be designed to help pedestrians cross the intersection safely and efficiently.

The most common treatment for serving pedestrians at an RCI is the "Z" crossing treatment. This configuration is illustrated in **Figure 10** at a four-legged RCI.

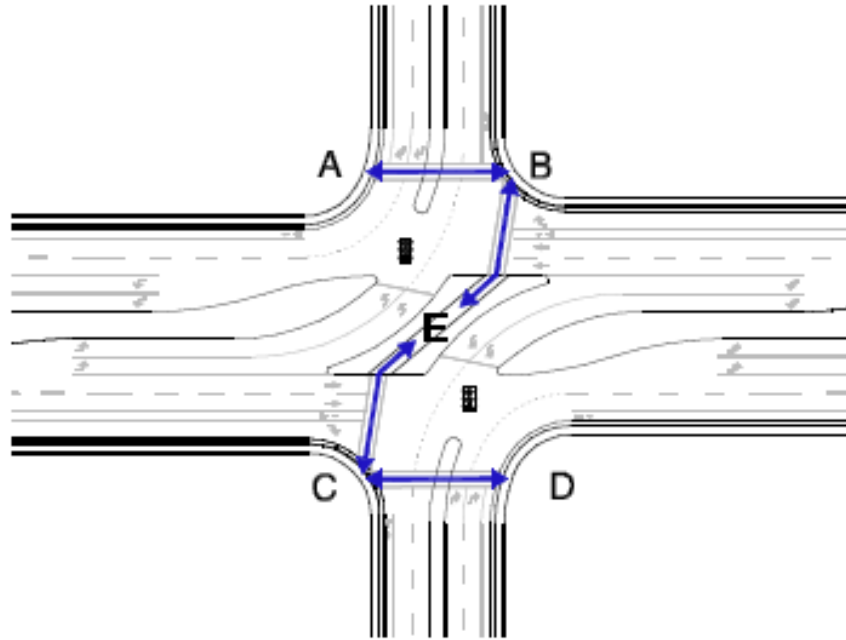


Figure 10: "Z" Pedestrian Crossing Treatment at an RCI

Source: FHWA¹

The FHWA explains the crossing procedure at and RCI in the following section:

A "Z" crossing allows all six desired pedestrian movements at an intersection. The two minor street crossings (A to B, C to D) are made similarly to a conventional intersection. Three of the movements (A to C, B to D, and A to D) require pedestrians to take a longer, unconventional route. The sixth movement (B to C) requires pedestrians to take a shorter, unconventional route.¹

Unintended crossing routes (A to C directly, B to D directly) should be discouraged through the use of buffer treatments.¹

The large geometric footprint of an RCI creates longer crossing distances for pedestrians. Pedestrian crossing distances can be decreased by eliminating right turn lanes and/or using tighter radii on right turns, however these changes will impact vehicular traffic operations and must be evaluated before implementing. An option for shortening the major road crossing distance is adding a raised barrier or channelization between major street through lanes and right turn lanes.

There are other, less favorable options for crossing pedestrians at an RCI. The first alternative option is creating an offset approach RCI, where pedestrians are allowed to cross directly across the major streets. This option is illustrated in **Figure 11**. This offset option is typically not feasible where streets already exist, but may be applicable when planning new developments.

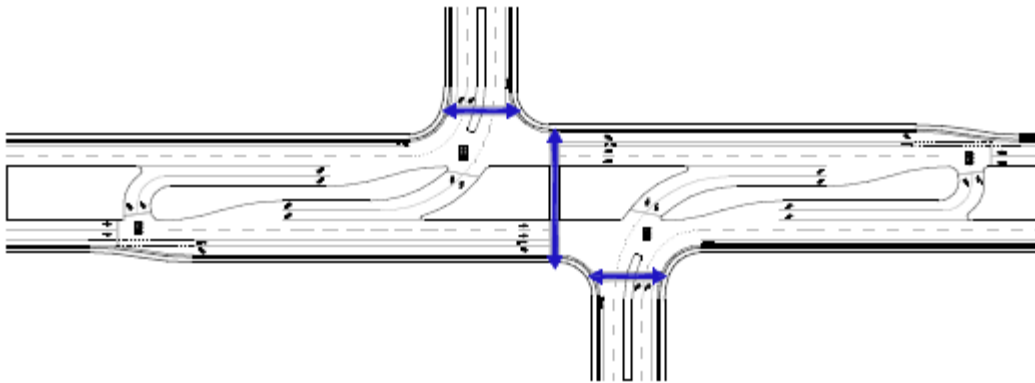


Figure 11: Offset Approach RCI Pedestrian Crossing

Source: FHWA¹

It is also possible to cross pedestrians at one or both of the U-turn crossing with a signalized mid-block crossing. This option is illustrated in **Figure 12**. This treatment would require an additional signal on the mainline (shown on the eastbound roadway in **Figure 12**) in order to stop through traffic that would not otherwise be required. In this case, the signal controlling the eastbound roadway can either be a regular traffic signal or a pedestrian hybrid beacon (PHB; formerly referred to as a HAWK signal), to reduce impacts to eastbound vehicular traffic.

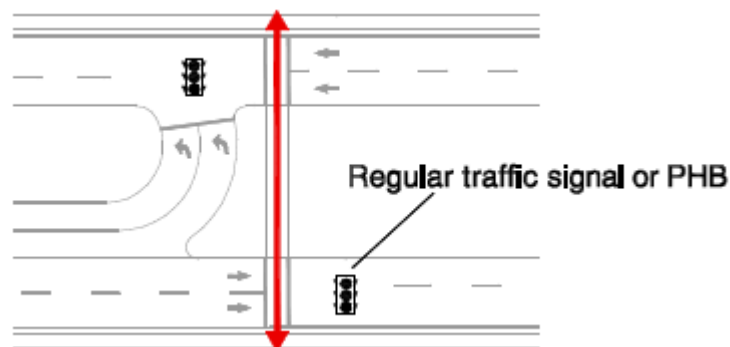


Figure 12: Pedestrian Crossing at a Signalize U-Turn Crossover

Source: FHWA¹

Crossing pedestrians at a three-legged RCI requires unique pedestrian crossings different from those at a four-legged RCI. This is a direct mid-block crossing route, and is located at the main intersection. An optional second pedestrian crossing may be included at the U-turn, which is also a direct mid-block crossing, as shown in **Figure 12**. The pedestrian crossing treatment for three-legged RCIs is illustrated in **Figure 13**.

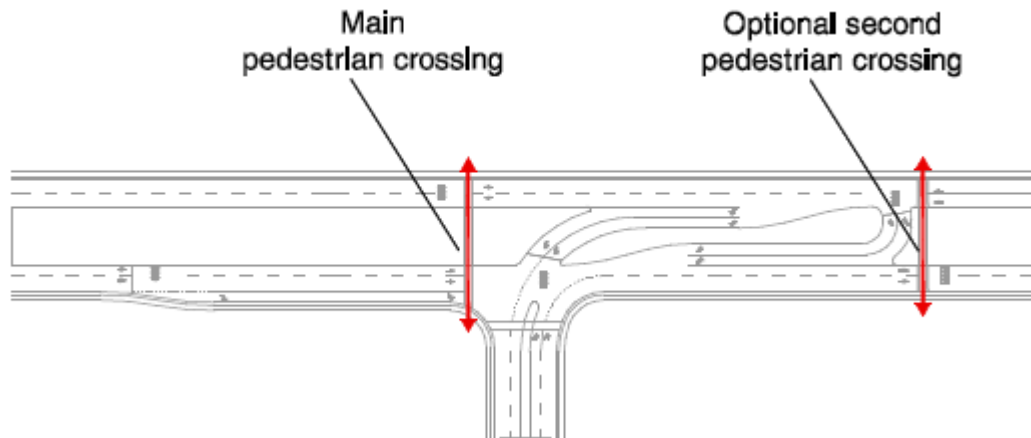


Figure 13: Pedestrian Crossing at a Three-Approach RCI

Source: FHWA¹

Proper ADA and PROWAG accessibility considerations must be taken into account at pedestrian crossings at RCIs. The unfamiliar geometry may be especially difficult to navigate for those with visual or cognitive impairments who may not be able to use wayfinding signs.

Bicycle Crossings

Cyclists on the major street act as vehicle traffic does when traveling through an RCI. RCIs are typically constructed on high volume roadways, sometimes with high speed limits; if this is the case and consistent bicycle traffic is expected to use the intersection, then physically separating bicycle lanes from mainline lanes should be considered. Options for achieving this could be buffered bike lanes, cycle tracks, or other similar treatments.

Cyclists turning left at the main intersection have the option of using the left turn lane or using the pedestrian sidewalk in the “Z” crossing to complete their movement. It is recommended that if bicycle lanes are provided for the major roadway, then the right turn lane should be shifted to the right of the bicycle lane, as shown in **Figure 14**. It is recommended that the intersection is designed with sidewalks to accommodate the bicyclists including ADA compliant ramps so that bicyclists can make use of the sidewalks.

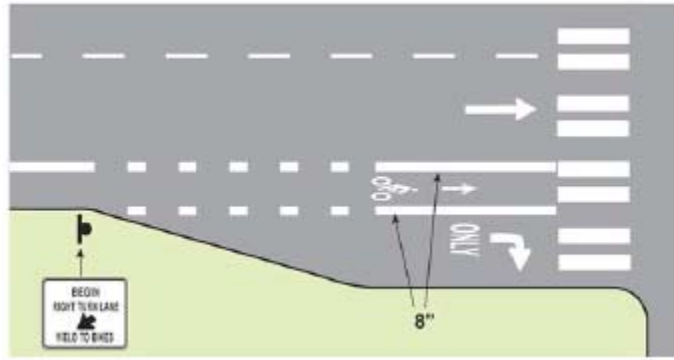


Figure 14: Bicycle Lane Configuration on the Major Approach at an RCI

Source: FHWA¹

Based on a review of the existing implemented signalized RCIs in the U.S. (provided in **Appendix A**), no state has implemented a signalized RCI with bike lanes at the time of this document.

Bicycles in an RCI have to decide to act like a vehicle or to act with the pedestrians. Bicycles on the minor street have three options, as shown in **Figure 15**; none of which provide a direct route if the bicycle travels in vehicular lanes. The preferred option is to cross the major street with the pedestrians on the sidewalks of the “Z” crossing. If that is not possible due to the lack of a sidewalk, then a second option is to cross the major street near the left turn lanes. This could cause issues with bicycles approaching left turning vehicles head-on. The last option is not preferred, but a bicycle could move with vehicle traffic that is making a thru movement (meaning turning right and making a U-turn on the major road to turn right onto the minor street).

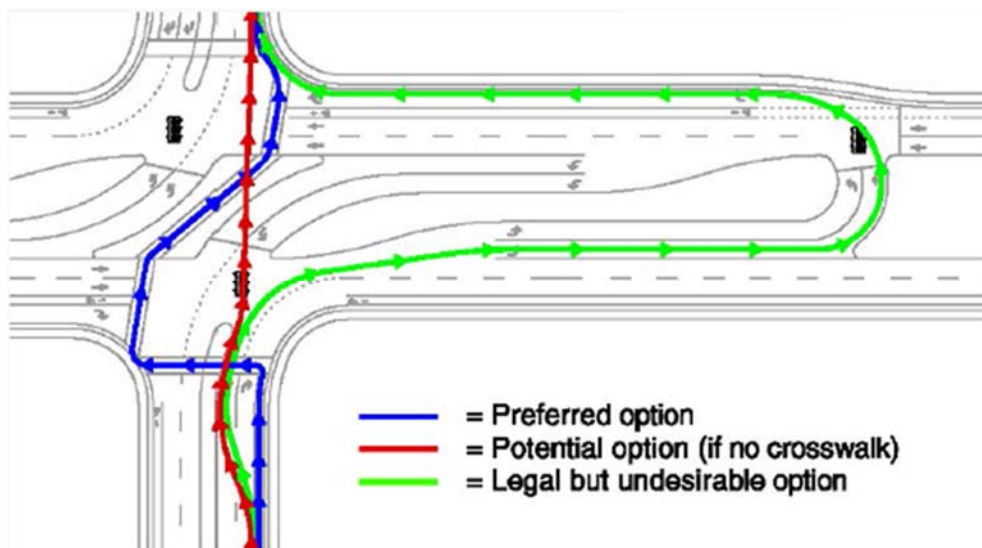


Figure 15: Bicycle Route Options for the Minor Street of an RCI

Source: FHWA¹

PAVEMENT MARKINGS AND SIGNING

Traffic control devices are an important component of all intersections. They are even more important in the case of alternative intersection design, such as an RCI. Signing and pavement markings are essential components of RCI design, as they can help users navigate the unconventional geometry of the RCI and mitigate wrong-way violations.

The MUTCD does not provide specific guidance for pavement markings at RCUT intersections. However, the Michigan DOT has developed pavement marking standards for U-turn crossovers at MUT intersections in Michigan that could be used at the U-turn portion of a RCUT intersection.¹ Additionally, AASHTO's Green Book provides guidance for median U-turn design.

PAVEMENT MARKINGS

The North Carolina DOT provides a plan for typical pavement markings at an RCI, shown in **Figure 16**.

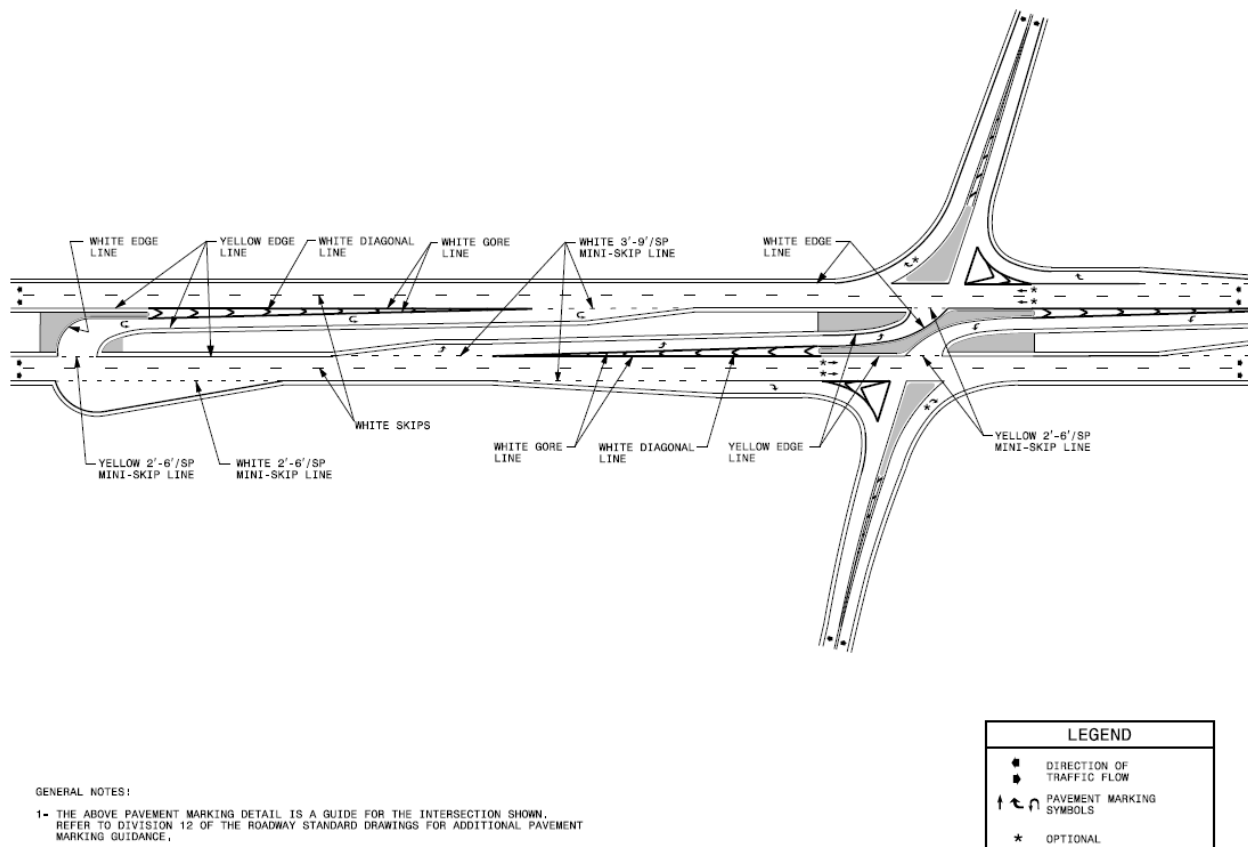


Figure 16: NCDOT Example Pavement Marking Plan at an RCI

Source: NCDOT¹²

Guidance on typical pavement marking for a single lane median U-turn crossover is provided in **Figure 17**. Typical pavement marking for a dual-lane median U-turn crossover is provided in **Figure 18**.

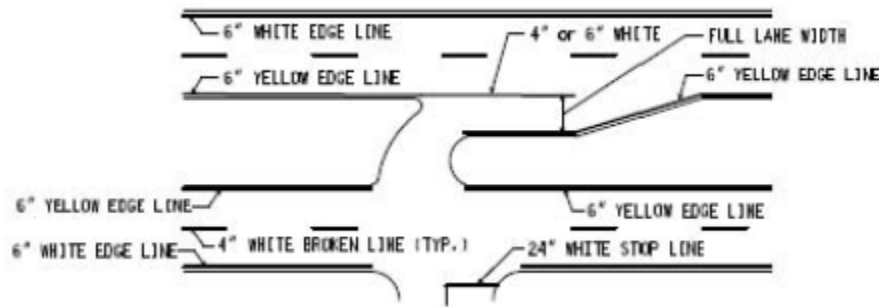


Figure 17: Typical Pavement Marking at a Single-Lane Median U-Turn Crossover

Source: FHWA¹

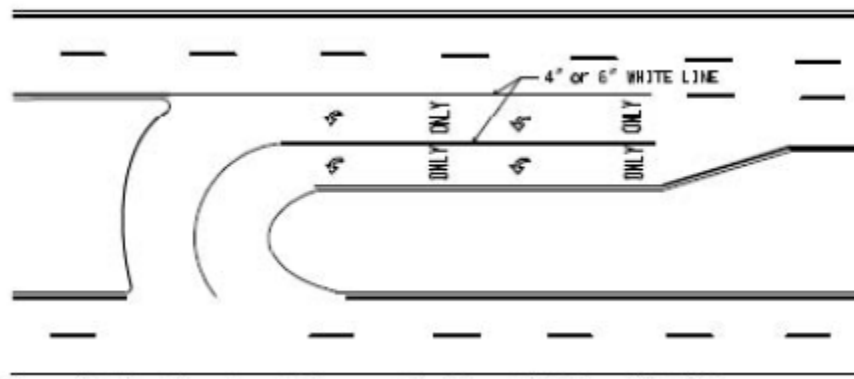


Figure 18: Pavement Marking Standard at a Dual-Lane Median U-Turn Crossover

Source: FHWA¹

The Michigan Department of Transportation provides the following guidance for pavement markings at an RCI, with reference to **Figure 17** and **Figure 18**.

The pavement marking concepts from the figures follow the general pavement marking concepts in the MUTCD. While not specifically shown in [the figures], stop bars could be placed across the lane(s) of the U-turn crossover. The MUTCD requires stop bars to be placed no more than 30 feet or less than 4 feet from the nearest edge of the pavement.¹

In the case of a signalized median U-turn crossover, stop bars would be mandatory for the each of the U-turn lanes.

Designers may use one-lane or two-lane crossovers for U-turns depending on traffic volume demands and the number of receiving lanes. **Figure 19** shows the swept path of two trucks in a dual U-turn lane median U-turn crossover that features a loon.

Based on a review of pavement marking standards for RCIs, nothing deviates from typical MnDOT highway pavement marking practices.

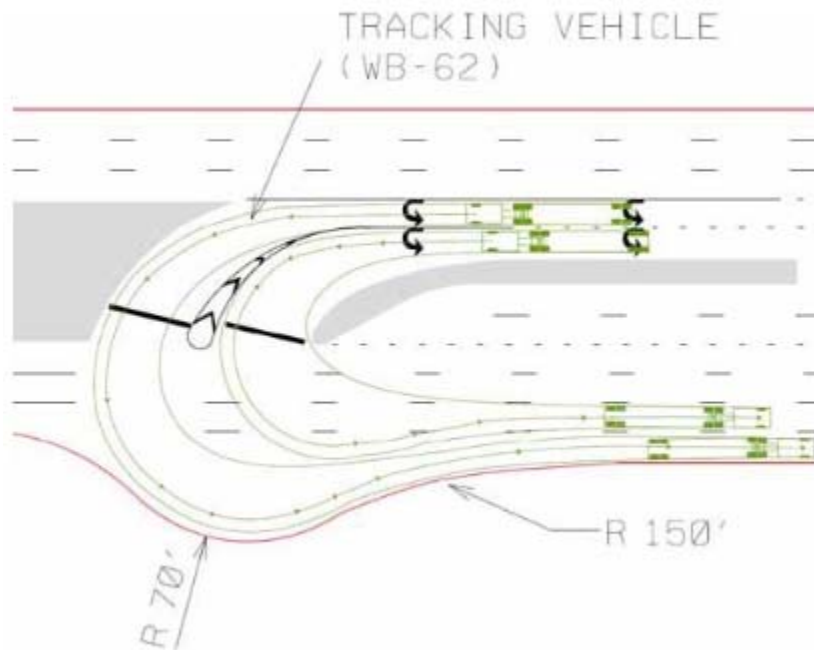


Figure 19: Median U-Turn Crossover Design with a Separating Striped Median

Source: FHWA⁶

In practice, striping separating dual U-turn lanes at the median U-turn crossover of an RCI varies by region. Texas and Ohio are the only two states that provide striping to separate dual U-turn lanes. A table showing the specific intersections that have this type of striping is provided in **Appendix A**.

The FHWA provides the following guidance for pavement markings at an RCI:

Pavement markings are an integral part of the information system at a RCUT intersection. On minor street approaches, each lane could have right turn arrow markings, repeated several times, supplemented with the word "ONLY." In left turn crossovers, each lane could have left turn arrow markings, repeated several times, supplemented with the word "ONLY." On the minor street approaches and in the crossovers, the arrows could be supplemented with route numbers or street names.¹

Due to snow cover and the potential for pavement marking damage from snow plows, MnDOT does not typically use pavement markings to display route numbers or street names.

In the deceleration and storage lanes leading to U-turn crossovers, each lane could have U-turn arrow markings, repeated several times, supplemented with the word "ONLY."¹

In practice, both U-turn arrows and left turn arrows are used in the U-turn lanes. The majority of U-turn lanes use a U-turn arrow, as shown in **Appendix A**.

SIGNING

Special consideration must be taken when signing an RCI, as the signing treatment for an RCI differs from that of a conventional intersection. The signing of an RCI is similar to the signing of a median U-turn

intersection, or other alternative intersections that displace the left turn movements from the minor roadway. Some of the main considerations when signing an RCI as compared to a conventional intersection include the following:

- Destination guide signing for minor street left and through movements, as these movement are diverted to the U-turn intersection
- Signs to guide drivers to the appropriate lane for the movement they intend to make when the minor roads and median U-turn crossovers have multiple lanes
- Signs for right turn on red and left turn on red restrictions, if applicable

The following guidance on signing an RCI is provided by the FHWA in reference to **Figure 20**:

Some of the signing and marking practices depicted in this section reflect observed practice at RCUT intersections that may not be included in the MUTCD. The MUTCD includes a procedure for agencies wishing to conduct field experiments with new signs and markings.

[The figure] shows a signing plan for one direction of travel at a signalized RCUT intersection based largely on Maryland State Highway Administration guidance. RCUT intersection signing is not explicitly addressed in the MUTCD.

The key elements are well-placed regulatory signs to indicate prohibited movements and clear and visible guide signs to aid the minor street left turn and through traffic. In the plan shown in [the figure] there is no sign or marking provided for U-turn crossover or minor street vehicles on which lane they should choose to reach a particular destination. However, such a sign was developed for a RCUT intersection in Texas. Whether to provide lane choice signing and marking is left to the agency's discretion and is discussed below. Standard street name signs at the main intersection may be helpful for main street motorists.

Source: FHWA¹

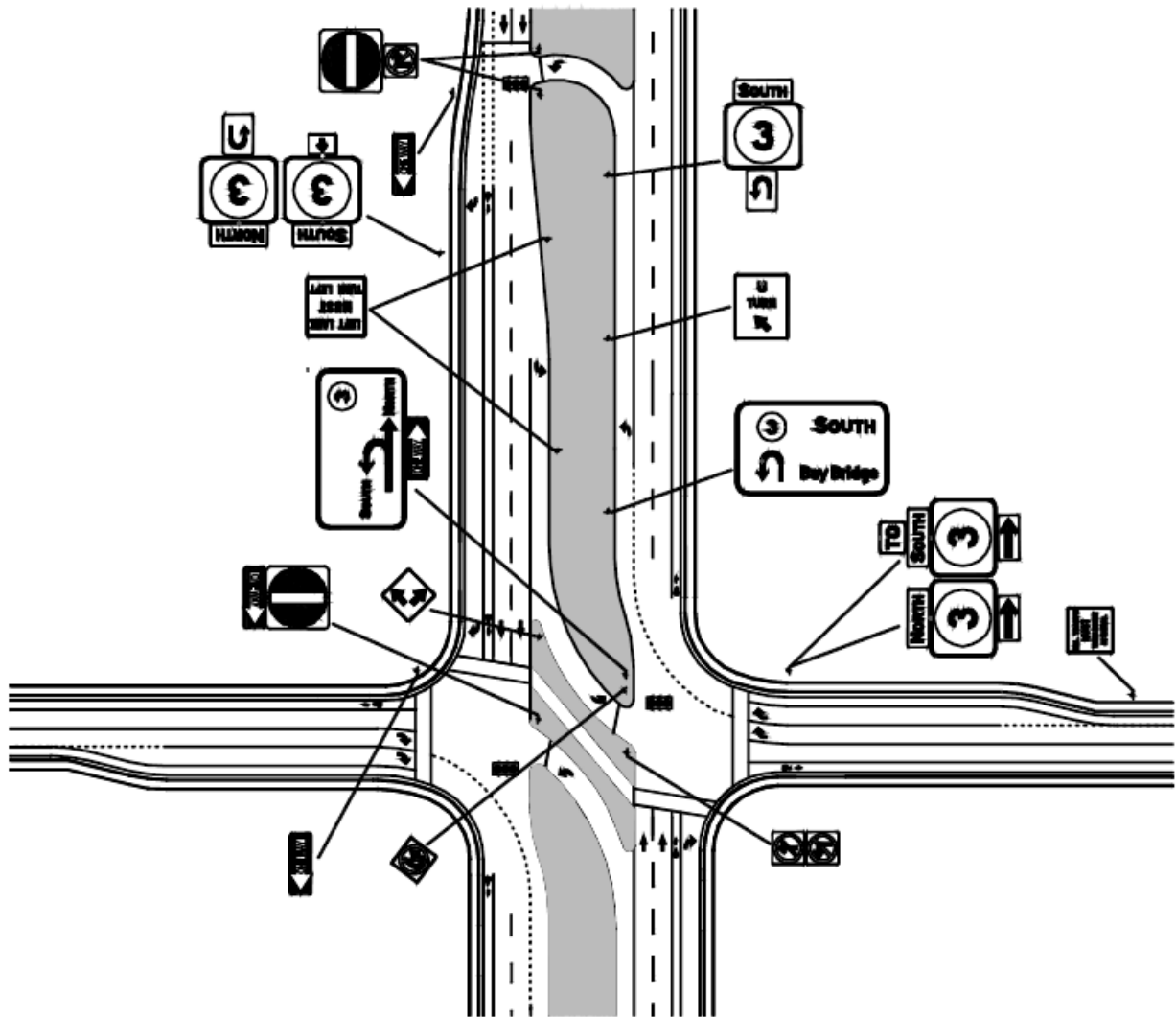


Figure 20: Example Signing Plan from a Signalized RCI in Maryland

Source: FHWA¹

In applications where the mainline roadway is wide, drivers can benefit from guide signs placed both in the median beyond the main intersection and on the outside shoulder of the street. **Figure 21** gives examples of two different options from Maryland and Texas for the guide sign located in the median at the approach to a median U-turn crossover.

If two lanes are present at the median U-turn crossover, it is recommended that signing should direct trucks to use the outside lane.

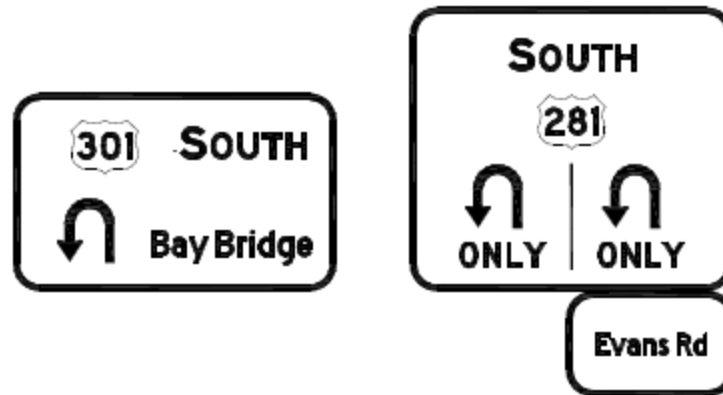


Figure 21: Guide Signs for Median U-Turn Crossovers from Maryland (Left) and Texas (Right)

Source: FHWA¹

The following guidance on signing for RTOR and LTOR prohibitions at an RCI is provided by the FHWA:

Prohibiting RTOR and/or LTOR is conveyed via regulatory signing. This can include multiple signs on any particular approach prohibiting RTOR or LTOR, especially on wide minor street approaches or multilane crossovers. Some agencies chose to post signs saying what is allowed. For example, Texas agencies have posted “TURN ON GREEN ARROW ONLY” regulatory signs on some of its U-turn crossovers. An agency in Michigan posts regulatory “PROCEED ON GREEN [ball] ONLY.”

Source: FHWA¹

For conditions where the minor streets are particularly heavy, drivers wishing to make the through movement from the minor street may benefit from additional guidance on the median signs. Texas has implemented such guide signs, which are placed overhead on the minor street approaches approximately 350 feet in advance of the stop bar so that drivers can position themselves in the appropriate lane before reaching the intersection. **Figure 22** shows this application at a three-lane approach to the intersection of US 281 & Evans Road in San Antonio, Texas. In this situation, the left lane is designated specifically for left turn movements from the minor road. The center lane is designated for both minor street through movements and right turn movements. The rightmost minor street lane is designated for right turns from the minor approach only.

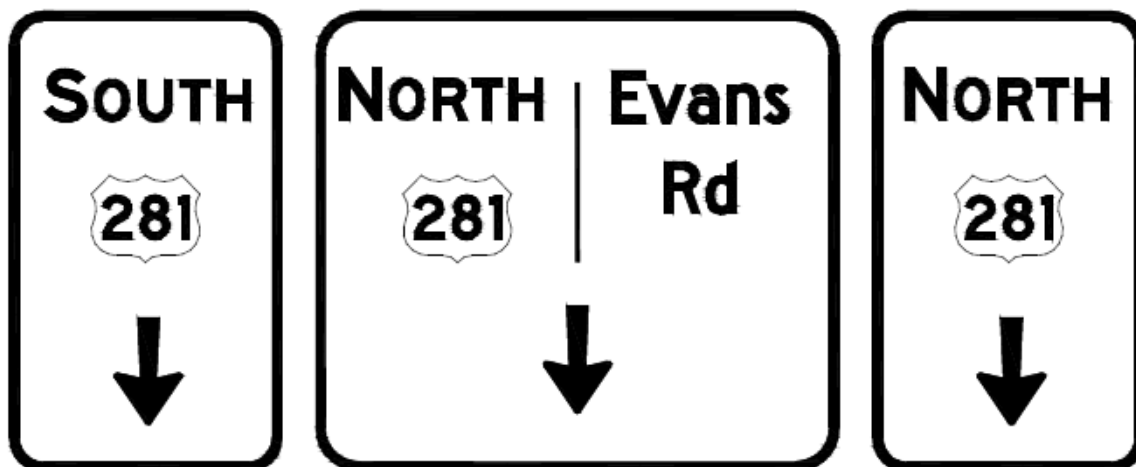


Figure 22: Overhead Signing on the Minor Street (Evans Rd) Approaching the Major Street (US-281)

Source: FHWA¹

There is not a single standard for setting and signing for lane designations at an RCI. In practice, signing and lane designation vary by region. An example of this variance between different entities is explained in the following paragraph from the FHWA:

In multilane U-turn crossovers on MUT corridors in Michigan, the inner lane is typically marked as a U-turn only lane while the outer lane is marked as an optional U-turn or straight through lane (if there is a driveway or side street at the end of the crossover). By contrast, at the RCUT intersections in Michigan and in North Carolina, the agencies provide no guidance to minor street or crossover traffic as far as which lane of a multilane approach or crossover drivers should use for a certain destination.

Source: FHWA¹

The Mississippi DOT also provides guidance for signing at a RCI and other diverted left intersections. **Figure 23** and **Figure 24** show customized guide signs recommended for inclusion at the left turn (J-turn) and median U-turn portions of an RCI, respectively.



Figure 23: Recommended Signage at the Left Turn (J-Turn) Intersection of an RCI

Source: Mississippi DOT²



Figure 24: Recommended Signage at the Median U-Turn Crossover Intersection of an RCI

Source: Mississippi DOT²

SIGNAL AND LIGHTING DESIGN

Traffic signals may not be warranted for all RCIs based on traffic volume conditions at the intersection. If a traffic signal is warranted at the main intersection, that does not necessarily mean that they are warranted at the U-turn crossover locations. When signals are warranted, the design of traffic signals at an RCI may differ from those at a conventional intersection. Traffic signals at the median U-turn crossovers require specific guidance. Additionally, the pedestrian signals at an RCI differ from conventional intersections due to the unique pedestrian crossing paths at RCIs.

Lighting design must be carefully considered at an RCI. Because the conflict points at an RCI are dispersed when compared to a conventional intersection, lighting should be located near the location of each conflict point to help minimize safety issues at the intersection.

Guidance on when traffic signals are warranted at an RCI, the use of flashing yellow arrows on traffic signals at an RCI, lighting locations, and traffic signal pole locations is provided in this section.

SIGNAL WARRANTS FOR U-TURNS

RCUT intersections may be signalized or unsignalized with stop signs, yield signs, or merges at the minor streets and crossovers. Unsignalized RCUT intersections can provide adequate operations if the traffic demands are low. If the minor street ADT is 5,000 or more, a RCUT intersection will generally operate better with signals.¹

The signal warrants in the MUTCD apply to RCIs and other intersections. The traffic signal warrants provided by the MUTCD should also be used to determine the need for signalization at the U-turn crossovers of an RCI. The median U-turn volume can be treated as the minor street higher volume approach when evaluating signal warrants.

In MnDOT's Metro District, right turning traffic from the minor leg is usually not included in the warrants analysis. However, if there is right turning traffic and conflicting traffic meet criteria set forth by MnDOT, 50% of the minor street right turns can be added back into the approach counts. Further guidance for this is provided in MnDOT's document entitled "Metro Traffic Signal Justification Methodology".¹³

FLASHING YELLOW ARROWS FOR U-TURNS AND LEFT TURNS

The following guidance on the use of flashing yellow arrows is provided by the FHWA:

Most two-phase signals at RCUT intersections have green ball indications for each direction. To reduce delay where sight distances and other site features are favorable, many agencies allow RTOR from the minor street or LTOR from a U-turn crossover. If LTOR is prohibited by law, but site conditions would otherwise allow it, a flashing yellow arrow indication is possible instead of a red ball. The two crossover phases would use a green arrow display for a protected turn and flashing yellow arrow for a permissive turn. NCDOT has used this treatment for several years at the left turn and U-turn crossover signals of a RCUT intersection on US-421 just south of its junction with NC-132 in Wilmington. Traditionally, flashing yellow arrow treatments have been used for one-lane turn bays. However, the NCDOT has installed a flashing yellow arrow on a two-lane turn bay in Cary, NC.

Source: FHWA¹

Base on a review of the implemented signalized RCIs in the U.S. (provided in **Appendix A**), utilizing flashing yellow arrows is not standard practice. The only implemented flashing yellow arrow at a signalized RCI is located in Wilmington, NC, as described in the preceding paragraph.

LIGHTING DESIGN

Lighting at a RCI is important to minimize driver confusion when driving through during the night or during inclement weather. Lighting can also help to illuminate conflict points, helping to improve safety conditions at these locations. In addition to other resources, the NCHRP Report 152 – “Warrants for Highway Lighting” may be used to evaluate the lighting needs of an intersection. Lighting should be particularly considered at rural intersections where there is a greater need to improve the visibility of the roadway for road users. **Figure 25** provides a layout of potential traffic lights placement at an RCI.

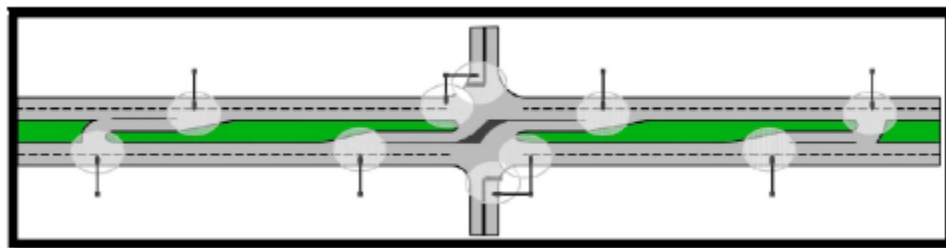


Figure 25: Example Street Lamp Placement at an RCI

Source: Mississippi DOT²

The FHWA provides the following guidance on the lighting of RCIs:

Lighting standards and specifications outlined in AASHTO's Street Lighting Design Guide, FHWA's Lighting Handbook, and the Illuminating Engineering Society of North America (IESNA) publications including American National Standard Practice for Street Lighting can be used to determine optimal lighting for RCUT intersections.

Based on national lighting guidance, agencies establish street lighting design guidelines along their facilities based on the road functional classification and pedestrian conflict area classifications. Intersection lighting is typically 1.5 times the street lighting along the approaches, or the street lighting of the two crossing streets are added together to determine the lighting guidelines for the intersection.

Generally, signalized RCUT intersections are constructed on streets with high traffic volumes likely meeting the corridor volume criteria for lighting. It is desirable to light the main and crossover intersections according to the determined intersection light levels. Depending on the intersection spacing, the light levels for the road segments between the intersections may be reduced to street segment light levels. If there is no lighting along the approaches, then transition lighting coming from dark into light and vice versa may enhance user experience and performance. Even with sufficient lighting provided for the overall intersection, additional supplemental lighting could be added in the median to illuminate the pedestrian refuge area.

Lighting at a stop- or merged-controlled RCUT intersection will follow similar lighting criteria as conventional intersections. These types of RCUT intersections are more likely to be located on a street without continuous lighting.

Source: FHWA¹

MnDOT's "Roadway Lighting Design Manual" can be referenced for additional MnDOT lighting criteria.¹⁴

SIGNAL POLE PLACEMENT

The FHWA provides detailed instruction on where signal equipment should be located at an RCI. The following excerpt from the FHWA's document entitled "Restricted Crossing U-turn Informational Guide" provides guidance for signal equipment location, with reference to **Figure 26**:

Mast arms and signal head locations should result in signals that are highly visible to the applicable traffic stream, especially to traffic using the crossovers. The placement should not be confusing to drivers. As with any signalized intersection, traffic equipment must be located to minimize crash potential. Traffic equipment placement should consider pedestrian and bicycle travel areas and not be an obstacle or inadvertently screen these users from the street. [Figure 26] shows pole, mast arm, and head locations for a typical signalized RCUT intersection constructed by NCDOT. The figure shows a pole-mounted signal head in the median for traffic using the U-turn crossover to supplement the overhead far-side heads. Some agencies in Michigan also use this configuration.

Source: FHWA¹

The standard MnDOT practice is to provide overhead signal indications.

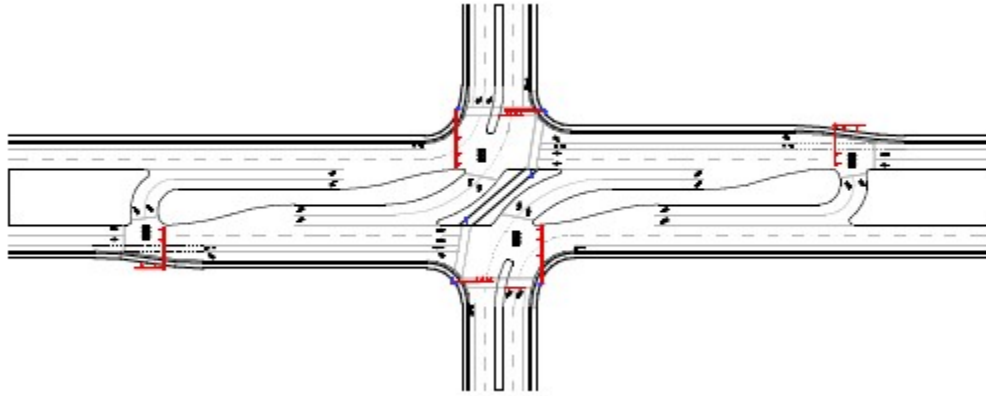


Figure 26: Possible Signal Pole Locations at an RCI

Source: FHWA¹

In practice the vast majority of signal poles for the minor street right turns are located in the median. This is standard practice in Minnesota for intersections with wide medians, and is recommended for signalized RCIs in Minnesota.

Figure 27 through **Figure 30** show the signal pole locations at RCIs along the US 17 corridor in Brunswick County, North Carolina.



Figure 27: Signal Pole Locations at an RCI on US-17 in North Carolina

Source: FHWA¹



Figure 28: Signal Pole Locations at an RCI on US-17 in North Carolina

Source: FHWA¹

Figure 29 shows the location of a signal at a median U-turn crossover with a loon. Signals at loons can be located in the loon, as shown in the figure, or slightly downstream from the loon.



Figure 29: Median U-Turn Crossover Signal Pole Locations at an RCI in North Carolina

Source: FHWA¹



Figure 30: Signal Pole Locations on the Minor Approaches of an RCI on US-17 in North Carolina

Source: FHWA¹

SIGNAL OPERATIONS

Reduced conflict intersections offer operational benefits over conventional intersections. These benefits are mainly derived from the reduction in phases needed at the main signal, and from the greater optimization ability due to the fact that the signals on each direction of roadway can operate independently. This section will provide guidance on how to operate the signals at an RCI.

SIGNAL PHASING AND RING STRUCTURE

All traffic signals at a reduced conflict intersection are able to operate with only two phases, which allows for the shorter cycle lengths at the signal. Because each direction of roadway is able to operate independently from one another, each direction can have different cycle lengths. The upstream intersection at the median U-turn should have the same cycle length as the signal at the main intersection for that direction of roadway to maintain progression. An example of the two-phase structure of at the main signals at an RCI is provided in **Figure 31**.

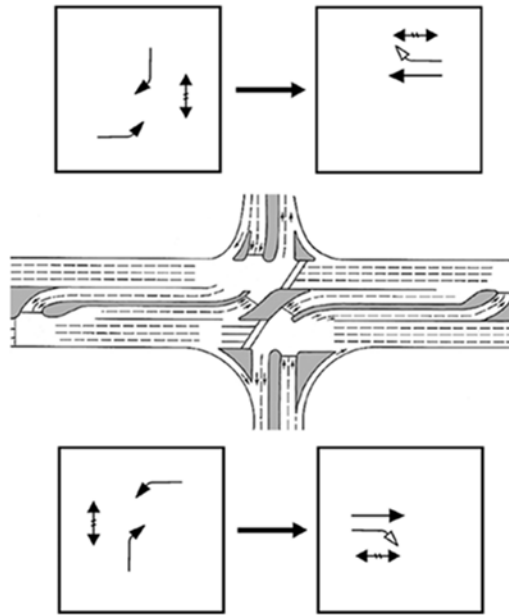


Figure 31: Two-Phase Signal Phasing at the Main Intersection of an RCI

Source: FHWA⁶

The FHWA provides the following guidance on split times for the signals at an RCI:

A rule of thumb is for the main street at a RCUT intersection to receive two-thirds to three-quarters of the green time during a cycle. At anything under 60-percent of green time for the main street, other intersection designs will likely serve the relatively heavy minor street demand more efficiently. RCUT intersection designs allowing LTOR from the U-turn crossovers where legal, RTOR from the minor street, and/or permissive left turns from the left-turn crossovers (using a flashing yellow arrow signal) to minimize the need for green time for the minor phases. Major street minimum green times for serving pedestrians are also relatively short because major street pedestrian crossings almost always happen in two stages.¹

SIGNAL COORDINATION

The FHWA provides information on progression at an RCI. It is important to note that the signal progression optimization ability of an RCI is dependent on the number of signal controllers at the intersection. RCIs with two or four signal controllers are capable of having different cycle lengths in each direction of the major roadway, whereas RCIs with one or three signal controllers are not. This will be covered more in the following section.

The following information on signal progression is provided by the FHWA.

A key reason to install a signalized RCUT intersection is to improve signal progression on the main street. The RCUT intersection is the only at-grade design known at this time to enable each direction on a two-way arterial to operate independently. No movement crosses both directions of the major street, so there is no need for both directions of the major street to receive the same signal indication at the same time. Both directions can be progressed at any speed and at any

signal spacing. The green band can be set equal to the length of the shortest green split along the arterial.¹

Figure 32 illustrates progression on an arterial with multiple RCIs. This figure demonstrates the ability to provide independent progression in each direction of the major roadway. At an RCI, each direction of the major roadway effectively acts as a one-way street, with the ability to have its own progression speed and cycle length.

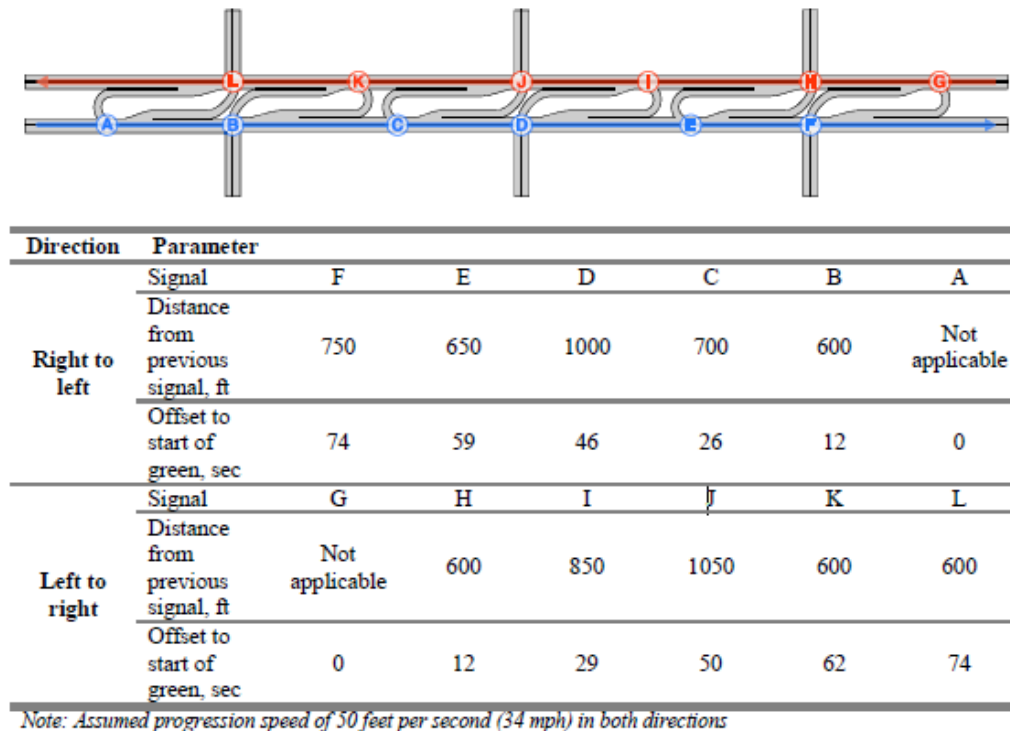


Figure 32: Example of Bidirectional Progression on an RCI Arterial

The ability to independently progress each side of a corridor with multiple RCIs allows for traffic signals to be added or relocated as traffic and land use patterns change with minimal impact on through arterial traffic.¹

NUMBER OF CONTROLLERS

The FHWA provides information on the number of signal controllers at an RCI, and the different capabilities associated with different configurations. The following section is an excerpt from the FHWA document entitled “Restricted Crossing U-turn Informational Guide”, referencing **Figure 33**, related to the use of four controllers:

For a four-legged RCUT intersection with four typical signal locations, separate signal controllers can be installed at each of the four signal locations. This preserves the independence of the signal control on either side of the arterial. This practice may increase the implementation cost of RCUT intersection installation and may prevent the signals from working together optimally in an actuated environment. [The figure] illustrates a RCUT intersection with four separate controllers.¹

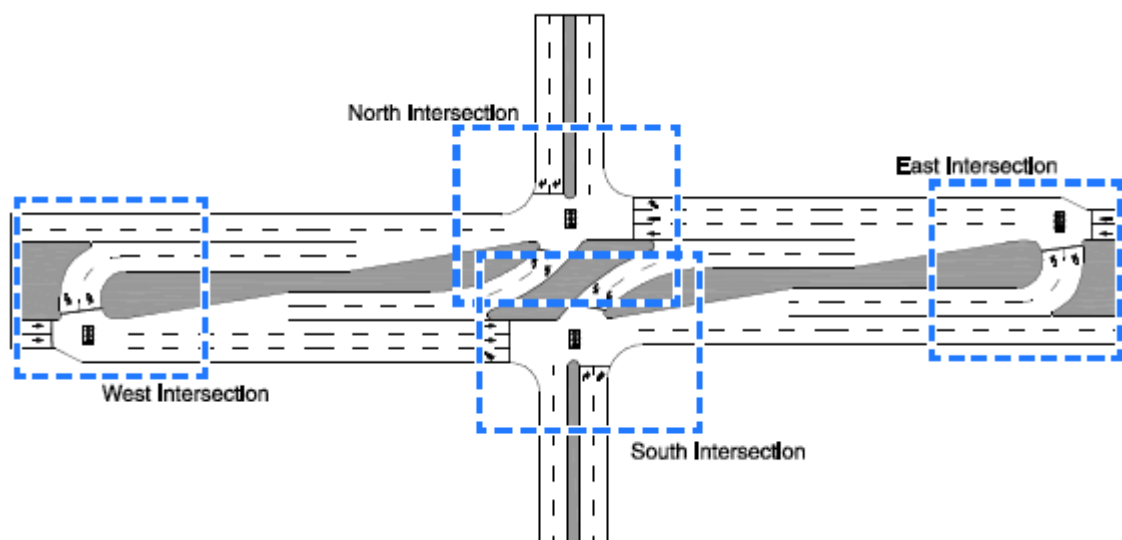


Figure 33: Signalized RCI with Four Separate Signal Controllers

Source: FHWA¹

FHWA also provides the following guidance for three controllers, with reference to **Figure 34**:

RCUT intersections may feature three controllers. One controller would handle the signal displays at the main intersection, and the other controllers would handle the signal displays at the U-turn crossovers. This design would not allow different cycle lengths in each direction of the arterial. [The figure] illustrates a RCUT intersection with three separate controllers.¹

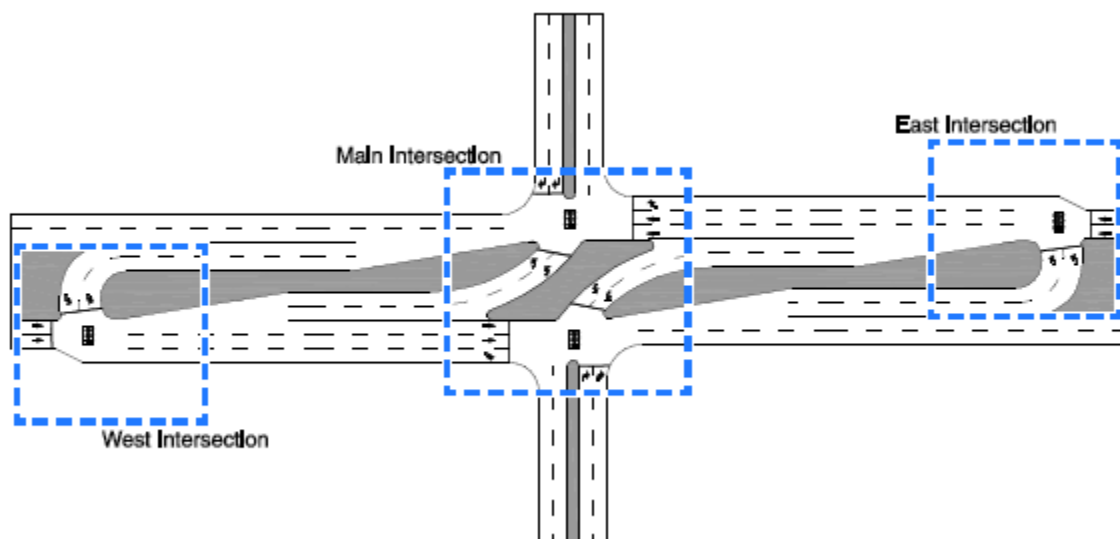


Figure 34: Signalized RCI with Three Separate Signal Controllers

Source: FHWA¹

For two controllers, with reference to **Figure 35**:

It is possible for a RCUT configuration to use two controllers; with each controlling the signals for each direction of the arterial. This design would allow different cycle lengths in each direction of the major street. [The figure] illustrates a RCUT intersection with two separate controllers.¹

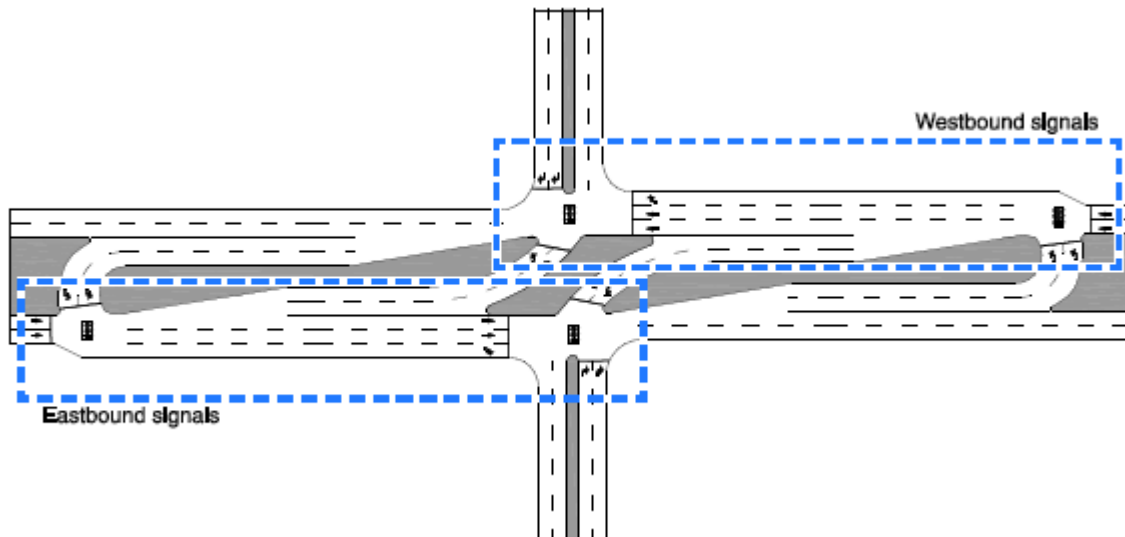


Figure 35: Signalized RCUT with Two Separate Signal Controllers

Source: FHWA¹

Finally, one controller could also be used, as discussed with reference to **Figure 36**:

One controller would be less expensive but would result in fewer control options and no chance to have different cycle lengths in each direction of the major street. [The figure] illustrates a RCUT intersection with a single controller.¹

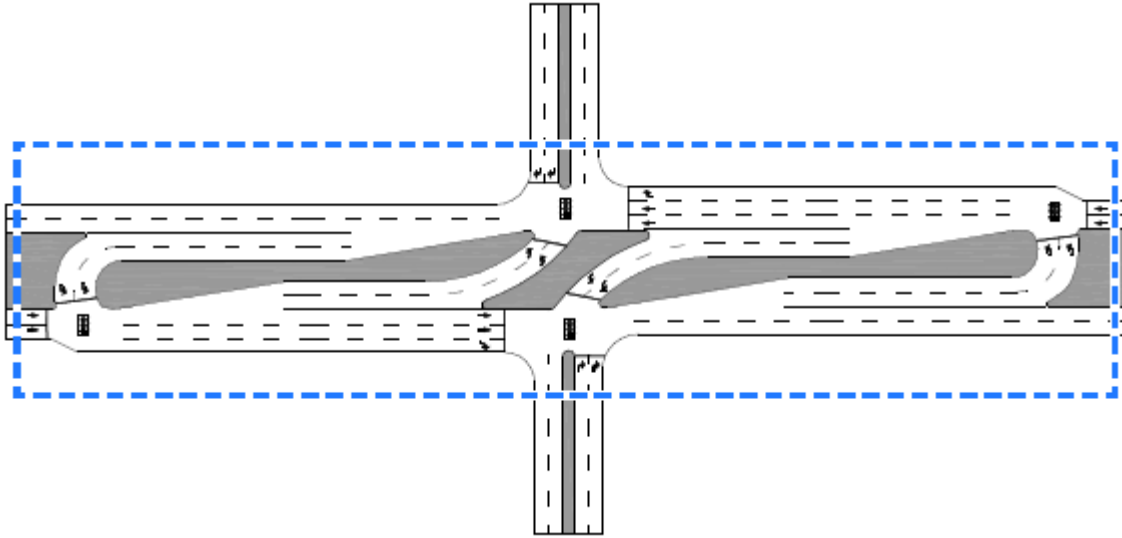


Figure 36: Signalized RCI with One Signal Controller

Source: FHWA¹

FHWA identifies the following advantages for single- and multiple-controller systems:

Advantages of multiple controllers instead of a single controller include:

- *Independent, bi-directional coordination is easier to operate*
- *If one controller fails, the other intersections of the RCUT can still function*
- *Programming phases and signal timing are simpler to install and maintain*
- *Installations require shorter wire lengths (signal conductor wire/detector wire runs to local controller only)*
- *Easier for signal maintenance in that each cabinet will likely be placed with visibility provided to the signal heads it controls*

Advantages of a single controller instead of multiple controllers include:

- *The system requires fewer cabinets and controllers to purchase, install, and maintain*
- *Interconnection is not required to keep signals coordinated*
- *There is a single controller to program and maintain*
- *There is a single service point for power*
- *There are fewer components to fail*
- *Vehicle detection may be easier to configure*

Source: FHWA¹

RIGHT TURN ON RED AND LEFT TURN ON RED

The FHWA provides the following guidance on right turn and left turn on red allowance/restrictions:

Allowing right turn on red (RTOR) and/or left turn on red (LTOR) (if allowed by law) at a RCUT intersection can reduce travel times. RTOR is generally easier for motorists to execute from a

minor street at a RCUT intersection compared to a conventional intersection. This is because there is no legal crossing for pedestrians on that corner seeking to cross the main street. The LTOR movement from a U-turn crossover generally does not encounter pedestrian traffic. Prohibiting RTOR and/or LTOR is conveyed via regulatory signing. This can include multiple signs on any particular approach prohibiting RTOR or LTOR, especially on wide minor street approaches or multilane crossovers. Some agencies chose to post signs saying what is allowed. For example, Texas agencies have posted "TURN ON GREEN ARROW ONLY" regulatory signs on some of its U-turn crossovers. An agency in Michigan posts regulatory "PROCEED ON GREEN [ball] ONLY."¹

The allowance of RTOR and LTOR at signalized intersections varies between different authoritative entities. The state, county, or city guidance for allowing/restricting RTOR or LTOR as applied to a one-way street should be followed for signalized RCIs.

Based on a review of the implemented signalized RCIs in the U.S. (table provided in **Appendix A**), RTOR is more often permitted than restricted, however this varies by location. In general, Alabama, Michigan, and North Carolina permit RTOR, while Texas and Ohio restrict it. There are no signalized U-turns at implemented RCIs that permit LTOR.

MAINTENANCE

The FHWA provides the following guidance on the maintenance of an RCI:

Maintaining a RCUT intersection is similar to a conventional intersection. Maintaining pavement and striping of the U-turn crossover lanes is similar to left turn lane maintenance at a conventional intersection, although it can be more challenging due to the confined nature of the channelized area. In both cases, maintenance of left turn lanes requires temporarily closing the lane and detouring traffic. Like for conventional streets, conducting maintenance activities during off-peak times can minimize traffic disruptions. In addition, this process generally follows the appropriate work zone guidelines as for all conventional intersections. Where RCUT intersections are part of a continuous corridor, maintenance can be done at one crossover while vehicles can use the next primary intersection. Maintaining signals and lighting at RCUT intersections is also similar to conventional intersection signal maintenance, although there are generally more signals and lighting to maintain. In most cases, RCUT intersections provide the advantage of being able to locate utility vehicles in the median to work on overhead signal and lighting fixtures, where utility vehicles at conventional intersections may have to block travel lanes or locate on private property to perform maintenance functions.

A RCUT intersection likely needs a larger median and/or right-of-way than a comparable conventional intersection, which may increase maintenance costs. Wider RCUT intersection medians create opportunities for landscaping. This could more expensive than at a conventional intersection but offers intangible benefits to road users and nearby land users.

Source: FHWA¹

SNOW REMOVAL

Snow removal for a RCUT intersection is accomplished similar to a conventional intersection. Through lanes are plowed as part of the corridor and snow is systematically pushed to the

outside of the street. Snow removal for the U-turn crossover is similar to a conventional left turn lane. These are typically plowed after the through lanes, and snow is pushed through the crossover to the opposite side of the street. The same technique is used for when a loon is part of the RCUT intersection. Snow is pushed through the U-turn crossover to the opposite side of the loon.

Source: FHWA¹

If a channelized pedestrian crossings are provided across the intersection, such as at a “Z” crossing, these should also be kept clear of snow.

SAFETY

As the name implies, reduced conflict intersections reduce the number of conflict points at an intersection when compared to a conventional intersection. This can lead to a reduction in the total number of crashes at an intersection, as well as a reduction in the severity of the crashes that occur.

CONFLICT POINTS

A standard intersection has 32 vehicle-vehicle conflict points. An RCI reduces the number of vehicle-vehicle conflict points to 14. A comparison of vehicle-vehicle conflict points is provided in **Table 4** and **Figure 37**.

Table 4: Conflict Point Comparison between an RCI and Conventional Intersection

Number of Intersection Legs	Conflict Points	
	Conventional	RCUT
3	9	7
4	32	18

Source: FHWA¹

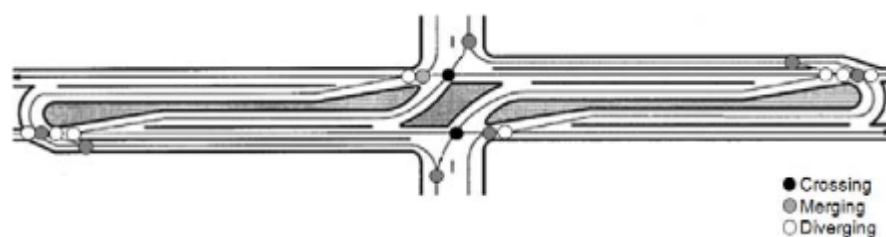


Figure 37: Conflict Points at an RCI from the FHWA

Source: FHWA⁶

CRASH TYPES

At a standard intersection there is a high risk of far-side conflict points that occur with direct minor road left turns and crossing maneuvers. Since minor street traffic wishing to make a left turn at an RCI is diverted to first make a right turn, weave to the left, and then make a U-turn, the right angle conflict points at the intersection are removed. The diverted vehicle paths for minor street movements reduce the

number of crossing vehicle paths, which reduces the number of crossing conflict points. Crossing maneuvers create the risk of angle crashes, which are typically more severe than other types of crashes. By reducing the potential for angle crashes, an RCI is generally expected to result in less severe crashes than would be expected at a conventional intersection.

CRASH MODIFICATION FACTOR

The Crash Modification Factor (CMF) is a metric used to evaluate the safety improvements due to the implementation of a given countermeasure at a specific type of site.

A draft study completed by the FHWA was completed to determine a CMF for the conversion of a conventional signalized intersection into a signalized RCI. The study analyzed crash data from 11 signalized intersections before and after their conversion from a conventional signalized intersection into a signalized RCI.

The study reports CMF for overall crashes of 0.85, and a CMF for injury crashes of 0.78. These results support the concept that RCIs generally reduce the number and severity of crashes at an intersection when compared to a conventional signalized intersection design. Additionally, the fact that injury crashes were reduced more than overall crashes reflects the concept that the crashes that occur at the conflict points of an RCI are generally less severe than those at a conventional intersection.

Source: FHWA¹⁵

SPECIAL USER CONSIDERATIONS

This section discusses considerations that should be made specific types of road users at an RCI. Special users that were not covered in previous sections are included in this section. This includes transit vehicles and emergency vehicles.

TRANSIT

The FHWA provides extensive guidance on transit vehicle consideration at an RCI in their document “Restricted Crossing U-turn Informational Guide”. The following section is an excerpt from this document:

A RCUT intersection can provide significant benefits to most transit users due to the ability to progress traffic in both directions along the major street, which results in higher average bus speeds. However, bus routes following the minor street at a RCUT intersection, or making a minor street left turn, will likely experience extra time compared to a conventional intersection as the buses use the U-turn crossovers. U-turn crossovers designed to accommodate large combination trucks without curb encroachments, should be able to accommodate standard transit and school buses.¹

Figure 38 shows potential bus stop locations for the mainline of a signalized RCI, as referenced in the following discussion on bus stop locations from the FHWA:

Bus Stop Locations

RCUT intersections may serve bus stops on either the intersection's near- or far-sides, just like at conventional intersections. Mid-block stops near the U-turn crossover are also an option,

particularly if a signalized crossing on the major street is also provided at this location. [The figure] shows these three options. Unique aspects of RCUT intersections that should be considered when locating bus stops are discussed below.¹

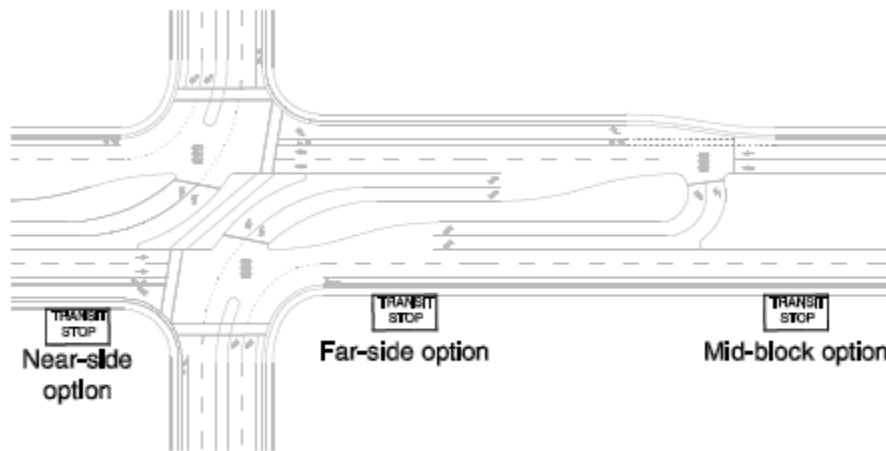


Figure 38: Potential Bus Stop Locations at an RCI

Source: FHWA¹

Far-side bus stops typically result in lower levels of vehicular delay than near-side bus stops. However, far-side stops at a RCUT intersection with a “Z” crossing place the bus stops away from the pedestrian crosswalk across the minor street. This placement may encourage prohibited pedestrian crossings and will increase the time required for alighting bus passengers to reach destinations on the other side of the street. A far-side stop would be located, in order of preference, (1) in an exclusive bus lane, (2) in a pullout accessed via the near-side right turn lane (exempting buses from the right turn requirement), and (3) in the curbside travel lane (potentially blocking cross-street right turns). If a pullout is used, consideration should be given to how the bus will re-enter the travel lanes.¹

A nearside stop is also an option at a RCUT intersection. In this case, a bus stopped at a nearside stop in the right turn lane will block right turn movements, which could cause motorists to make undesirable turns in front of the bus from an inside lane. One alternative would be to channelize the right turn, develop a short bus lane out of the right turn lane up to the intersection, and to place the bus stop on the channelizing island. This alternative keeps buses from blocking the right turn lane. The two-phase signal operation minimizes delay to buses that fall out of progression while serving passengers at the bus stop. Buses could be provided with a queue-jump phase when exiting the stop or could continue on an extension of the bus lane.¹

The following guidance on bus stop locations for the minor street of an RCI is also provided by the FHWA, referencing **Figure 39**.

When bus routes run along the minor street and must cross the intersection, offering bus stops on both the near- and far-side of the intersection is preferred. Far-side stops can be located on the major street at a shared major street/minor street bus stop if major street bus service is present. [The figure] shows major street nearside bus stops can be located in conjunction with minor street stops and the “Z” crossing.¹

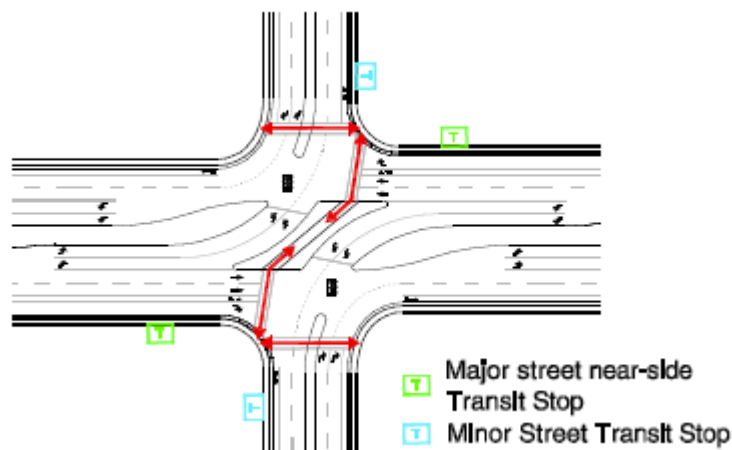


Figure 39: Potential Bus Stop Locations on the Minor and Major Streets of an RCI

Source: FHWA¹

Bus stops should be located on the minor street for bus routes that require a left turn from the mainline. This eliminates bus weaving to make lane changes, and the need for buses to use the U-turn. It is not recommended that bus stops are located at the loon of a median U-turn. An alternative option for corridors with multiple RCIs is to locate bus stops between the median U-turn crossovers, as illustrated in **Figure 40**.

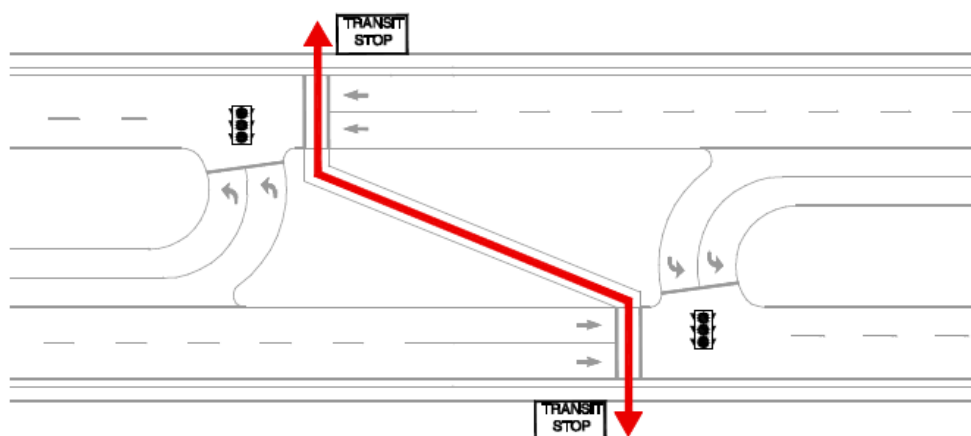


Figure 40: RCI Major Street Bus Stop Location Options between U-Turn Crossovers

Source: FHWA¹

The advantage of this option is that there is no major street right turning traffic and bus conflicts and pedestrians have a signal-controlled crossing of the arterial nearby. However, the disadvantage of this stop placement is that it is not near the minor street. Bus stops could be “nearside” in front of the stop bar or “far-side” beyond the stop bar; nearside placement could mean loss of efficiency in the lane where the bus stops are while far-side placement could mean longer lost times for main street traffic.¹

RCUT with Bus Rapid Transit or Light Rail

A RCUT corridor is efficient for major street movements and could be beneficial to rail transit operations. As with conventional intersections, bus rapid transit (BRT) or light rail transit (LRT) could be incorporated at a RCUT intersection. Key elements to be evaluated with the RCUT operations include route alignment, stop or station placement, and connectivity with pedestrian crossing locations.¹

EMERGENCY VEHICLES

The following guidance related to incident response is provided by the FHWA:

Most incident responses and emergency vehicle operations at a RCUT intersection will be unchanged from a comparable conventional arterial with a median because major street vehicles proceed in the same way. Considerations for other movements are noted below:

- *One-lane crossovers can be designed wide enough for emergency vehicles to pass a queue if needed. The typical one-lane U-turn crossover width in Michigan at MUT intersections is 30 feet, which is also sufficient for this purpose at a RCUT intersection.*
- *Channelizing islands in the median opening of the main intersection can be mountable to allow emergency vehicles to make left turn or minor street through movements. Many of Maryland's RCUT intersections with merges have this treatment.*
- *RCUT intersections may be undesirable at intersections where an emergency vehicle station is located on the minor street. Emergency vehicles making left turns or through movements from minor streets will have to negotiate the U-turn crossover or cross mountable channelizing islands, which will add to the response time.*

Source: FHWA¹

REFERENCES

1. FHWA. *Restricted Crossing U-Turn Intersection Informational Guide*. Washington, DC: USDOT, 2014
2. Mississippi Department of Transportation. *Synthesis of J-Turn Design Standards and Criteria*. Mississippi, 2010
3. FHWA. *Restricted Crossing U-Turn Intersection*. Informational Brochure. Obtained from: http://www.virginiadot.org/FHWA-SA-14-040_RCUT_Informational_Brochure.pdf
4. FHWA. Tech Brief: *Restricted Crossing U-Turn Intersection*, Report No. FHWA-HRT-09-059. Washington, DC: USDOT, 2009
5. North Carolina Department of Transportation. (2005). *Roadway Design Manual Part 1*, Section 4, Rev. 4, Chapter 9. Obtained from: <https://connect.ncdot.gov/projects/Roadway/Roadway%20Design%20Manual/09.%20At%20Grade%20Intersections.pdf>
6. FHWA. *Alternative Intersections/Interchanges: Informational Report (AIIR)*, Report No. FHWA-HRT-09-060. Washington, DC: USDOT, 2010
7. Minnesota Department of Transportation. (2000). *Roadway Design Manual*, Section 3, Chapter 5. Obtained from: <http://dotapp7.dot.state.mn.us/edms/download?docId=1062358>
8. Google Inc. Google Earth. Accessed July 2016
9. Edara, P., C. Sun, and S. Breslow, "Evaluation of J-turn Intersection Design Performance in Missouri," report cmr 14-005, Missouri Department of Transportation, Jefferson City, December 2013.
10. American Association of State Highway and Transportation Officials (AASHTO). *A Policy on the Geometric Design of Highways and Streets*. Washington, DC: AASHTO, 2011.
11. FHWA. Tech Brief: *Synthesis of the Median U-Turn Intersection Treatment, Safety, and Operational Benefits*, Report No. FHWA-HRT-07-033. Washington, DC: USDOT, 2009
12. North Carolina Department of Transportation. Pavement Markings. Division of Highways. https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Superstreet_Signing%20and%20PM_Typicals.pdf
13. Minnesota Department of Transportation. (2007). *Metro Traffic Signal Justification Methodology*. Traffic Engineering Branch. <http://www.dot.state.mn.us/trafficeng/signals/worksheets/SJR-Methodology.pdf>
14. Minnesota Department of Transportation. (2010). *MnDOT Roadway Lighting Design Manual*. Traffic Engineering Branch. http://www.dot.state.mn.us/trafficeng/lighting/2010_Roadway%20Lighting_Design_Manual2.pdf
15. FHWA. *DRAFT Development of a Crash Modification Factor for Signalized RCUTs*, Report No. TBD. Washington, DC: USDOT, 2016

APPENDIX A

TH 65 Reduced Conflict Intersection Analysis
Webinar with TxDOT-Meeting Summary
MnDOT's Water's Edge (Conf Rm WE 176)
Thursday, July 7, 2016 (8:00-10:00 a.m. CST)

Meeting Participants at MnDOT:

Brian Kary, MnDOT
Paul Jung, MnDOT
Kevin Schwartz, MnDOT
Mike Kruse, MnDOT
Chris Bosak, MnDOT
Kevin Sommers, MnDOT
Gayle Gedstad, MnDOT
Kent Barnard, MnDOT
Josie Tayse, MnDOT
Tod Sherman, MnDOT
Shuo Wang, MnDOT
Lars Impola, MnDOT
Brandon Bourdon, Kimley-Horn
Michael Kondziolka, Kimley-Horn

Meeting Participants in Texas:

Clayton Ripps, TxDOT
Dale Picha, TxDOT
Kwaku Obeng-Boampong, San Antonio
Miguel Barrera, San Antonio
Marc Jacobson, San Antonio

Questions from Kimley-Horn and
MnDOT are in black

Responses in blue are from the
webinar conversation

Roadway Design

- Distance between main intersection and median U-turn crossover
 - On US 281 the spacing of the existing intersections and driveways drove the U-turn crossover spacing
 - They did not want any loons to line up at an existing driveway location
 - For new RCIs, they are using a closer spacing (600'-800') to achieve better traffic flow
 - Side note: TTI did a study to determine
- Angle of U-turn approaches (always 90 degrees to approaching traffic)
 - They currently design the stop bars to be perpendicular to approaching traffic, but are open to staggering stop bars
 - Staggering could allow oncoming vehicles to see both vehicles in case one runs the red at the U-turn
 - Trucks are restricted from some Texas RCUTs
 - The hatched striping between dual lefts is due to tracking of trucks (design vehicle was WB-62)
- U-turn storage lane design
 - Begin at main intersection or begin taper downstream
 - They bring the taper back from the main intersection when the left and through traffic volumes from the side streets are high; based on turning movements

TH 65 Reduced Conflict Intersection Analysis
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- Use of acceleration lanes
 - Minor street right merge onto mainline
 - Would depend on if RTOR is allowed from the outside lane or not
 - If the right turn volume is very high then it makes sense to provide them
 - U-turn merge onto mainline
 - The do not provide
- Channelizing right turns (are minor rights always separated from minor thru and lefts)
 - They prefer to include a splitter island for right turns to provide channelization (and provide indication that something is different on each side of the splitter island)
 - Right-of-way could be a limiting factor
- Discuss continuity between number of right turn lanes at minor street and U-turn lanes
 - On 1604 they introduced a through lane from the right turn at the side street, brought it through to the next intersection, then tapered it off following the next intersection
- Curb type (main intersection)
 - Mountable for emergency vehicles
 - Surmountable versus vertical face
 - They typically use mountable curb on any roadway with a posted speed over 45 mph, including at RCIs (similar to MnDOT)
 - Some of their RCIs have side street curbing that is non-mountable

Emergency Vehicles

- Some emergency vehicles have gone directly across the curb (although this is the minority)
- There is a fire station on Evans Road where they have an RCI
 - The fire trucks make a right turn then use the U-turn

Signage & Striping

- Dotted striping from side street right turns feeding into U-turn lanes
 - They do use dotted lines
- Striping preferences for median U-turns
 - TxDOT does use chevrons at U-turns to provide room for trucks
- Any signing preferences guide or regulatory signs
 - Additional one-way, do not enter, and keep right signs are encouraged
 - Guide signs - Triple rights require overhead signing
 - On side streets use advanced signing

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Signal Operations

- Flashing yellow arrow for U-turns and/or left turns
 - TxDOT does not use FYA on roads with speeds over 45 mph
 - Also would want to consider how many lanes that turning vehicles must cross (dual U-turns)
- When to restrict RTOR from side street right turns or LTOR from U-turns
 - TxDOT does not typically allow RTOR because people are trying to use the outside lane then weave to the inside to make the U-turn
 - They do not see an advantage because the light at the U-turn is coordinated with the side street and won't turn green until the side street is released
 - They allow RTOR at US 281 & Marshall Rd from the outside lane only due to the simple design
 - If allowing RTOR, suggest delineating it with striping
- How is preemption handled?
 - Do not have preemption
- Have others allowed for left turns to be taken at the U-turn signal into another street or private drive, and if so, how was this designed? If so, what is the lane configuration and how is it signed?
 - They have been asked, but they do not allow
- Actual controller settings
 - Phasing/ring structure
 - Will send timing plans
- Are any Syncho/SimTraffic files and timing plans available for review?
 - Will send Synchro files
- Number of controllers
 - TxDOT uses four controllers at their superstreets
 - They use cycle lengths from 80s to 180s
- Coordination approach (independent by direction, preference for side-street, mainline, etc.)
 - US 281 is being heavily favored over the side streets since it is over capacity
 - U-turns from the side street are forced to stop when they reach the U-turn

Cycle Lengths

- Can be different between directions
- Difficulty comes with adjacent intersections that aren't RCIs since they only have one cycle length (could half cycle)

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- o Seems to be coordination with side street right turns and U-turns on San Antonio RCIs

Safety

- Any signalized RCUT crash data?
- Any crash modifications factor for signalized RCUT intersections?
 - o FHWA study looked at Texas's RCUTS
 - o They do not have safety data on hand

Extra Information

- TTI did a study and found that business actually increased along the US 281 corridor with RCIs by 20-30% based on gross sales receipts
- U-turns are restricted from the left turn at the main intersection using signing
- They never extend two U-turn lanes back to the main intersection, only one
- Complaints have increased on US 281, but it is over capacity due to development traffic
- They provided signal timing plans for their RCIs
- RCIs were used as an intermediate step before grade separation
- US 281 has an ADT of 80,000

Lessons Learned

- When grade separating 1604, want to maintain RCUT elements as long as possible to maintain traffic operations
- Some conspiracy theories that TxDOT was making signals worse intentionally so that they could get a tollway arose
- Developers want to line up directly with the loon; TxDOT hasn't allowed this yet and doesn't plan to

TH 65 Reduced Conflict Intersection Analysis
Webinar with NCDOT-Meeting Summary
MnDOT's Water's Edge (Conf Rm WE 176)
Thursday, July 14, 2016 (1:00-3:00 p.m. CST)

Meeting Participants at MnDOT:

Brian Kary, MnDOT
Paul Jung, MnDOT
Kevin Schwartz, MnDOT
Mike Kruse, MnDOT
Chad Erickson, MnDOT
Mike Fairbanks, MnDOT
Kevin Sommers, MnDOT
Gayle Gedstad, MnDOT
Josie Tayse, MnDOT
Tod Sherman, MnDOT
Brandon Bourdon, Kimley-Horn
Michael Kondziolka, Kimley-Horn

Meeting Participants at NCDOT:

Jim Dunlop, NCDOT
Joe Hummer, NCDOT
Shawn Troy, NCDOT
Matt Williams, NCDOT

Questions from Kimley-Horn and
MnDOT are in black

Responses in blue are direct responses
from Jim Dunlop

Responses in green are from the
webinar conversation

Roadway Design

- Distance between main intersection and median U-turn crossover
 - o Typically 800-1000'. Sometimes longer if field conditions warrant (for instance, if there's a stream or driveway or other feature in the way, or if extending the distance helps with something else, such as providing more convenient access on either side.)
 - o The first RCI they designed had spacing of 800' (didn't have direct left turns at the main intersection); this had queuing and weaving problems
 - o The minimum distance is based on queues and deceleration needs
 - o Shorter distances equal less emissions, shorter travel time, and shorter queues
- Angle of U-turn approaches (always 90 degrees to approaching traffic)
 - o It depends on the width of the median. We try to get to 90 degrees, but if all we have is a 23 foot median, it makes it tougher to get that.
 - o Tied to location of signal heads.
- U-turn storage lane design
 - o Begin at main intersection or begin taper downstream
 - o We have a few installed that start at the main intersection. Primarily where we needed the side street rights to go into this lane (triple rights onto a main road when mainline only has two continuous through lanes.)
 - o They originally had triple right feeding into two U-turns

TH 65 Reduced Conflict Intersection Analysis
Webinar with NCDOT-Meeting Summary
MnDOT's Water's Edge (Conf Rm WE 176)
Thursday, July 14, 2016 (1:00-3:00 p.m. CST)

- o Prefer to have right turns turn directly into U-turn lane if there are three right turn lanes turning into two U-turn lanes
 - o If the left-most right turn lane is fed into a U-turn lane, signing and striping should be used to enforce that movement
- Use of acceleration lanes
 - o Minor street right merge onto mainline
 - Rare, not in urban signalized situations. Those that exist are in rural areas.
 - Signalized RCI's do not use acceleration lanes
 - o U-turn merge onto mainline
 - In some cases, we'll create a new lane coming out of the U-turn bulb that will become a right-turn lane at the main intersection. Other than allowing trucks to complete the U-turn movement, we don't provide additional acceleration space.
 - Signalized RCI's do NOT use acceleration lanes
- Channelizing right turns (are minor rights always separated from minor thru and lefts)
 - o We may channelize the right turns, separating lanes, especially if there's triple rights. Texas has done this, I don't believe we have any right now.
 - o Don't have any now, but don't have a problem with it at side streets with three right turn lanes
 - o They think that a median on the minor roads is always a good idea
- Discuss continuity between number of right turn lanes at minor street and U-turn lanes
 - o We've planned a few triple rights that require the U-turn lane to be back to the intersection.
- Curb type (main intersection)
 - o Mountable for emergency vehicles
 - o Sometimes, if requested. We had one location where the local volunteer fire department insisted on the mountable median during planning, but then told us during construction (after they saw the superstreet concept) that they were fine with making the U-turn and that they wanted a normal median at the main intersection.
 - o Surmountable versus vertical face
 - o They will provide a depressed median if the local entities require it
 - o They have had a local fire station require them to provide a depressed median, then the fire station came back to them and said they actually prefer to use the U-turn versus the depressed median

TH 65 Reduced Conflict Intersection Analysis
Webinar with NCDOT-Meeting Summary
MnDOT's Water's Edge (Conf Rm WE 176)
Thursday, July 14, 2016 (1:00-3:00 p.m. CST)

- o Prefer to use larger curb to discourage wrong-way maneuvers (more important at side streets)

Signage & Striping

- Dotted striping from side street right turns feeding into U-turn lanes
 - o Do use if they have U-turn lanes extended back to the main intersections
- Striping preferences for median U-turns
 - o At Europa Drive & US 15 in Chapel Hill they provided dotted striping for inside left turn lane (mini-loon)
 - o Trucks generally use the outside lane at the U-turn; NCDOT signs for trucks to use the outside lane only
 - o The size of the loon is based on the turning radius of the design vehicle
- Any signing preferences guide or regulatory signs
 - o They do not use the "U-turn" with an arrow under it sign
 - o At the Wilmington/Carolina Beach Rd RCI they have used guide signs saying "Wilmington Keep Left" and "Myrtle Beach Keep Right" signs

Signal Operations

- Flashing yellow arrow for U-turns and/or left turns
 - o If single lane and protected-permitted phasing (this is our preference.)
 - o They allow FYA at the U-turn signal with one lane only so far, none with two lanes yet
 - o Will allow it if sight distance and other things don't prohibit it
 - o Dual left turns and dual U-turns will be protected only
- When to restrict RTOR from side street right turns or LTOR from U-turns
 - o North Carolina does not allow LTOR. Sight distance would determine if we'd restrict RTOR. I'd have to review sites with triple rights to see if we did anything differently.
 - o North Carolina is one of thirteen states that does not allow LTOR
 - o They do allow RTOR off-peak hours along with flashing yellow arrows so side street vehicles can essentially use it as if it was stop-controlled
 - o Dual left turns and dual U-turns will be protected only
- How is preemption handled?
 - o Depends on the paths of the emergency vehicles. No real difference from our normal practice (not sure if we have any preemption at any superstreet.)
 - o They have provided an emergency vehicle preemption system at an unsignalized RCI that stops traffic (US 601 & Landsford Rd)
 - o Would provide preemption if there was a fire station on the minor street

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- o Preemption is not as common in North Carolina
- Have others allowed for left turns to be taken at the U-turn signal into another street or private drive, and if so, how was this designed? If so, what is the lane configuration and how is it signed?
 - o We've allowed a left turn into a driveway, but egress is directed to another location so as to not conflict with the predominant U-turn movement.
 - o They allow the ingress move at the loon, but not egress at the loon
 - o Would rather have a driveway 100' away downstream of the loon
 - o Due to the wide median at TH 65 & Viking, we could potentially allow access because we don't need a loon
 - o Must be forced to allow access at the loon although would not through the entire concept out due to some compromise
- Actual controller settings
 - o Phasing/ring structure
 - o Two phase signals.
 - o Suggest setting cycle length as short as possible
 - o Would go as low as 60 second cycle lengths
- Are any Syncho/SimTraffic files and timing plans available for review?
 - o We'll have to collect them for you but they are available.
- Number of controllers
 - o One per signal location, meaning for a four leg superstreet, four signals/controllers. We are looking at a site that will only have one controller for the two left turn intersections.
- Coordination approach (independent by direction, preference for side-street, mainline, etc.)
 - o Yes. We have probably tried all of these in the field, definitely in planning analysis. We have run (in preliminary analysis) different cycle lengths for the two main street directions.
 - o Because AADTs are 5:1 for the mainline vs. minor streets, they always try to favor the mainline as much as possible

Safety

- Any signalized RCUT crash data?
- Any crash modifications factor for signalized RCUT intersections?
 - o Sites with three right turn lanes do not perform as well in regards to crashes
 - o There have been more rear end crashes at signalized RCIs compared to conventional intersections because you are moving from 1 signal to 4 signals

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Extra

- If an intersection is being converted and already has two lanes on the minor street but only would require one right turn lane from the minor street, just keep the two lanes even if it is not required based on the existing demand
- For public outreach the message to the public should be “pay 20-30 extra seconds on the side street, and get better, safer, and faster ride once you get onto the mainline.”
 - Additionally, people destined to the side street will have a faster time getting to their street when returning on a corridor with RCIs
- How did before and after compare for an implemented RCI?
 - Before the intersection had six phases and was a 5-legged, split-phased intersection with a 200 second cycle length
 - They converted to an RCI and now run 140-160 second cycle lengths due to the close spacing to a conventional intersection
 - Would prefer to have a 100 second cycle
- Spacing is a factor that drives whether or not RCIs are feasible
- If building at a new 4-lane divided facility, you shouldn't have any full-movement intersections
- Pedestrian accommodations at RCIs should be looked at as a positive
- Still don't have a good solution for crossing bicyclists
- Missouri DOT has a 4 minute video (produced by Wal-Mart and the DOT)

State	City	Intersection	Number of Side Street Lanes	RTOR Permitted at Minor Street	Signalized U-turns	LTOR Permitted at U-turn	Stop Bar @ U-turn Parallel to Mainline	Access @ U-turn	Striped Truck Median at Dual U-turns	Minor Approach Channelization	Right Turns Striped into U-Turn Lane	Acceleration Lane for Minor Right	Acceleration Lane for U-turn	Distance to Median Crossover - 1	Distance to Median Crossover - 2	"Z" Ped Crossing	Bike Lanes Provided	Pavement Markings: Minor RTs	Pavement Markings: U-turns	Use of Overhead Signs on Minor Road	Signal Mounting Type	Signal Pole Placement for Minor Street	Angled / Offset Left Turn	Flashing Yellow Arrow @ U-turns
Alabama	Dothan	US 231 & Plum Rd	2	Yes	0	NA	NA	No	NA	Median	No	No	No	775	675	Yes	No	Arrow + ONLY	Left + ONLY	No	Wire	Far	No	NA
		US 231 & Retail Dr	2	Yes	0	NA	NA	No	NA	None	No	No	No	860	590	Yes	No	Arrow + ONLY	Left + ONLY	No	Wire	Far	No	NA
Michigan	Troy	Big Beaver Rd & Lakewood Dr	2	Yes	1	NA	Yes	Yes	No	None	No	No	No	550	360	No	No	Arrow + ONLY	Left + ONLY	No	Pole	Median	No	No
		Long Lake Rd & Corporate Dr	2	Yes	0	NA	NA	No	NA	None	No	No	No	560	550	Offset	No	Arrow + ONLY	None	No	Wire	Median	No	NA
Texas	San Antonio	US 281 & Evans Rd	3	No	2	No	Yes	No	Yes	Splitter	Yes	No	No	990	975	Yes	No	Arrow + ONLY	U-turn + ONLY	Yes	Pole	Median	No	No
		US 281 & Stone Oak Pkwy	3	No	2	No	Yes	No	Yes	Splitter	Yes	No	No	1200	1000	Yes	No	Arrow + ONLY	U-turn + ONLY	Yes	Pole	Median	No	No
		US 281 & Marshall Rd	2	Outside Only	2	No	Yes	Yes	NA	None	No	No	No	870	500	Yes	No	Arrow + ONLY	U-turn + ONLY	No	Pole	Median	No	No
	Austin	SH 71 & FM 973	2	No	2	No	Yes	No	Yes	Splitter	Yes	No	No	1035	1770	Yes	No	Arrow + ONLY	U-turn + ONLY	No	Pole	Median	No	No
		SH 71 & FM 973/Fallwall Ln	1 and 2	No	2	No	Yes	No	Yes	Median	Yes	No	No	1125	1640	Yes	No	Arrow + ONLY	U-turn + ONLY	No	Pole	Median	No	No
North Carolina	Chapel Hill	US 15 & Erwin Rd	2	Yes	2	No	Yes	No	No	None	No	No	No	735	750	Yes	No	Arrow + ONLY	Left	No	Pole	Median	NA	No
	Leland	US 17 & Brunswick Forest Pkwy	2	Yes	1	No	Yes	No	NA	Median	No	No	No	830	-	NA	No	Arrow + ONLY	U-turn + ONLY	No	Pole	Median	Yes	No
		US 17 & Lanvale Rd	1 and 3	Yes	2	No	Yes	No	No	Median	Yes	No	No	790	765	None	No	Arrow	U-turn + ONLY	No	Pole	Median	Yes	No
		US 17 & Ploof Rd	1 and 2	Yes	2	No	Yes	No	No	Median	No	No	No	560	615	None	No	Arrow	U-turn + ONLY	No	Pole	Median	Yes	No
		US 17 & Gregory Rd	1	Yes	2	No	Yes	No	NA	Median	No	No	No	700	840	None	No	Arrow	U-turn + ONLY	No	Pole	Median	Yes	No
	Winnabow	US 17 & Graniflora Rd	2	Yes	2	No	Yes	Yes	No	Median	No	No	No	1025	1380	None	No	Arrow	U-turn + ONLY	No	Pole	Median	Yes	No
		US 17 & Maco Rd	1	Yes	0	NA	NA	No	NA	Median	No	No	No	725	-	None	No	Arrow	U-turn	No	Pole	Median	Yes	No
		US 17 & Rice Creek Pkwy	1	No	0	NA	NA	No	NA	Median	No	No	No	870	-	None	No	Arrow	U-turn	No	Pole	Median	Yes	No
	Bolivia	US 17 & Bus 17/Old Ocean Hwy	2	Yes	1	No	No	No	No	Median	No	No	No	740	-	None	No	Arrow	U-turn	No	Pole	Median	Yes	No
		US 17 & Hospital Dr	2	Info Not Avail.	1	No	No	No	No	Median	No	No	No	1000	-	None	No	Arrow	U-turn	No	Pole	Nearside	Yes	No
	Holly Springs	NC 55 & Green Oaks Pkwy	2	Yes	2	No	No	No	No	Median	No	No	No	805	860	Yes	No	Arrow + ONLY	U-turn	No	Pole	Median	Yes	No
		NC 55 & New Hill Rd	2	Yes	2	No	No	No	No	Median	No	No	No	845	805	Yes	No	Arrow + ONLY	U-turn	No	Pole	Median	Yes	No
		NC 55 & Grand Hill Pl/Vinewood Pl	2	Yes	1	No	No	No	No	Median	No	No	No	910	-	None	No	Arrow	U-turn	No	Pole	Median	Yes	No
		NC 55 & Bennet Knoll Pkwy	2	Info Not Avail.	1	No	No	No	No	Median	No	No	No	820	-	None	No	Arrow + ONLY	U-turn	Info Not Avail.	Pole	Median	Yes	No
	Wilmington	Carolina Beach Rd (US 421) & Retail Center	2	No	2	FYA	No	No	No	Median	No	No	No	1210	800	None	No	Arrow	U-turn + ONLY	No	Pole	Median	Yes	Yes
Ohio	Hamilton	Ohio 4 & Symmes Rd	3	No	2	No	Staggered	No	Yes	Median	Yes	No	No	720	685	None	No	Arrow	U-turn	Yes	Pole	Diagonal	No	No
		Ohio 4 & Tylersville Rd	2 and 3	No	2	No	Staggered	No	Yes	None	Yes	No	No	865	810	None	No	Arrow	U-turn	Yes	Pole	Diagonal	No	No
		Ohio 4 & Hamilton Mason Rd	2 and 3	No	2	No	No	No	Yes	Median	Yes	No	No	925	860	None	No	Arrow	U-turn	No	Pole	Diagonal	Yes	No
Maryland	Gambrills	Maryland 3 & Waugh Chapel Rd	3	No	2	Unknown	No	No	NO	Median	Yes	No	Yes	740	520	Yes	No	Arrow	Left	Yes	Pole	Median	No	No



Summary of findings from NCDOT webinar, TxDOT webinar, and a benchmarking review of implemented signalized reduced conflict intersections

U-TURN DESIGN

Distance to U-turn Storage Lanes

- Keep as close to 600' as queueing, geometric requirements, and spacing to nearby intersections and driveways will allow

U-turn Storage Lanes

- If dual U-turn lanes are provided, it is preferable to extend one of the lanes (the inner lane) back to the main intersection to act as a receiving lane for the left-most minor street right turn lane
- If the median width allows, align the U-turn stop bar to be parallel with the mainline direction of travel

MAIN INTERSECTION DESIGN

Minor Street Right Turn Design

- Channelize the right-most right turn lane when the three right turn lanes are provided, but not necessary if there are only two right turn lanes

Curb Type

- Provide mountable curb in the median island in the center of the intersection, as is typical for high-speed roadways
- Do not provide a median depression through center median unless forced to for emergency vehicle access

AUXILIARY LANES

Acceleration Lanes

- Generally do not provide acceleration lanes at signalized RCIs
- May create a new lane at the U-turn that turns into the mainline right turn lane if demands for this movement are high (i.e. auxiliary lane between loop and main intersection right turn lane), otherwise provide a standard right turn lane tapered downstream from the U-turn

SIGNING AND STRIPING

Dotted Striping from Minor Street Right Turn into U-turn Lane

- Provide dotted striping to guide the left-most minor street right turn lane into the U-turn lane if the U-turn lane extends back to the main intersection



Striping at the Median U-turn Crossover

- When two U-turn lanes are provided, striped chevrons may be provided to separate the lanes and better accommodate the vehicle path of large trucks
- Dotted striping guiding U-turn lanes into receiving lanes should be provided with two U-turn lanes are provided at the median U-turn crossover

Guide Signs

- Advanced overhead guide signs should be used at minor approaches with three right turn lanes

SIGNAL OPERATIONS

Flashing Yellow Arrow

- Can use if the median U-turn crossover has one lane, though it is not common practice
- Most do not use with dual lefts or on high-speed facilities

Right and Left Turn on Red and Restrictions

- Sight distance determines if right turn on red should be restricted
- Dual left turns and dual U-turns should be protected only (left turn on red restricted) according to TxDOT and NCDOT policies.

Preemption

- Mainline and U-turn signals may be preempted for emergency vehicles

Driveway Access at U-turn Signals

- Preference is to not allow driveway access within 100' from a U-turn median crossover

Signal Timing/Phasing/Controllers/Coordination

- Signals should be two phases
- Signal lengths should be kept as short as possible, down to 60 seconds
- Each intersection has typically been operated with its own controller (i.e. four controllers)
- Mainline directions can and if appropriate should have different cycle lengths
- The mainline typically should be favored over the minor road due to mainline volumes generally having considerably higher volume than minor street volumes