APPENDIX A3 INNOVATIVE INTERSECTION AND INTERCHANGE DESIGN GUIDELINES

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SECTION 1 - INNOVATIVE INTERSECTIONS AND INTERCHANGES

CURRENT VDOT INNOVATIVE INTERSECTION AND INTERCHANGE CONTROL TYPES

Below are examples of Innovative Intersection and Interchange Control Types that VDOT currently recognizes as effective traffic control treatments: *

Intersections

- Displaced Left-Turn (DLT)
- Median U-Turn (MUT)
- Restricted Crossing U-Turn (RCUT)
- Continuous Green-T (CGT)
- Quadrant Roadway (QR)
- Jug-handle
- Roundabouts

Interchanges

- Diverging Diamond Interchange (DDI)
- Single Point Urban Interchange
- Double Roundabout Interchange

Other Innovative Intersection and interchange designs may be developed in the future and will be listed in this Appendix.

For more information on the above mentioned Innovative Intersection Designs see:

http://www.virginiadot.org/info/alternative_intersection_informational_design_guides.asp

https://safety.fhwa.dot.gov/intersection/alter_design/

* Added 7/17

SECTION 2 - INNOVATIVE INTERSECTION DESIGN GUIDELINES

DISPLACED LEFT-TURN INTERSECTION (DLT)

These intersections are also known as Continuous Flow Intersection (CFI) or Crossover Displaced Left-Turn Intersections.

Any intersection form relocating one or more left-turn movements on an approach to the other side of the opposing traffic flow.

- Allows left-turn movements to proceed simultaneously with the through movement.
- Eliminates the left turn phase for this approach.
- Reduces the number of traffic signal phases and conflict points (locations where user paths cross).
- Can result in improvements in traffic operations and safety performance
- Green time can be reallocated to facilitate pedestrian crossings

For more information on the above mentioned Innovative Intersection Designs see:
http://www.virginiadot.org/FHWA-SA-14-041DLTInformationalBrochure_1.pdf

http://www.virginiadot.org/FHWA-SA-14-068DLTInformationalGuide.pdf

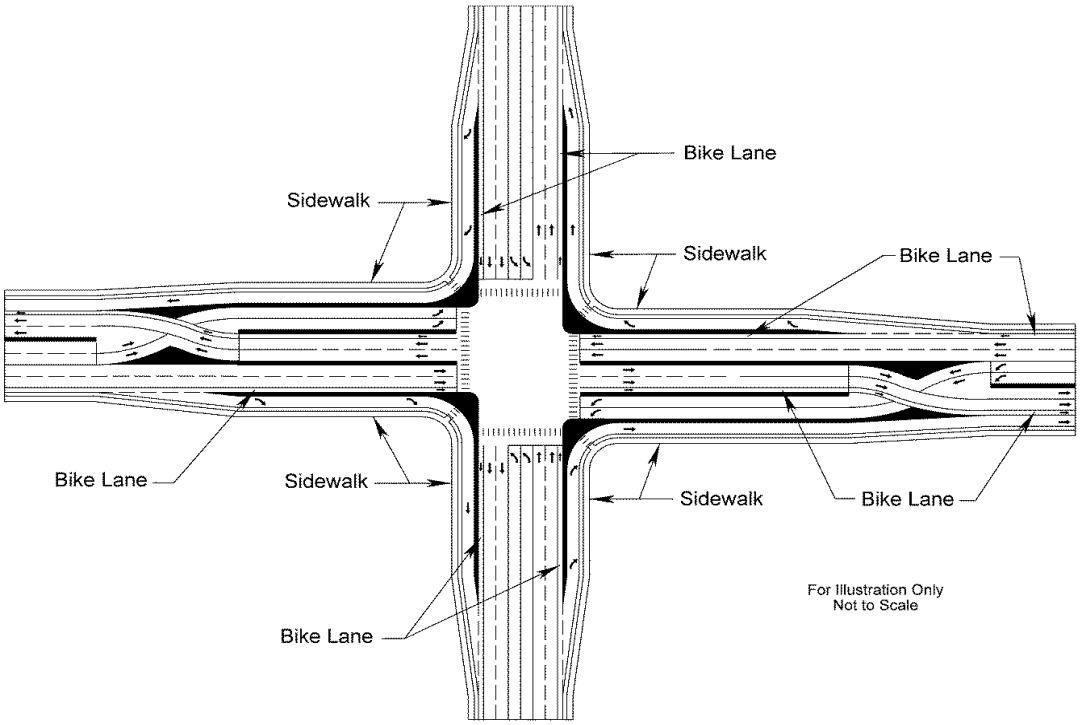

FIGURE A3-1 DISPLACED LEFT TURN INTERSECTION*

* Added 10/20

MEDIAN U-TURN INTERSECTION (MUT)

These intersections are also known as Median U-Turn Crossover, Boulevard Turnaround, Michigan Loon and ThrU-Turn Intersection.

- Replaces all direct left turns at an intersection with indirect left turns using a U-turn movement in a wide median.
- Eliminates left turns on both intersecting side streets and the major street.
- Reduce the number of traffic signal phases and conflict points - May result in improved intersection operations and safety.
- Can also utilize unsignalized median U-turns.
- Distance of the secondary intersections from the main intersection should provide adequate taper and storage length for vehicles, signing, and sight distance. Recommend spacing the secondary intersections ±660 feet from the main intersection.

For more information on the above mentioned Innovative Intersection Designs see:
http://www.virginiadot.org/FHWA-SA-14-042_MUT_Informational_Brochure.pdf

http://www.virginiadot.org/FHWA-SA-14-069_MUT_Informational_Guide.pdf

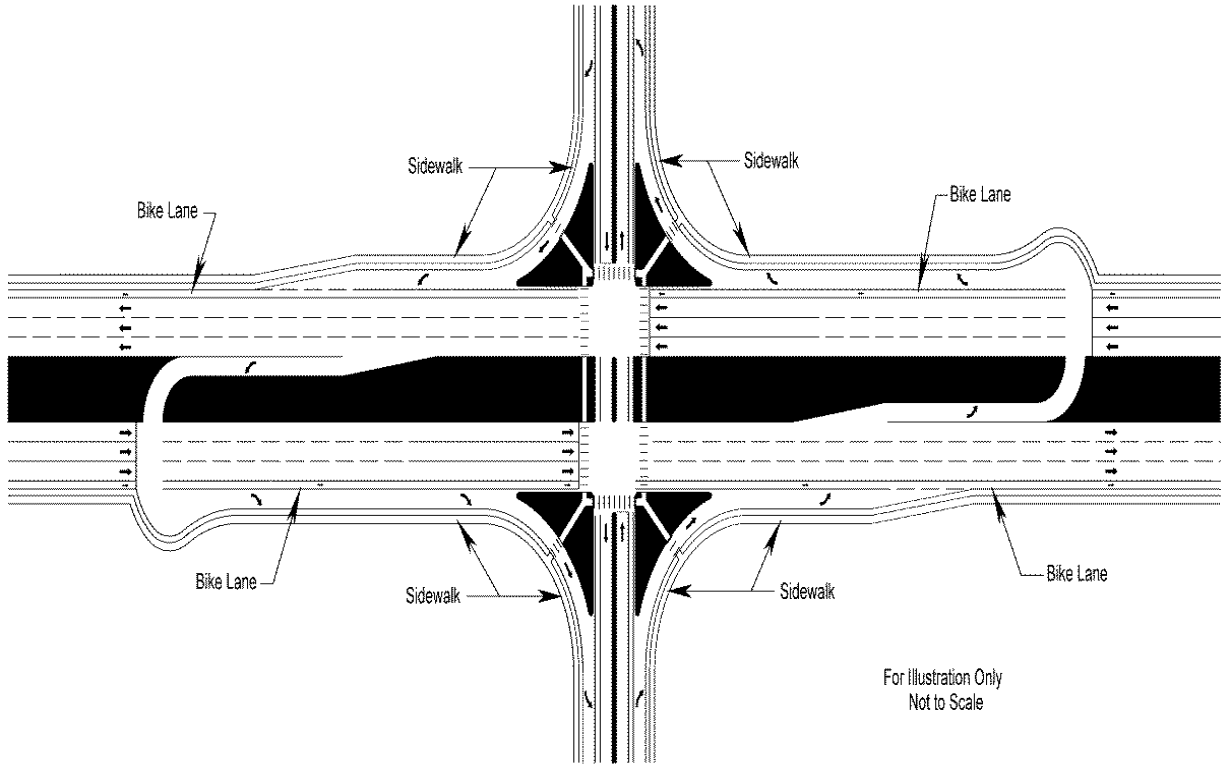

FIGURE A3-2 MEDIAN U-TURN INTERSECTION*

RESTRICTED CROSSING U-TURN INTERSECTION (RCUT)

These intersections are also known as Superstreet Intersection, J-Turn Intersection and Synchronized Street Intersection

- Replaces side street direct left turns at an intersection with indirect left turns using a U-turn movement in a wide median.
- Eliminates left turns on both intersecting side streets. Left turns are provided on the major street.
- Can be signalized or unsignalized.
- Reduce the number of traffic signal phases and conflict points. When implemented as a corridor treatment, almost perfect signal progression is possible as the main intersection can be operated as two separate signals with the two major street direction phases operating independently of each other.
- Will usually result in improved intersection operations and safety.
- Distance of the secondary intersections from the main intersection should provide adequate taper and storage length for vehicles, signing, and sight distance. Recommend spacing the secondary intersections ±660 feet from the main intersection.

For more information on the above mentioned Innovative Intersection Designs see: *http://www.virginiadot.org/FHWA-SA-14-040_RCUT_Informational_Brochure.pdf*

http://www.virginiadot.org/info/alternative_intersection_informational_design_guides.asp

https://safety.fhwa.dot.gov/intersection/alter_design/

* Added 10/20

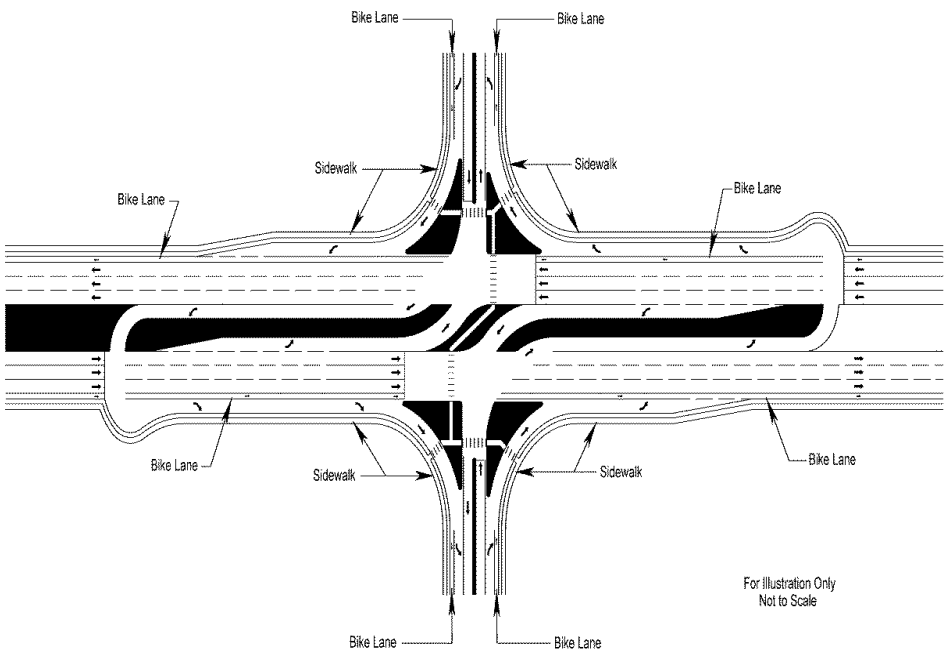

FIGURE A3-3 RESTRICTED CROSSING U-TURN INTERSECTION*

CONTINUOUS GREEN-T (CGT)

This design provides free-flow operations in one direction on the major street and can reduce the number of approach movements that need to stop to three by using free-flow right turn lanes on the arterial and cross streets and acceleration/merge lanes for left turn movements from the cross street. Physical separation or barrier is typically required between the acceleration/merge lanes and the mainline free flow movement.

For more information on the above mentioned Innovative Intersection Designs see:
https://www.fhwa.dot.gov/publications/research/safety/16036/16036.pdf

https://safety.fhwa.dot.gov/intersection/innovative/others/casestudies/fhwasa09016/fhwasa09016.pdf

* Added 10/20

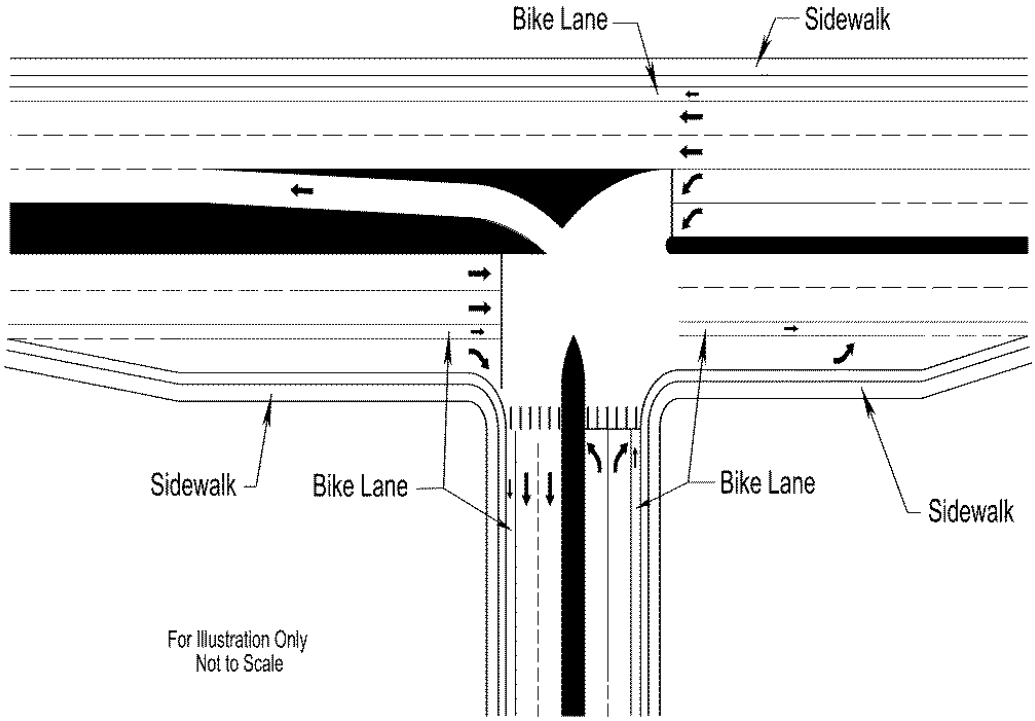

FIGURE A3-4 CONTINUOUS GREEN T INTERSECTION*

* Added 10/20

QUADRANT ROADWAY INTERSECTION (QR)*

The primary geometric design considerations of the QR intersection are as follows:

- Left turns are not permitted at the main intersection.
- The location of the connector road should be primarily determined by the left-turn volume at the intersection.

U-turns are not permitted at the main intersection and are rerouted similar to left turns.

- Distance of the secondary intersections from the main intersection should provide adequate taper and storage for vehicles, signing, and sight distance. Recommend spacing the secondary intersections ±660 feet from the main intersection.
- If permitted, driveways from the connecting road to the parcel inside the connecting road may be placed in the curve of the connecting road or near one of the secondary intersections. If driveways are not permitted, then the parcel inside the connecting roadway can be accessed via driveways off one or both of the intersecting streets.

At a QR intersection, some pedestrians will need to cross an extra street; however, others who follow the curved connection roadway or the main intersection crosswalks will have shorter walking distances. Also, the shorter cycle lengths at QR intersections benefit pedestrians.

A QR with more than one connection road can be implemented if right-of-way is available and if left-turn volumes justify it. Geometric principles remain largely the same for QRs with one or more connection roadways.

Applicability

They are most applicable where the following exists:

- A roadway in the road network can be used as a connection roadway.
- There are heavy left turns and through volumes on the major and minor roads.
- The minor road total volume to total intersection volume ratio is typically less than or equal to 0.35.

* Added 7/17

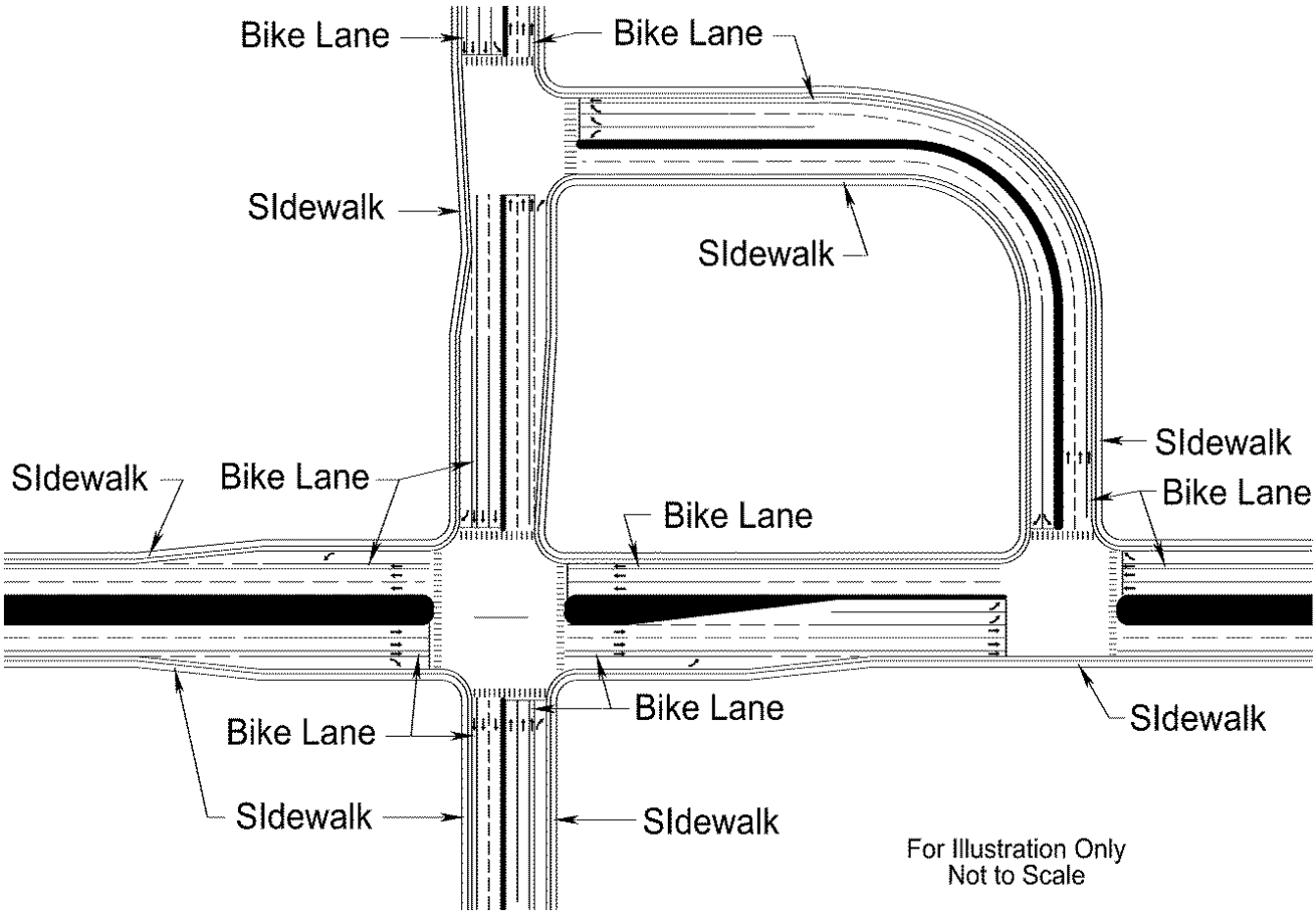

FIGURE A3-5 QUADRANT ROADWAY INTERSECTION*

For more information on the above mentioned Innovative Intersection Designs see:
https://www.fhwa.dot.gov/publications/research/safety/09058/09058.pdf

https://www.fhwa.dot.gov/publications/research/safety/09058/

* Added 10/20

JUG-HANDLE

A jug-handle is a type of ramp or slip road that changes the way traffic turns left at an at-grade intersection. Instead of a standard left turn being made at the intersection from the left lane, left-turning traffic uses a ramp or slip road on the right side of the road.

Jug-handles are common in many states including New Jersey, Connecticut, Delaware, Oregon, and Pennsylvania.

Drivers wishing to turn left exit the major roadway at a ramp or slip road on the right, and turn left onto the minor road at a terminus separated from the main intersection.

For more information on the above mentioned Innovative Intersection Designs see:

https://www.fhwa.dot.gov/publications/research/safety/07032/

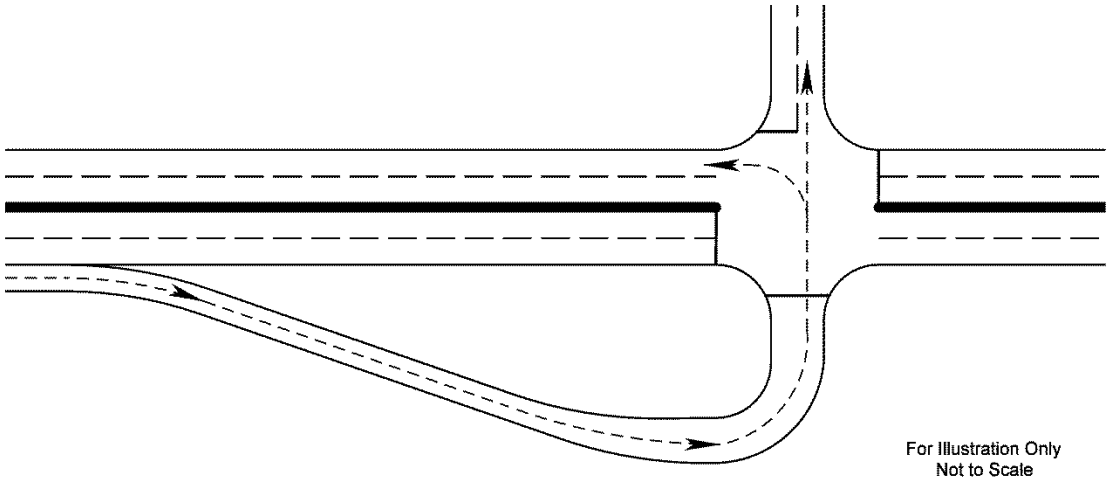

FIGURE A3-6 JUG HANDLE INTERSECTION*

* Added 10/20

SECTION 3 - ROUNDABOUTS

GENERAL

Roundabouts are circular intersections with specific design and traffic control features. These include yield control of all entering traffic (circulating vehicles have the right-of-way), channelized approaches, and geometric curvature to ensure that travel speeds are typically less than 30 mph (single-lane 20-25 mph; two-lane 25-30 mph).

Roundabouts are generally safer than other types of intersections for low and medium traffic conditions. These safety benefits are achieved by eliminating vehicle crossing movements through the conversion of all movements to right turns and by requiring lower speeds as motorists proceed into and through the roundabout. The potential for right angle and left turn head-on crashes is eliminated with single lane roundabouts. Roundabouts treat all vehicle movements equally, each approach is required to yield to circulating traffic. Roundabouts typically handle higher volumes with lower vehicle delays (queue) than traditional intersections at capacity.

While roundabouts usually require more right-of-way at an intersection compared to a traffic signal, they require less right-of-way on the upstream approaches and downstream exits. At new intersection sites that will require turn lanes, a roundabout can be a less expensive intersection alternative. Operating and maintenance costs are less than signalized intersections since there is no signal equipment. The roundabout has aesthetic advantages over other intersection types particularly when the central island is landscaped.

VDOT has adopted the *NCHRP Report 672 Roundabouts: An Informational Guide, 2nd Edition* as our design guide. However, design criteria mentioned in this Manual takes precedence over NCHRP Report 672.*

* Rev. 1/18

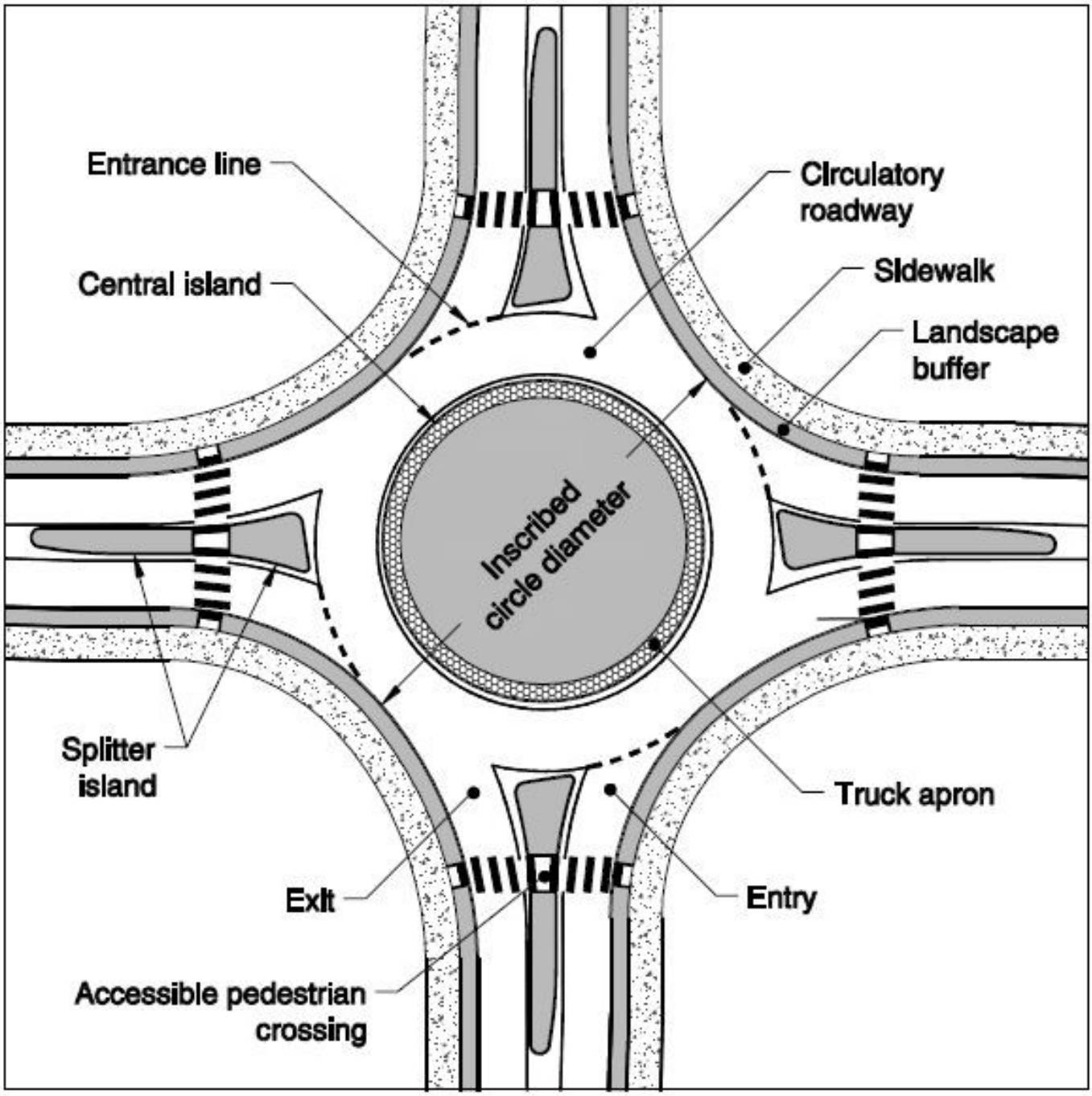

FIGURE A3-7 ROUNDABOUT DESIGN ELEMENTS*

Source: *NCHRP Report 672 Roundabouts; An Informational Guide, Second Edition.*

* Rev 10/20

For Truck Apron Curb use cell Mod. CG-3 found in the cell library.

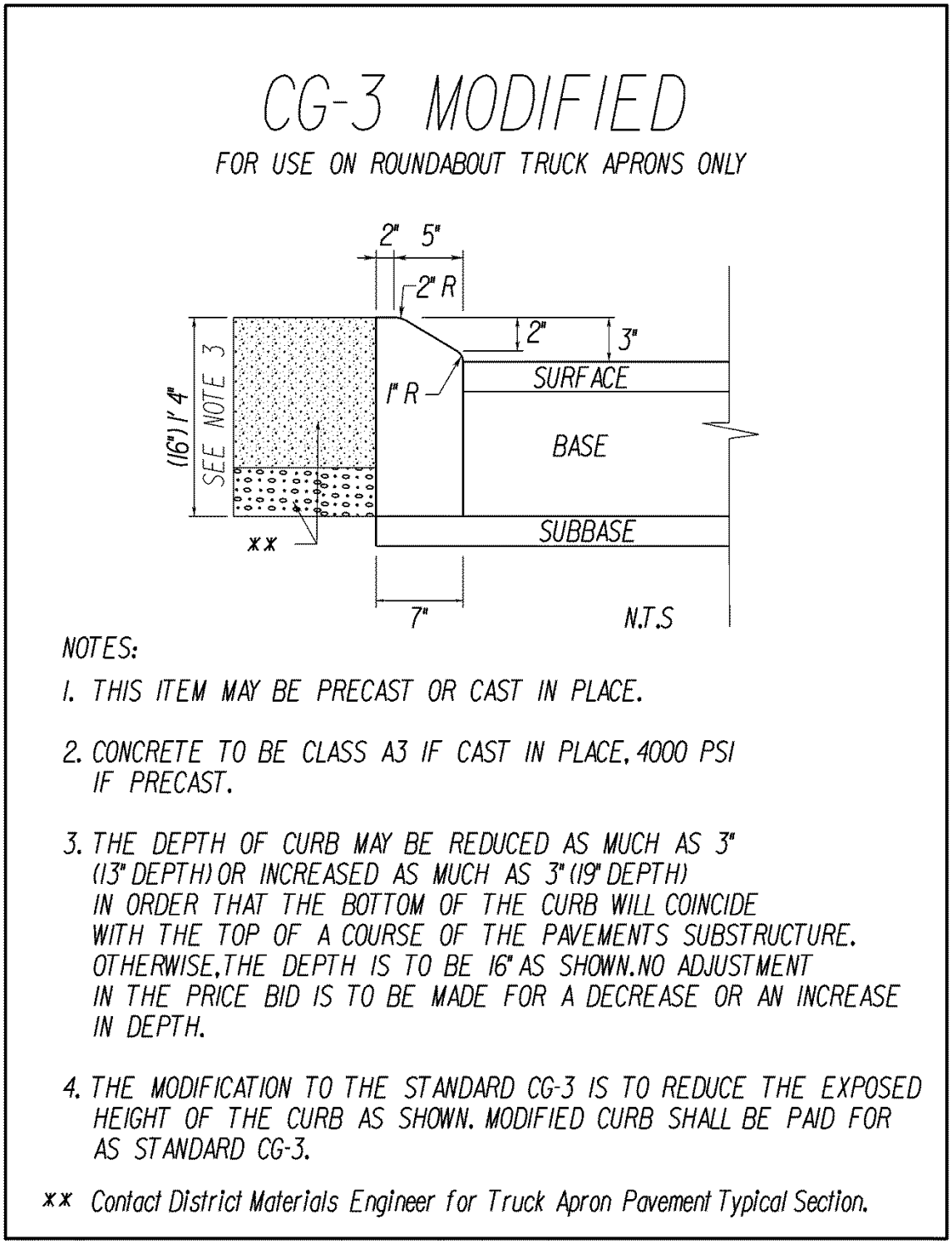

FIGURE A3-8 ROUNDABOUT TRUCK APRON CURB DETAIL*

* Rev 10/20

There are three basic categories of roundabouts based on size and number of lanes: mini-roundabouts, single-lane roundabouts and multi-lane roundabouts.

MINI-ROUNDABOUTS

Mini-Roundabouts are applicable in urban environments with speeds less than or equal to 30 mph. They adapt to existing boundaries by providing a fully traversable central island, a mini-roundabout can be a low-cost solution for improving intersection capacity and safety without the need for acquiring additional right of way. The suitability of a mini-roundabout depends on:

1) Traffic Volumes (comparable ADT from each approach roadway)
2) Truck Volumes < 5%
3) Frequency of School Bus use

Mini-Roundabouts should meet the following geometric design criteria:

1) Central island diameter* of 25 to 50 feet, which is fully mountable
2) Central island and splitter island curb height is less than 2 inches high and is flush (traversable) and painted when frequently used by buses
3) Central island that are raised should be domed using 5% - 6% cross slope, with maximum height of 5 inches
4) Circular roadway width of 12 feet (may be wider for intersections with acute angles)
5) Approach lanes 10 to 11 feet (to reduce speeds)

The majority of traffic (usually estimated at 97%) should be able to pass through the mini-roundabout while staying within the circulatory roadway. The fully traversable central island and splitter islands allow larger vehicles to pass through. Mini-Roundabouts are generally recommended for intersections in which the total average daily traffic (ADT) volume is no more than approximately 15,000 vehicles.

Sources: ITE Journal, November 2012, Article by Lochrane, Zhang and Bared;
Public Roads Magazine, Nov. /Dec. 2012, “They’re Small But Powerful” at:
NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition,
Chapter 6, Section 6.6

FHWA Technical Summary Mini-Roundabouts

* Rev. 1/19

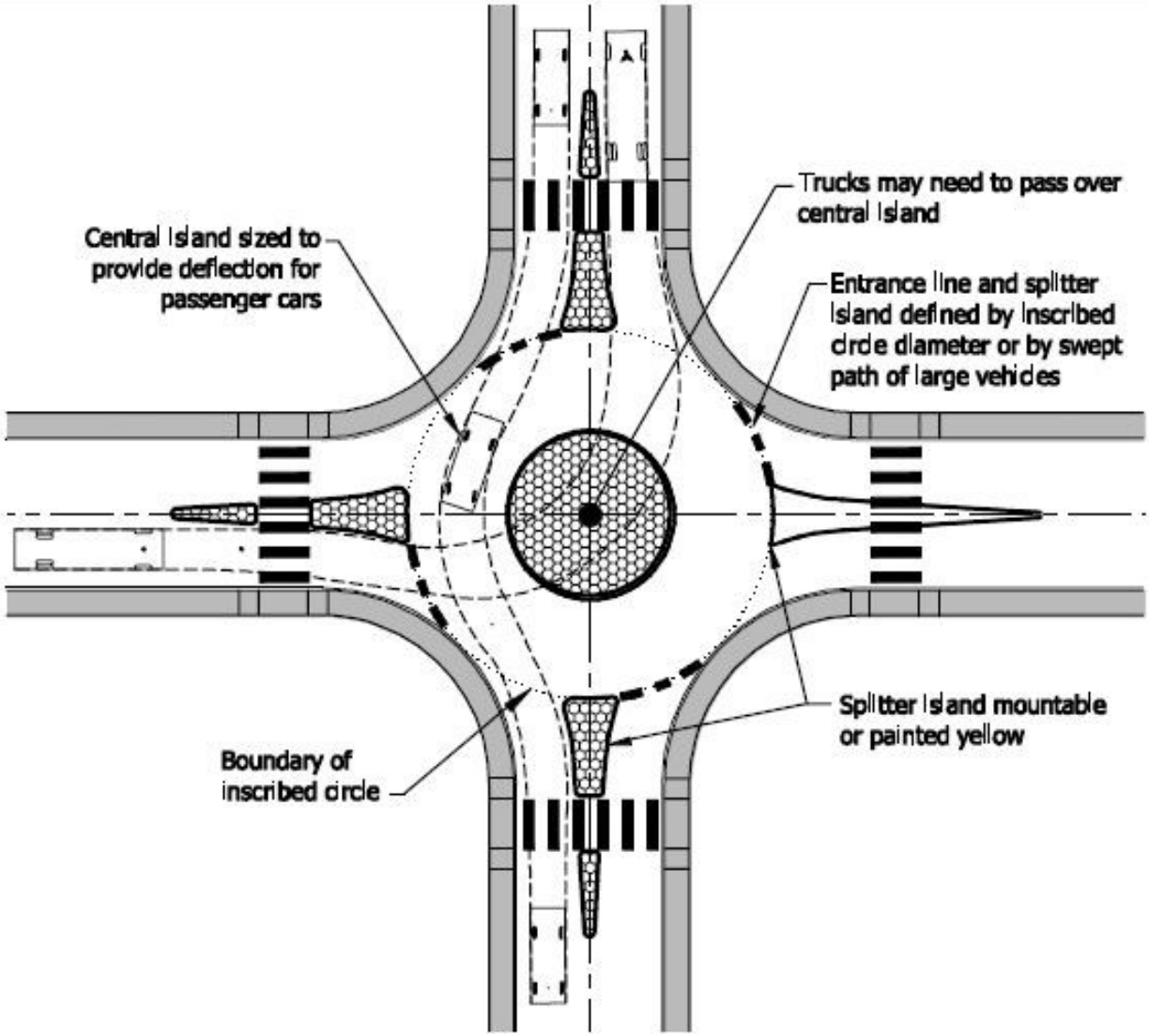

FIGURE A3-9 FEATURES OF TYPICAL MINI-ROUNDABOUT*

Source: *NCHRP Report 672 Roundabouts; An Informational Guide, Second Edition.*

* Added 10/20

SINGLE-LANE ROUNDABOUTS

- Single-Lane Roundabouts have single-lane entry at all legs and one circulating lane. They are distinguished from mini-roundabouts by their larger inscribed circle diameter and non-traversable central island. The geometric design features include: raised splitter islands with appropriate entry path deflection, a raised non-traversable central island, crosswalks, and a truck apron vertically separated by a *VDOT CG-3 Modified* curb from the circulatory roadway.

- The maximum daily service volume of a single-lane roundabout varies between 20,000 and 26,000 vehicles per day (2,000 - 2,600 peak hour volume), depending on the left turn percentages and the distribution of traffic between the major and minor roads.

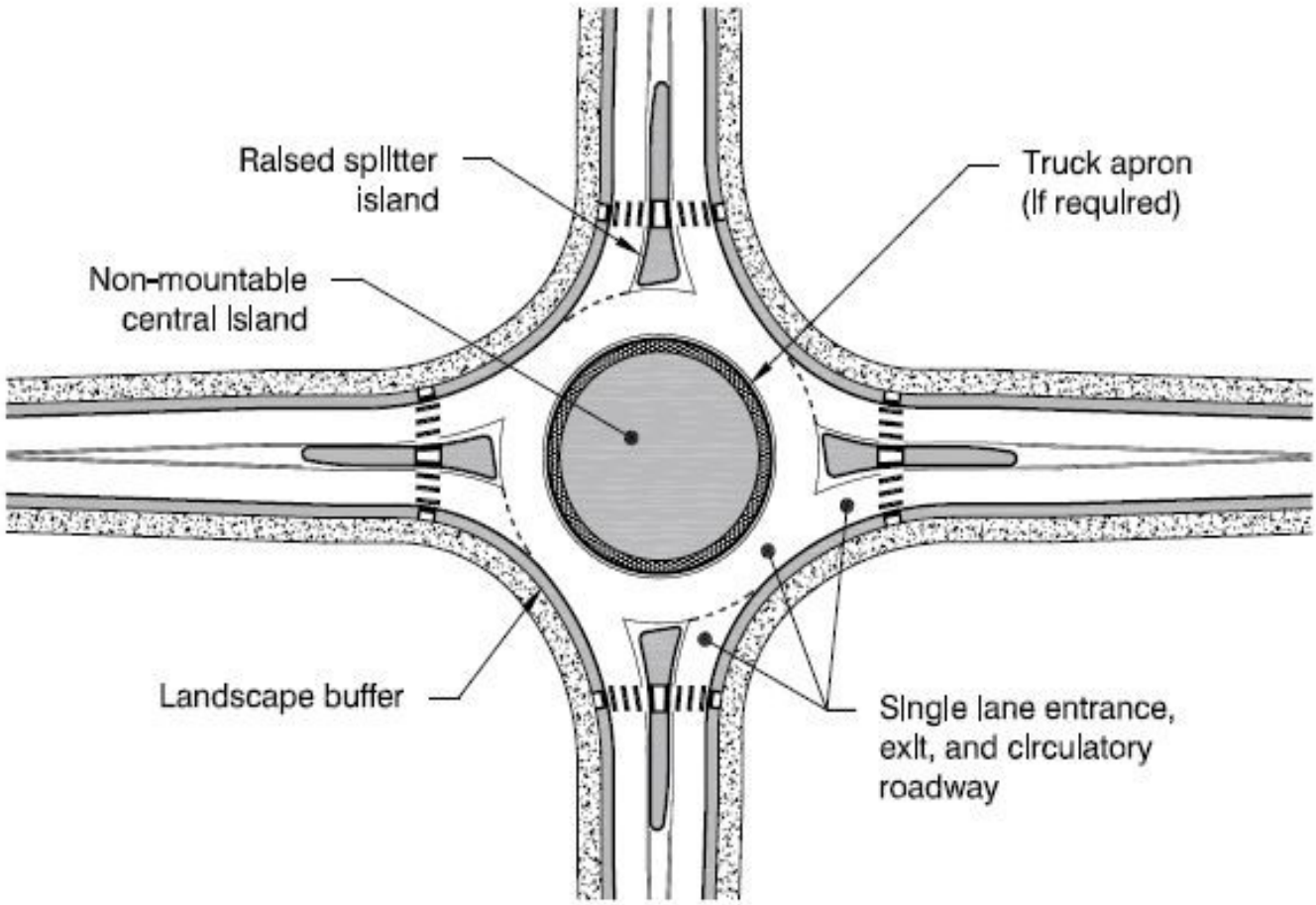

FIGURE A3-10 FEATURES OF A TYPICAL SINGLE-LANE ROUNDABOUT*

Source: *NCHRP Report 672 Roundabouts; An Informational Guide, Second Edition.*

* Added 10/20

MULTI-LANE ROUNDABOUTS

- Multi-Lane Roundabouts have at least one entry with two or more circulating lanes. In some cases, the roundabout may have a different number of lanes on one or more approaches (e.g., two-lane entries on the major street and one-lane entries on the minor street). They may have entries on one or more approaches that flare from one to two or more lanes. They also require wider circulating roadways to accommodate more than one vehicle traveling side by side. The geometric design features include: raised splitter islands with appropriate entry path deflection, a raised non-traversable central island, crosswalks, and a truck apron separated by a *VDOT CG-3 Modified curb* from the circulatory roadway. Driver decisions are more complex for multi-lane roundabouts. These decisions include: proper lane when entering, lateral positioning while circulating and proper lane for exiting.

- If a Multi-Lane Roundabout design is warranted in the long term, it should be designed as a Multi-Lane Roundabout, but striped and signed as a Single-Lane Roundabout when initially opened to traffic.

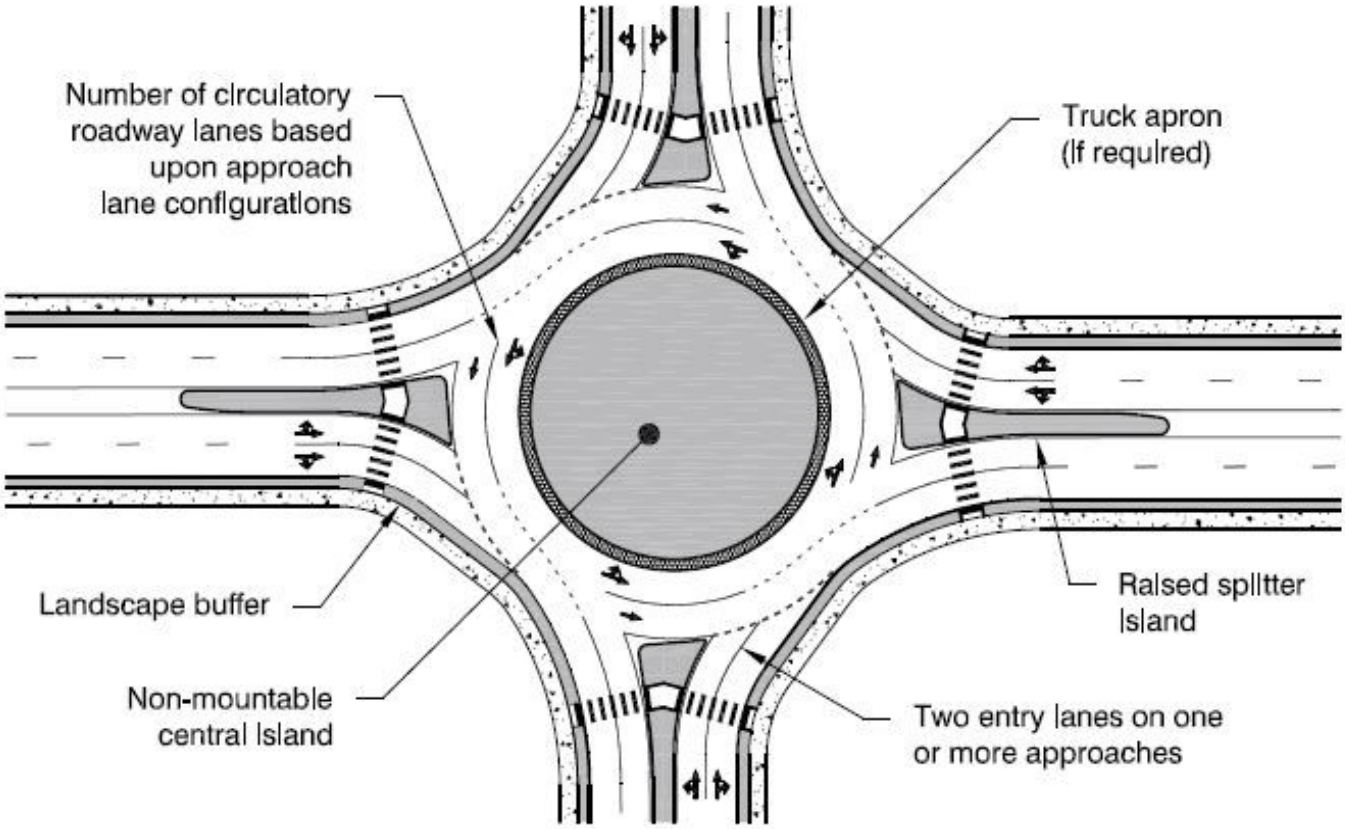

FIGURE A3-11 FEATURES OF A MULTI-LANE ROUNDABOUT*

Source: NCHRP Report 672 Roundabouts; An Informational Guide, Second Edition.

* Added 10/20

GEOMETRIC DESIGN CRITERIA FOR SINGLE-LANE AND MULTI-LANE ROUNDABOUTS

- Central Island, **shall be raised** (non-mountable) and sloped outward away from the center. The island is typically landscaped for aesthetic reasons and to enhance driver recognition for the roundabout upon approach. The truck apron is also considered to be a portion of the central island, but is traversable.

- Truck Aprons shall be designed such that they are traversable to trucks but discourage passenger vehicles from using them. Truck apron width shall be determined by the tracking of the appropriate project design vehicle using AutoTurn. They shall be 4 feet to 15 feet wide and have a cross slope of 1% to 2% outward away from the central island. All roundabout shall be analyzed using AutoTurn to verify that S-BUS-36 school buses, (and for roundabouts on transit routes, CITY-BUS) will be able to traverse the circulatory roadway without the rear wheels tracking over the truck apron.

  If the percentage of trucks anticipated to use the road exceeds 5%, that radius should be sufficient to serve those vehicles. The outer edge of the truck apron shall include a CG-3 Modified Curb (See Figure A3-8* Roundabout Truck Apron Curb Detail), to vertically separate the truck apron from circulatory roadway surface. The truck apron shall also be constructed of a different material to differentiate it from the circulatory roadway. The truck apron shall also be a different color and texture.

- Circulatory Roadway shall be sloped 2% outward away from the central island. The outward cross-slope design means drivers making through and left-turn movements must negotiate the roundabout at negative superelevation. Sloping the circulatory roadway outward away from the central island is required for the following reasons:

  - It promotes safety by raising the elevation of the central island and improves visibility,
  - It promotes lower circulating speeds due to the adverse superelevation,
  - It minimizes breaks in the cross slopes of the entrance and exit lanes, and
  - It allows surface water to drain to the outside of the roundabout.

- Curb and/ or Curb and Gutter shall be provided on the outside of the circulatory roadway and on all approaches a minimum distance equal to the length of the splitter island to help approaching drivers recognize the need to reduce their speed, prevent corner-cutting, and to confine vehicles to the intended design path.

- Inscribed Circle diameter is the distance measured across the circle inscribed by the face of the outer curb or front edge of the gutter pan of the circulatory roadway. See Figure A3-7* Roundabout Design Elements.

* Rev 10/20

- Entry and Exit Design*

  The entry curb radius is an important factor in determining the operation of a roundabout because it affects both capacity and safety. The entry curb radius, in conjunction with the entry width, the circulatory roadway width, and the central island geometry, controls the amount of deflection imposed on a vehicle's entry path and speed. See NCHRP Report 672, Chapter 6, Section 6.4.5.

  - Entry angle, Phi, is not discussed in NCHRP Report 672, but additional information can be found in the *Wisconsin Department of Transportation Facilities Development Manual, Chapter 11, Roundabouts Section 26-30.5.23*. This angle is not a controlling design parameter, but instead a gauge of sight to the left and ease of entry to the right. This affects both capacity and safety at the intersection.

  The exit curb radii are usually larger than the entry radii in order to minimize the likelihood of congestion and crashes at the exits. This, however, is balanced by the need to maintain slow speeds through the pedestrian crossing on exit. The exit design is also influenced by the design environment (urban vs. rural), pedestrian demand, the design vehicle, and physical constraints. See NCHRP Report 672, Chapter 6, Section 6.4.6.

- Profiles – The vertical design shall begin with the development of the approach roadway and the central island. Each profile shall be designed to the point where the approach baseline intersects with the central island. A profile for the central island is then developed that passes through these four points (in the case of a four-legged roundabout). The approach roadway profiles shall be refined as necessary to meet the central island profile. For examples see, Chapter 6 of the *NCHRP Report 672 Roundabouts; An Informational Guide, Second Edition*. In addition to the approach and central island profiles, creating an additional profile around the inscribed circle of the roundabout and / or outer curbs are also beneficial. The combination of the central island, inscribed circle, and curb profiles allows for quick verification of cross slopes and drainage and provides additional information to contractors for staking out the roundabout.

- Example Plan Sheets, Typical Section, Profile Sheets for a Typical Single-Lane Roundabouts can be accessed at:
  http://www.virginiadot.org/info/faq-roundabouts.asp as well as in
  NCHRP Report 672 Roundabouts; An Informational Guide, Second Edition. page 6-82.

* Rev. 1/18

Design Element	Mini-Roundabout	Single-Lane Roundabout	Multi-lane Roundabout
Desirable maximum entry design speed	15 to 20 mph	20 to 25 mph	25 mph to 30 mph
Maximum number of entering lanes per approach	1	1	2+
Typical inscribed circle diameter	45 to 90 ft.	90 to 180 ft.	150 to 220 ft. (two-lanes)
Central island treatment	Fully traversable	Raised (w/ traversable apron)	Raised (w/ traversable apron)
Typical daily service volumes on 4-leg roundabout below which may be expected to operate without requiring a detailed capacity analysis (veh/day)*	Up to approximately 15,000	Up to Approximately 25,000	Up to Approximately 45,000 for two-lane roundabout
*Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.			
Definitions: Capacity: The maximum rate of flow at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a specified time period under prevailing roadway, traffic and control conditions, usually expressed as vehicles per hour or persons per hour. Operational analysis: A use of capacity analysis to determine the prevailing level of service on an existing or projected facility, with known or projected traffic, roadway and control conditions.			

[*]TABLE A3-1 ROUNDABOUT CATEGORY COMPARISON

Source: *NCHRP Report 672*, page 1-12, Exhibit 1-9

[*] Added 10/20

BICYCLE AND PEDESTRIAN ACCOMMODATIONS FOR ROUNDABOUTS

Bicycle and Pedestrian accommodations should be considered when designing roundabouts. For pedestrians, the risk of being involved in a severe collision is lower at roundabouts than at other forms of intersections due to the slower vehicle speeds (20-30 mph). Likewise, the number of conflict points at roundabouts is also lower and thus can lower the frequency of crashes. For pedestrian design consideration, see Chapter 6 of the *NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition*.

For bicyclists, safety and usability of roundabouts depends upon the roundabout design. Since typical on-road bicyclists travel is between 12 and 20 mph, roundabouts that are designed to constrain vehicle speeds to similar values will minimize the relative speeds between bicyclists and motorists, and thereby improve the safety and usability for bicyclists.*

Single-lane roundabouts are much easier for bicyclists than multi-lane roundabouts since they do not require bicyclists to change lanes to make left-turn movements or otherwise select the appropriate lane for their direction of travel.

In addition, at single-lane roundabouts, motorists are less likely to cut off bicyclists when exiting the roundabout. Therefore, it is important not to select a multi-lane roundabout over a Single-lane roundabout in the short term, even when long term traffic volumes and LOS suggest a multi-lane roundabout. However, if a multi-lane roundabout design is selected for the long term, it should be striped and signed as a single-lane roundabout initially.

For roundabout intersection spacing standards and other intersection spacing standards, see *Appendix F, Table 2-2 MINIMUM SPACING STANDARDS FOR COMMERCIAL ENTRANCES, INTERSECTIONS AND MEDIAN CROSSOVERS*.

* Rev. 7/17

ROUNDABOUT DESIGN RESOURCES

For Roundabout Consideration & Alternative Selection Guidance Tool, see Roundabouts in Virginia @ *http://www.virginiadot.org/info/faq-roundabouts.asp.*

Additional information can be found in *NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition.*

Additional information can also be found at VDOT's roundabout web site at *Roundabouts in Virginia*.

THE REVIEW AND APPROVAL PROCESS FOR ROUNDABOUTS

Existing and Proposed Subdivisions - The District Location & Design Engineer shall review and approve roundabouts in subdivisions if VDOT owns and maintains the roadway or if it is the desire of the developer / locality for VDOT to accept the roadway into the State Highway System.

Secondary System – The District shall approve roundabouts up to a traffic design volume of 10,000 VPD. Roundabout designs in which the traffic volume exceeds 10,000 VPD shall be submitted to the Innovative Intersection Committee* at the preliminary field inspection, public hearing/design approval and right of way stages and for review and comments. The committee will make recommendations to the State Location and Design Engineer for approval or disapproval. Appeals of the State Location and Design Engineer's decision will go to the Chief Engineer for resolution.

When a District receives a request for a roundabout from an outside entity, and the design volume is below 10,000 VPD but requests the Innovative Intersection Committees review and comments, the submittal shall be sent to the State Location and Design Engineer. It will be reviewed and comments and/or recommendations will be returned in a timely manner.

Primary or Urban System - The District Location & Design Engineer shall submit roundabout designs to the Innovative Intersection Committee at the preliminary field inspection, public hearing/design approval and right of way stages for review and comments. The approval and appeals will be the same as mentioned above.

The process mentioned above applies to:

- Roundabouts proposed through six year construction program.
- Roundabouts proposed during road safety improvements and/or upgrades.
- Roundabouts proposed by Counties, Localities, Consultants and Developers

The plan submittal shall contain and depict the following criteria:

- Design speed & fastest theoretical path

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- Design vehicle for Circulatory Roadway (S-BUS-36 or City Bus*)
- Appropriate project design vehicle for Truck Apron
- Approach Grades/sight triangles/sight distances
- Inscribed outer diameter of circulatory roadway
- Apron composition, width, slope and curb standard
- Circulatory lane width
- Approach lane width/Deflection/radii
- Departure lane width/Deflection/radii
- Splitter island lengths/raised/flush
- Pedestrian crossing locations/width, composition, raised/flush, markings.
- Bicycle lane/approach & termination point.
- Pavement markings (directional arrows, yield lines, edge lines, etc.)
- Signing
- Roadway Lighting (preferred)
- Location of nearest entrances to outer inscribed diameter and nature of land use
- Present & design year volumes, % trucks & turning movements on all approaches
- AASIDRA analysis on all approaches/peak hrs. LOS/queue lengths in design year
- AUTO-TURN results of Design Vehicle for all turning movements
- Planting scheme/landscaping for mounded central island and splitter islands.
- Proximity of roundabout to nearest traffic signal.

If for some reason, the District does not have capability to run the subject computer programs, the Central Office Roundabout Review Committee can provide assistance upon request.

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SECTION 4 - INNOVATIVE INTERCHANGES

DIVERGING DIAMOND INTERCHANGE (DDI)

An alternative to the conventional diamond interchange or other Innovative Interchange forms.

A DDI is different from a conventional diamond interchange

Directional crossovers on either side of the interchange eliminate the need for left turning vehicles to cross the paths of approaching through vehicles.

Improves the operations of turning movements to and from the freeway facility

Reduces the number and severity of vehicle to vehicle conflict points

Ramp terminal intersections operate with two-phase signals for increased efficiency

A diverging diamond interchange (DDI), sometimes referred to as a double crossover diamond (DCD), is a diamond interchange that facilitates heavy left-turn movements.

While the ramp configuration is similar to a traditional diamond interchange, traffic on the cross route moves to the left side of the roadway for the segment between signalized ramp intersections. By moving traffic to the left, left-turning vehicles can enter from the ramp to the major roadway without the need for a left-turn signal phase at the signalized ramp intersections. In addition, a DDI reduces conflict points of a traditional diamond interchange from 30 to 18 based on fewer crossing points. (See Table A3-2*). This includes merge and diverge points on the major road, not at the ramp terminals.

The upstream area consists of distance for travel during a perception-reaction time, travel for maneuvering and deceleration, and queue storage.

The downstream area includes the length of road downstream from the intersection needed to reduce conflicts between through traffic and vehicles entering and exiting a property (See Figure A3-12* for typical layout.) Refer to Appendix F, Figure 4-3* for Physical and Functional Areas of Intersection and Figure A3-13* to determine Functional Area of Intersection along the minor roadway. The Access Management Manual published by the Transportation Research Board notes that “Stopping sight distance is one method of establishing the downstream functional areas of an intersection.” When calculating downstream functional area with this method, traffic control at the intersection is not a factor.

This reduction in conflict points should represent significant improvement in safety.

Some of the situations where a DDI may be suitable are listed as follows:

- Heavy left turns from ramps onto major roadway
- Moderate or unbalanced through volumes on the crossroad approaches

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- Moderate to very heavy left-turn volumes from the major roadway off-ramps
- Limited bridge deck width
- Expected remaining life of the bridge should be evaluated when considering the DDI design when the project involves converting an existing diamond interchange to a DDI without widening the existing bridges.

TYPE	Diamond	SPUI	DDI
Diverging	10	8	8
Merging	10	8	8
Crossing	10	8	2
Total	**30**	**24**	**18**

TABLE A3-2 CONFLICT POINTS*

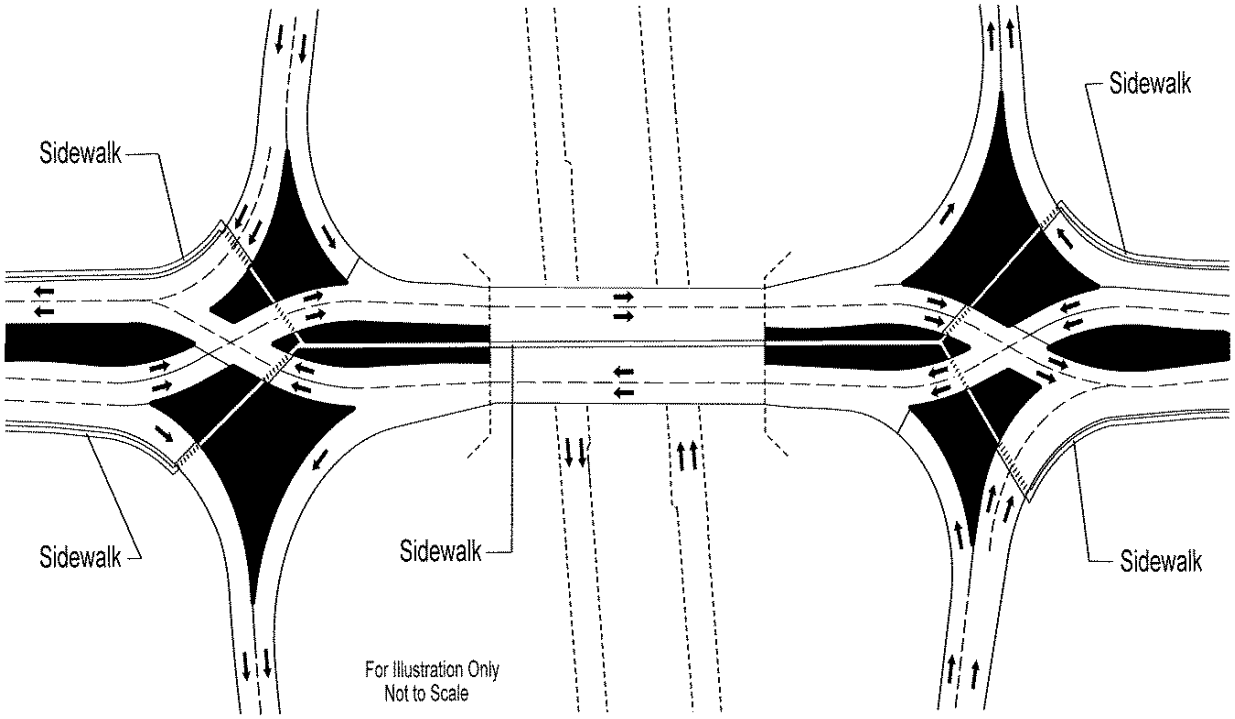

FIGURE A3-12 TYPICAL DIVERGING DIAMOND INTERCHANGE CONFIGURATION*

* Added 10/20

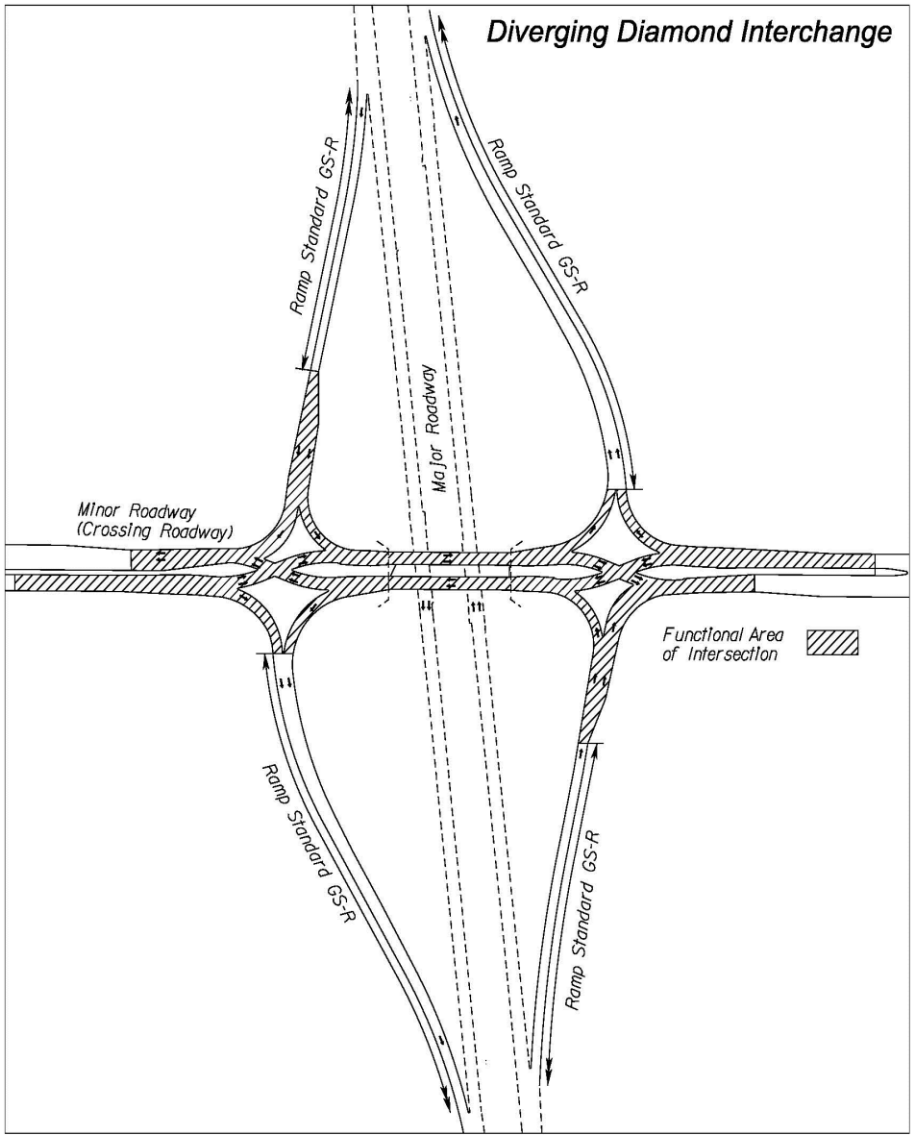

FIGURE A3-13 FUNCTIONAL AREA OF A DDI INTERSECTION*

For more information on the above mentioned Innovative Intersection Designs see: *http://www.virginiadot.org/info/alternative_intersection_informational_design_guides.asp*

https://safety.fhwa.dot.gov/intersection/alter_design/

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ADVANTAGES OF DIVERGING DIAMOND INTERCHANGE *

- The DDI interchange offers benefits over conventional interchange designs with its efficient two-phase signal operation, narrower bridge structure width, lower costs, fewer conflict points, expected increase in throughput, reduced vehicular delay, opportunities for reducing pedestrian / vehicle conflicts and reduced environmental impact.

- A DDI has a higher capacity for all signalized movements when compared to the conventional diamond interchange. The capacity of left-turn movements is approximately twice that of the corresponding capacity of left-turn movements of the conventional diamond interchange. Exclusive left-turn lanes on the cross route are not necessary for the DDI. The ability to accommodate a high number of left turns improves the efficiency and, thereby, the capacity of the interchange.

- To be comparable to a 4-lane DDI, a conventional diamond interchange would require 6 lanes to provide the same capacity. When additional future capacity is needed, it could be advantageous to convert a conventional diamond interchange to a DDI instead of pursuing the more costly option of widening the major and minor roadways in the interchange (including widening the bridge) and adding additional lanes to the ramps. Any conversions and capacity/efficiency benefit however should be analyzed using the appropriate traffic analysis tools.

- The application of a DDI may reduce project costs by allowing the use of existing structures and right of way or, at least, requiring the narrowest or shortest bridge and right of way template possible. This is mainly due to the reduction of required left-turn lanes. Under appropriate traffic conditions, there may be a possibility that designated left-turn lanes can be eliminated in one or both directions on the cross route. The appropriate lane geometry of a DDI should be however analyzed and modeled ahead for traffic operational behavior.

- The DDI's advantage is to make the movement from the cross route to the major roadway more efficient. The left turn from the cross-ramp onto the on-ramp should not be signalized unless necessary to address the potential for pedestrian conflicts.

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DISADVANTAGES OF DIVERGING DIAMOND INTERCHANGE

While the advantages of the DDI make it an attractive solution for a variety of traffic conditions, it is not applicable everywhere. As with any solution, there are disadvantages to consider.

- When current or projected cross route through volumes are high, the drivers inconvenienced the most by the installation of a DDI are those going through on the cross route because they must crossover to the left side of the road and then back again to reach their destination.
- Problematic for high-speed arterials. Reverse curves of crossovers based on 35 mph or slower.
- Through movements must be controlled and cannot be free-flow. If current or projected through traffic volumes on the crossing route are high, other interchange configurations should be considered at the conceptual stage.
- Off-ramp traffic may not directly re-enter an on-ramp. However this design does allow for U-turns from one direction of the major route to the other.
- In areas with HOV lanes located in the median, future HOV connections to the overpass structure may not be feasible with a DDI configuration.
- If there is a high volume of pedestrians, additional signals may be needed and must be timed for adequate pedestrian crossing times, thus, potentially influencing the effectiveness of the interchange.
- Geometry and traffic control device design must be very carefully thought out to minimize any possibility of drivers and/or bicyclists entering the wrong direction between the crossovers. More overhead sign structures with larger guide signs may be needed at a DDI as compared to a traditional diamond interchange
- There are no U-turns at the intersections of a DDI at the ramp.
- Closely spaced intersections to the DDI could heavily influence traffic demand to/from the DDI, potentially limiting the operational effectiveness of the DDI for vehicular traffic
- Generally, a DDI is limited to one of two operational strategies: emphasized coordination to the off-ramp left turn movement or emphasized coordination of the through traffic movement across the interchange. If both movements are heavy, the overlap of queues can be difficult to overcome during peak periods without sufficient capacity.
- Future traffic growth should be figured into the design including the modification for additional capacity.*

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GEOMETRIC DESIGN CRITERIA FOR DIVERGING DIAMOND INTERCHANGE

Crossovers (See Figures A3-14 & A3-15) *

The horizontal crossover geometrics consist of three main interacting elements: 1) crossing angle; 2) tangent length approaching and following the crossover; and 3) superelevation and curve radii approaching and following the crossover. Placement of the two crossovers is largely dependent upon the spacing and location of the ramps. The space needed for vehicular storage between the crossovers must also be considered. When there is room, there is a fair degree of flexibility in the placement of the crossovers. If more length is needed than the distance between ramp termini provides, the crossovers may be located farther apart. As a result, the ramp entrances and exits will need to be configured to merge or diverge with the cross route by either extending or shortening them. For practical design application, the center of each crossover can be slightly skewed from the crossroad centerline and/or offset, as shown in Figure A3-14*.

Crossing Angle

The crossing angle is the acute angle between lanes of opposing traffic within the crossover with optimum crossing angles ranging from 40-50°. The approach angle for cross-over intersections of a DDI should be 30° or greater. A recommended approach is to use the largest crossing angle possible while balancing each of the horizontal geometric crossover aspects. However care should be exercised in choosing a larger crossing angle, which could cause drivers to perceive it as a “normal” intersection.

Larger crossing angles in combination with sharper reverse curves can increase potential for overturning and excessive driver discomfort due to centrifugal forces acting on the driver. Cargo may also shift back and forth depending on speed. Another crossing angle factor that compounds driver discomfort is when the length of roadway between crossovers and/or approaching crossovers is limited. The appropriate geometry of a DDI should be analyzed and modeled ahead for traffic operational behavior

Superelevation Design / Curve Radii

The curves approaching and following the crossover should allow the design vehicle to navigate the interchange at the design speed as well as accommodate the turning movements to and from the ramps. In most instances, an urban low speed design (≤45 mph) should be used on the roadway containing the DDI and adhere to VDOT’s TC-5.11ULS superelevation criteria. The design vehicle, a WB-67 as shown in 2018* AASHTO Green Book Figure 2-24, should be able to operate through the DDI at 20 mph and make all turning movements to and from the ramps. A vehicle classification count should be done to determine the vehicle composition in the area and AutoTurn should be used to make sure the angles proposed are negotiable by the most restrictive vehicle. In addition, the urban low speed design should encompass the footprint (See RDM *Appendix F, Figures 4-2A and 4-3*) of the intersecting ramps.

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The remaining entrance ramp and exit ramp design (Standard GS-R) should continue with VDOT's TC-5.11 rural superelevation between the major roadway and the functional area limits of the minor crossroad (See Figure A3-13*).

Urban design criteria shall be used within the DDI. For entrance ramps to the major roadway, the urban designation ends at the gore area (See Figure Figure A3-13*).

Each curve along the minor roadway should transition to and from the tangents of the crossover. Curve radii used along the crossroad in DDI designs generally range from 150-400 feet depending on chosen design speed.

Tangent Length

The most valuable aspect of adding tangent length before and after a crossover is the propensity to align vehicles to the correct receiving lane as they approach the crossover.

When tangent length beyond the intersection is used, a length of 15-20 feet along the inner edge of pavement is recommended before the crossover. This distance should be provided measuring from behind the stop bar when possible, but may be provided from the crossover itself when space is limited. Since cars do not experience stopping after the crossover, a shorter length of about 10-15 feet along the inner edge of pavement is encouraged. Figure A3-14* shows the recommended minimum lengths.

Lane Width

The crossover lane width is a function of the layout and horizontal geometrics in conjunction with modeling the off tracking of a WB-67. A recommended approach is to begin the design using the minimum lane widths of 15 feet and widen them based on the off-tracking modeling until optimum lane width is achieved. Such might be the case if the crossroad has a wide median. All approach lanes on the crossroad should be tapered following the lane width transition as shown in Figure 3-23 in Appendix F of the RDM. The lanes should be tapered to meet the crossover lane width before entering the curve approaching the crossover and maintained through the curve after the crossover. Between the crossovers, lane widths may need to be tapered if existing conditions constrain the roadway. Existing structures can limit lane width between crossovers. Right-of-way can affect lane width approaching a crossover.

Pedestrian and bicycle accommodation can influence lane widths before, after and between the crossovers. The ramp spacing and distance between the crossovers are additional considerations. The lane width between the crossovers should meet standard lane width where possible but shall not exceed the lane width of the crossover.

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Shoulders

If the cross route has shoulders and there is space, they should be continued through the interchange. For a relatively short segment in a DDI, the left shoulder becomes the outside shoulder and the right shoulder becomes the inside shoulder. For this reason, some alterations to the shoulders may need to be considered.

Under normal circumstances, when a vehicle needs to pull over and stop, the driver expectation is to use the right shoulder. In addition, the left lanes between the crossovers will be heavily used for left- turn movements and potentially experience more weaving. While it is not desirable to have vehicles stop and pull over between the crossovers, the design should account for that possibility when feasible. The right shoulder is considered the safer place, which, in this case, is the inside shoulder. In addition, bicyclists riding on the right shoulder would expect to be able to continue using the same shoulder through the interchange.

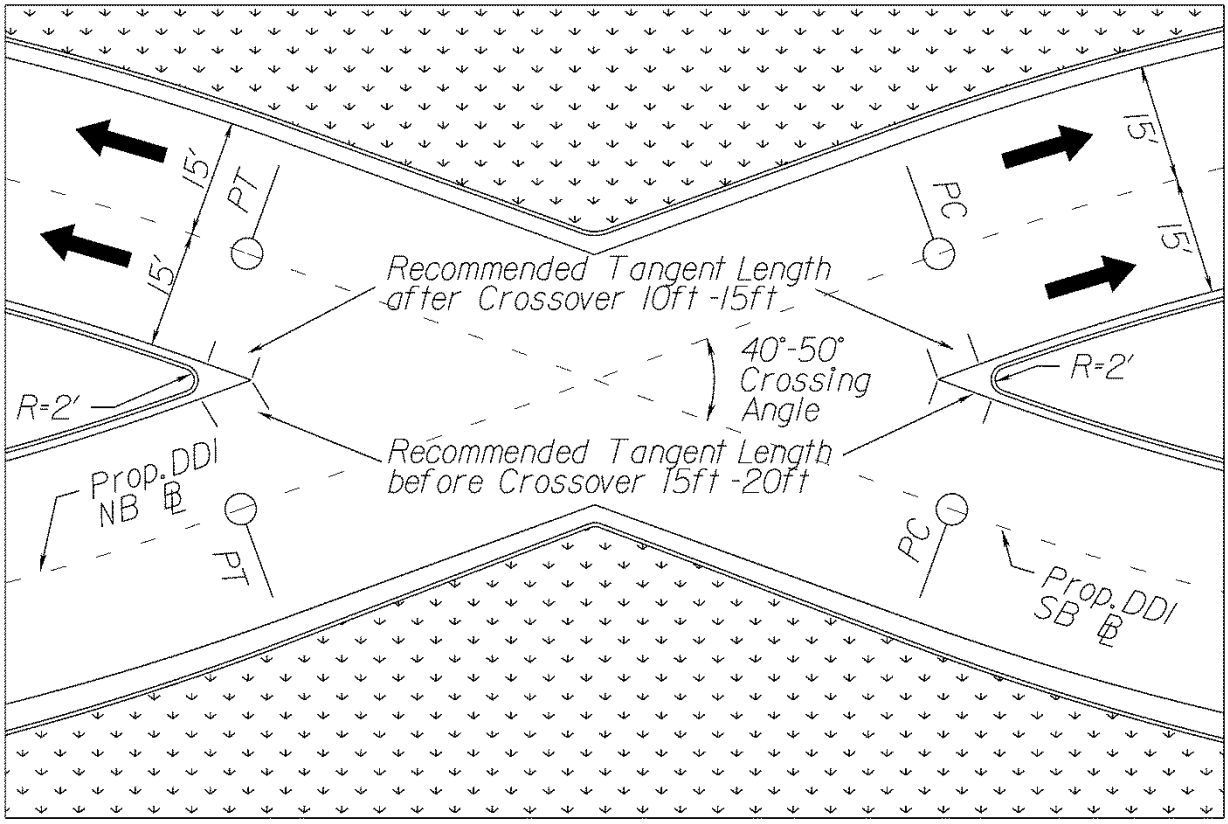

FIGURE A3-14* CROSSOVER GEOMETRICS

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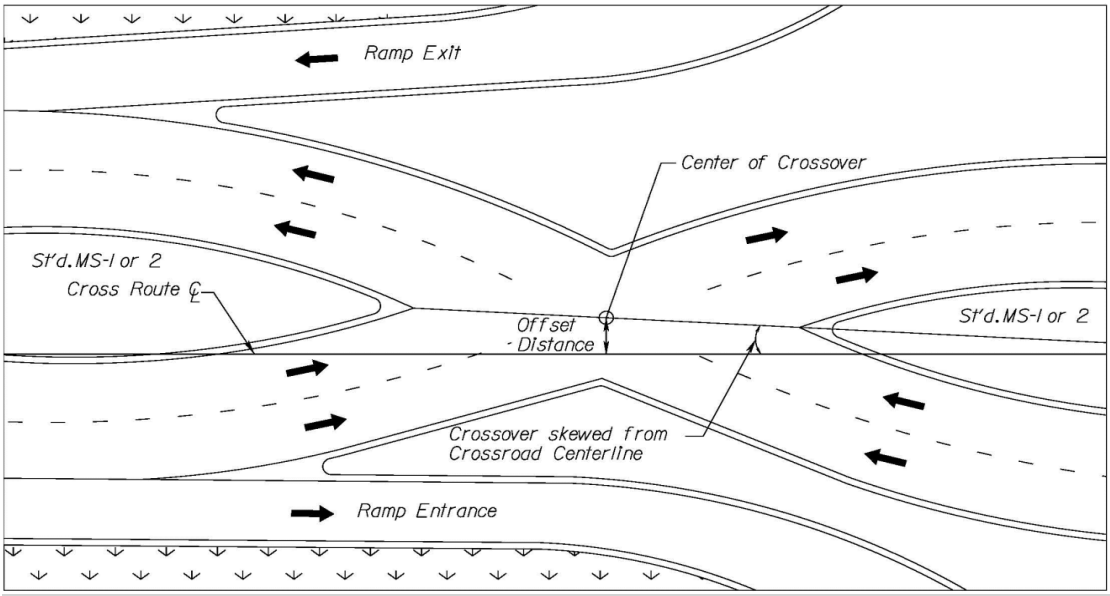

FIGURE A3-15* OFFSET DISTANCE FOR INTERSECTION

Current design practices that had shoulders on the cross route kept the right and the left shoulder widths constant through the interchange, as shown in Figure A3-16. However, it may be advantageous to narrow the left shoulder approaching and between the crossovers to discourage drivers from stopping. Cross routes passing over the major roadway on existing structures may require both shoulders to be narrowed similarly to a traditional diamond interchange.

Shoulder design requires more right of way or more bridge span length when the crossing roadway is under the bridge. Shoulders may not be feasible for a DDI located under a bridge.

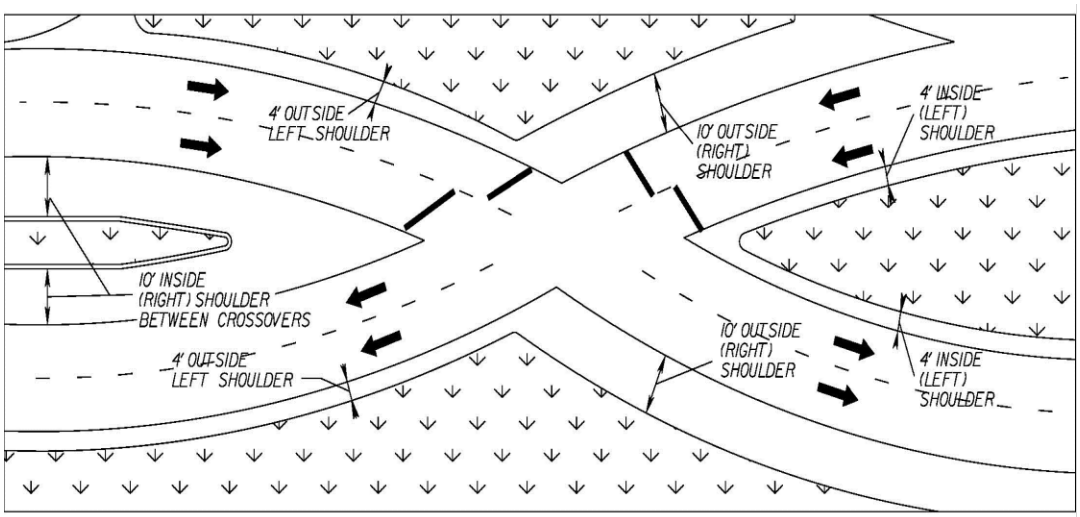

FIGURE A3-16* SHOULDER DESIGN FOR DDI

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Sight Distance

Two areas of specific importance to a DDI are sight distance for vehicles making crossover movements and vehicles exiting from the major roadway. The driver of a vehicle approaching or departing from an intersection should have an unobstructed view of the intersection, including any traffic control devices, and sufficient length along the cross route to permit the driver to anticipate and avoid potential collisions. The same sight distance principles, as described in the AASHTO Green Book, should be followed when designing a DDI.

Particular attention should be paid to the sight lines of vehicles turning from an exit ramp under yield control; this is true for either single- or multiple-turn lanes. For the driver making a right turn from the exit ramp of a DDI, their expectation is that traffic will be moving from the nearest lanes on their left. However, the traffic is actually approaching from the far left lanes since the direction of traffic is switched, as shown in Figure A3-17*.

If there is room, a possible way to minimize this issue is by moving the right turn further from the crossover to increase the amount of sight distance available to these right-turners as well as give them more time to realize where oncoming traffic is coming from. The approach angle should be such that drivers in the turning lane should be able to see the oncoming traffic without difficulty for yield control condition.

For a signal controlled condition, sight triangles between the left turns and right turns to and from the ramps should not be large. This means the island between the left and right turn lanes from the ramp should be designed accordingly. Smaller sight triangles will also shorten all the red times to clear traffic leaving the crossover intersections and also clear the next conflict point.

Another consideration is to channelize the right turn coming off the ramp more so when drivers turn to view the oncoming traffic, it more likely falls in their natural line of sight. The right turn lanes could be extended so that traffic is parallel and vehicles can merge further from the crossover.

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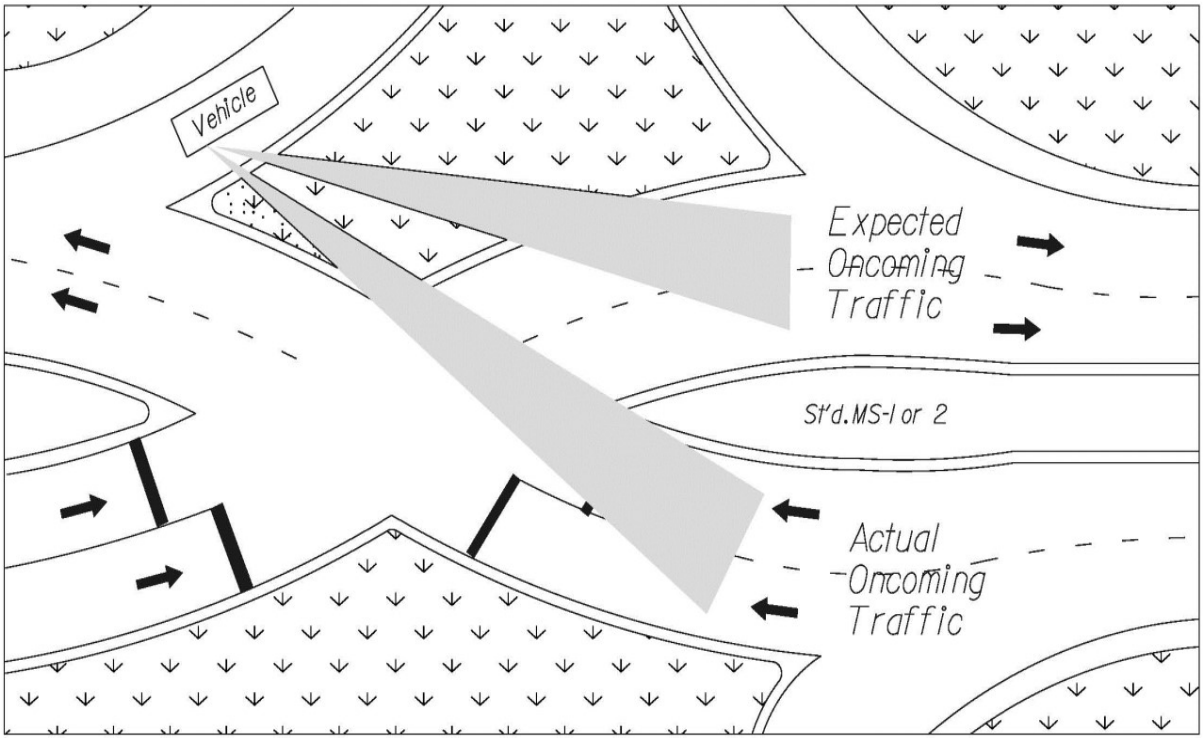

FIGURE A3-17* EXPECTED ONCOMING TRAFFIC VS. ACTUAL ONCOMING TRAFFIC

Clear Zones

Clear zones are to be provided on all ramps and the minor roadway. See RDM Appendix A2, Section 1 for more guidance on clear zone.

Lateral Offset

The minimum lateral offset of 1.5 feet is to be provided on the minor roadway when using curb and gutter design. See RDM Appendix A2, Section 1 for more guidance on lateral offset.

Ramps

Traffic capacities for ramp design are subject to variation and are limited by the geometric features of the ramp itself, the ramp termini, the weaving sections, the volume of through and turning traffic and intersection spacing within the functional area of the interchange. Because the ramp through-movement is physically prohibited, accommodations for this movement downstream of the interchange on the cross route should be considered. These accommodations should be considered when applying access management principles and evaluating capacity.

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Traffic operational analysis of the existing conditions at the interchange, as well as for the proposed DDI shall be performed to determine the appropriate DDI geometry and quantify the operational benefit in terms of delay (sec), queue lengths (feet), etc. The analyses shall be conducted for the existing traffic volumes for existing geometric conditions and DDI, and projected future traffic for existing geometric conditions and DDI, the projected year of analysis shall be discussed and determined with the VDOT project manager, it shall include any major change in traffic volume patterns anticipated due to land use, etc., this is necessary as the efficiency of a DDI is dependent on the traffic volume patterns.*

The analyses shall be based on the guidelines in VDOT's latest version of the Traffic Operations Analysis Tools Guidebook and in consultation with the VDOT project manager/ traffic engineer within a mutually agreed upon impact area. The traffic impact area shall contain at a minimum, the interchange being considered including the full length of all ramps proposed and the merging area of the on-ramp with the interchange/ main roadway; and any median accesses within ½ mile on either direction of the cross road. The traffic analysis shall at a minimum include all the proposed signal coordination plans within impact area, the controller configurations (single/multiple) and also include left turn on red analysis. In addition, engineering judgment should be used to determine the various aspects of the geometry and signal configuration proposed; all suggested geometry and signal configurations shall be evaluated as described above.

Ramp design for a DDI should take into consideration the need of separate lanes for left-and right-turning traffic especially when either movement is signalized. While traditional ramp designs allow for shared lane usage, exit ramp design for a DDI should provide separate left- and right-turn lanes prior to the ramp terminal. This is because the phasing for the signalized left turn and right turn typically does not occur simultaneously. The storage lengths of these lanes are dependent upon projected volumes and potential queuing.

Access Control / Spacing of Intersections

Nearby signalized intersections may reduce the effectiveness of a DDI. The two-phased signal phasing of the DDI typically allows for shorter cycles lengths which may impact the coordinated operations of nearby traffic signals. When evaluating a DDI, the traffic analysis should consider whether the entire interchange should be operated with a single signal controller or if multiple controllers should be used for the two separate intersections.

As with any interchange type, the minimum intersection spacing shown in the *RDM Appendix F, Table 2-3 and Figure 2-9* shall be used. VDOT's access control standards shall be followed. However in developed areas, it may be difficult to achieve the standards. If these standards are not met, an Access Management Exception (AM-E) or an Access Management Waiver (AM-W) shall be required.

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Special consideration must be given in evaluating a DDI when the nearest full access intersection is less than the minimum distance shown in *Appendix F*. The DDI typically operates essentially as a two-phase signal with only one direction of travel on the cross route allowed through the interchange at a time. When there is a signalized intersection in close proximity to the DDI, it is may not be possible to coordinate both directions of travel along the cross route with the adjacent signal resulting in one direction of travel queuing in the small space between the intersections. When considering a DDI with a signalized intersection close to the interchange functional area, other interchange types should also be considered.*

Traffic projections require additional attention when evaluating the use of a DDI in a closely spaced signal system. When this is the case, a sensitivity analysis should be performed. A sensitivity analysis evaluates how changes in the traffic projections affect the results of the operational analysis (LOS or capacity). The sensitivity analysis will show if the proposed improvements only work under a limited number of traffic conditions or if the proposed improvements are flexible enough to satisfy a variety of future traffic conditions.

At this time, it does not appear that closely spaced right-in, right-out access or left-in accesses pose a greater challenge for DDIs compared to other interchange types. When evaluating non-signalized access points, additional care should be given so the access does not interfere with the operations of the right turns either onto or off the ramps. Spacing between the two crossover intersections should be sufficient enough to accommodate the through queue for the design year. As a rule of thumb, spacing between the crossovers should be a minimum of 800 feet. Maximum queues based on microsimulation modeling should be used to verify the spacing between two crossover intersections.

Pedestrians

There are two basic ways to accommodate pedestrians at a DDI. They can be placed in the middle of the cross route between the crossovers (Figure A3-18) or kept on the outside perimeter Figure A3-19). This decision can influence the number of signals and the capacity of the interchange. If pedestrians are kept to the outside perimeter as shown in Figure A3-9, then they do not have the ability to cross from one side of the street to the other.

Pedestrian crossings for a DDI may involve crosswalks and signal pedestrian control features at the junctions of the interchange. Depending on the pedestrian network in the vicinity of the interchange, it may not be necessary to have pedestrian walkways on both sides. Since the crossover junctions in a DDI operate on a two-phase signal control, pedestrians are directed to cross the minor roadway in two stages. Adequate pedestrian refuge should be provided between all stages of the crossing. Depending on the configuration, pedestrians may have higher or lower numbers of controlled and uncontrolled crossing locations at a DDI as compared to a traditional diamond interchange.

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Any pedestrian crossings of free-flow movements should be carefully reviewed to ensure adequate sight distance for drivers approaching the crosswalk. In the case of a DDI where the cross route passes underneath the major road, the structure may also impact sight distance.*

The DDI design involves multiple-stage crossings with islands acting as refuges. In addition, the design of crossovers at the nodes of the interchange typically results in flares and large central islands. Barriers help prevent pedestrians from attempting to cross at undesirable locations. Barriers should be rigid with appropriate end treatment. Alternatively, guardrail systems that pose a lesser hazard to motorists (i.e., spearing hazard) can be used to channelize pedestrians. Barrier separation from traffic should be used when pedestrians are placed down the center of the cross route. If bicycles will be present, a barrier height of 54 inches is required. Minimum standard sight distance shall be provided when barrier is present.

All sidewalks and crosswalks shall be in compliance with VDOT standards. (See *IIM-LD-55* and *RDM Appendix A(1) Section 1*.

Pedestrian facilities located along the outside of the interchange may also cause pedestrians to make more conflicting movements, walk a longer distance, and cross at an unsignalized left-turn. Most pedestrians are not accustomed to crossing at the unsignalized left-turn of a DDI.

When pedestrian facilities are present, the left or right turn to and from the ramps may require signalization and negatively influence the interchange's operation. The negative impact may be minimized depending upon geometrics and other design choices. Some at-grade pedestrian crossings can be located where oncoming traffic approaches from an unfamiliar direction. Since pedestrians are typically conditioned to look "left–right-left" before crossing the street, there is potential for pedestrian confusion at these locations.

When the crossroad passes under the limited access highway, structural obstacles may restrict sight distance at free left turns approaching pedestrian crossings.

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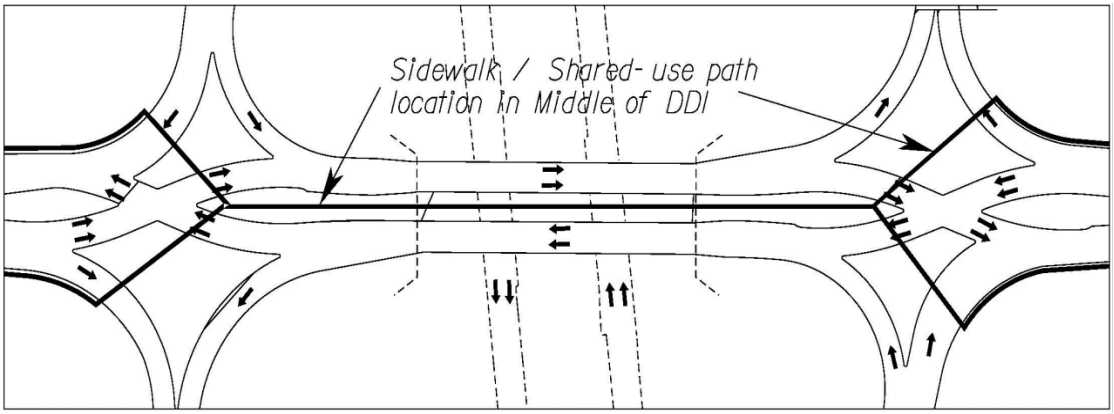

FIGURE *A3-18 PEDESTRIAN ACCESS IN MIDDLE OF CROSSROAD BETWEEN CROSSOVER

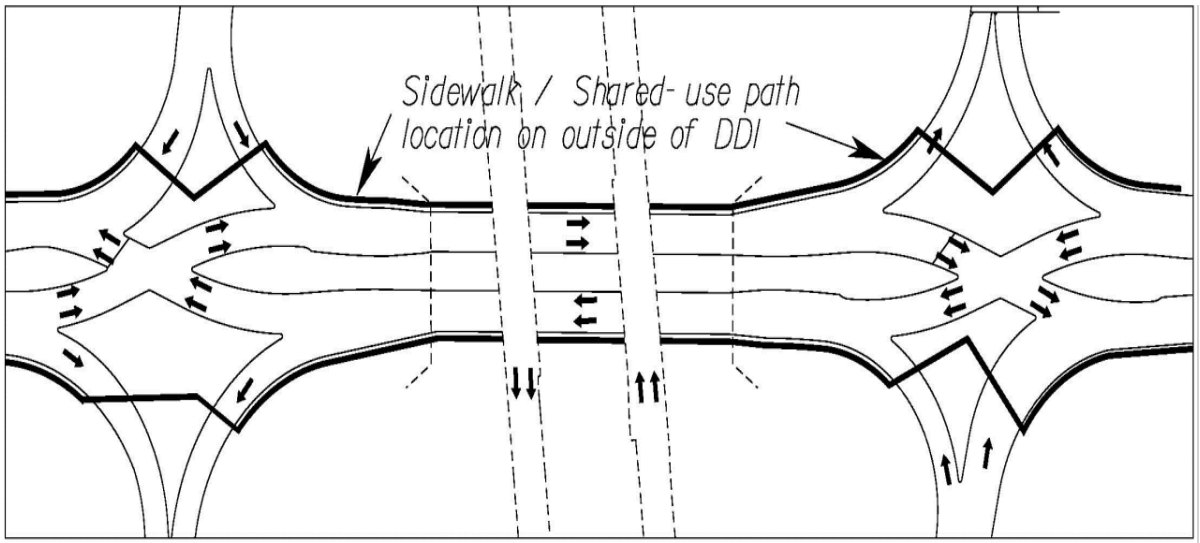

FIGURE A3-19 PEDESTRIAN ACCESS OUTSIDE OF DDI

Bicycles

Bicycle accommodations should be considered on all DDI designs and, whenever possible, existing bike accommodations should continue through the interchange. Bicycles operating along the minor roadway through a DDI can be accommodated with the use of bicycle lanes or shared-use paths. If bike lanes or shoulders cannot be carried through the interchange due to space constraints, they should be terminated far enough in advance to encourage cyclists to mix with vehicle traffic. Bicycles are encouraged to stay in the right side of the right lane through a DDI. If a high volume of bicyclists is expected and a sidewalk is proposed, it should be widened and constructed using Shared Use Path design criteria as shown in *RDM Appendix A(1) Section 1* and as given in AASHTO's *"Guide for the Development of Bicycle Facilities*." If bicycle lanes are carried through the interchange, bicyclists should be directed to stay to the right of traffic (on the inside) between the crossovers. Careful consideration needs to be given to the potential for bicycle-vehicle conflict and also to provide proper

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guidance for bicyclists so they do not attempt to ride on the wrong side between the crossovers.

Standards and Criteria

- Urban Low Speed criteria shall be followed along minor roadway of the DDI. A Design Exception is not required for Design Speed within the functional area of a DDI that does not meet the corridor design speed. (See Figure A3-13)
- Left-turn and through movements are relocated to the opposite side of the road on the bridge structure.
- The minimum spacing between crossovers should be 800 ft.
- The crossing angle of intersection should be between 30° and 50° (See Figure A3-14).
- The minimum design speed for the minor roadway shall be 25 mph.
- The minimum design speed where the ramps meet the crossroad shall be 25 mph (every attempt is to be made to use a design speed greater than minimum).*
- Turning radii used at the crossover junction are typically in the 150 to 400 ft range and shall be determined by design vehicle.
- Curb and gutter design is preferred along the crossing roadway.
- The appropriate GS standard shall be used based on the functional classification of the crossing roadway.
- Standard MS-1 is preferred along the cross road due to less maintenance requirements.
- Lane width through the crossover shall be a minimum of 15 ft.
- Design shall accommodate WB-67 trucks so that one truck in each lane of the design can make the required movements without encroaching into the adjacent lane (if there is one). Autoturn® should be run to determine the off-tracking of the design vehicles and lane width should be adjusted upward to accommodate. Please see 2018 AASHTO Green Book Tables 3-26b and 3-27.
- For channelization and safety reasons, a physical barrier should be provided between the crossovers to separate opposing directions of traffic. Either a barrier or a raised median shall be designed to physically separate opposing traffic between the crossovers.
- Adequate lighting should be provided. VDOT requires all roadway lighting designs to meet the lighting criteria as discussed in the current IESNA publication, Recommended Practices for Roadway Lighting (RP-8). See VDOT's *Traffic Engineering Design Manual*, Chapter 2 for more information.

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- DDI interchange designs may only be appropriate where there are high-turning volumes.
- Median width is increased to allow for the flaring required for reverse curves on the interchange approaches.
- The noses of the median island should extend beyond the off-ramp terminals to improve channelization and prevent erroneous maneuvers.
- Median openings may be placed upstream of the interchange to allow U-turn movements on the minor roadway. There will be no U-turns allowed within the DDI functional area.
- Left- and right-turn lanes should not be shared and should be designed assuming that they will run under separate signal phases.

Traffic Signal Considerations*

A DDI interchange typically has two signalized junctions or nodes at the points of left-turn crossovers. The signals operate with just two phases, with each phase dedicated to the alternative opposing movements.

While every movement within a DDI can be signalized, they are not necessarily required to be. Turning movements should be signalized after considering factors such as the volume of conflicting pedestrians, the nature of the lane merge (yield or free-flow), the volume of the turning movements as well as the through traffic on being processed through the crossovers, and the number of turning lanes. Signalization of all movements should be considered on a case-by-case basis.

Signal warrant analysis and the need for pedestrian control features for the DDI shall follow the guidelines provided in the *MUTCD*, the Virginia Supplement to the *MUTCD*, and engineering judgment.

When signalizing the off-ramp left-turn, the distance between the crossover intersection and the off-ramp left-turn should be minimized. The longer the distance for the through movement to clear the intersection the longer the duration of the all-red clearance interval. Increase in the clearance interval may reduce the effective green time for the signal and the efficiency of the signal. The need for the long red clearance interval may not be readily apparent to many drivers and public expectations may need to be addressed.

Since left turning movements do not conflict with the opposing through movement in the DDI, left turn on red can be considered from the ramp . Due the unique curvature and geometry of a DDI, special attention should be given to signal face placement. The primary consideration in the placement of signal faces is to optimize the visibility of signal indications to approaching traffic. Road users approaching the intersections are to be given a clear and unmistakable indication of their right-of-way assignment. All signal face placement, aiming, adjustment and positioning shall be in accordance with the *MUTCD* and/or *Virginia Supplement to the MUTCD*.

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Special attention should also be given to signal structure/mast arm and luminaire placement to ensure structures do not block the view of other traffic control devices. Straight-through green arrow signals, may be appropriate to discourage wrong-way turns, however the *MUTCD* expressly prohibits use of upward yellow arrow and upward red arrow signal indications.

Supplemental near-side traffic signal indications may be appropriate to provide optimal visibility for the movement to be controlled. It may also be appropriate to consider signal visors, signal louvers, or other means to minimize an approaching road user's view of signal indications controlling movements on other approaches.

Refer to Chapter 4D of the *MUTCD* and/or *Virginia Supplement to the MUTCD*.

Consideration should be made for yield control vs. signal control for the DDI off-ramp left turns. One advantage to signalizing the DDI off-ramp left turn movement is it removes the weaving between those drivers and drivers on the cross street intending to turn left onto the downstream on-ramp.

Signing and Pavement Markings*

Signing and pavement marking for the DDI shall follow the *MUTCD* and the *Virginia Supplement to the MUTCD*. Since the DDI is a newer design, placement of markings, wrong-way signs, approach signing, overhead approach signage and wrong-way arrows/directional arrows to emphasize the correct direction of travel is critical. In addition, advance guide signs for drivers to stay in appropriate lane are equally important. Consideration should also be given to minimizing the amount of "sign clutter" that could cause driver delay or confusion.

Stop bars, yield bars and arrow lane markings are all standard applications. Dotted lane-line extensions are typically used to help guide motorists through the crossovers.

The potential for wrong way traffic movements in a DDI can be minimized with geometrics, signing, pavement marking, signals and lighting.

Although a DDI's geometrics requires traffic on the cross route to move the left side of the roadway for the segment between signalized ramp intersections, the pavement marking used is similar to other interchanges. The yellow stripe shall be used on left of traffic and white on the right between crossovers.

Lane and edgelines that are 6" wide should be used through the DDI to improve driver recognition. Wider markings may be transitioned to normal markings downstream of the DDI at logical termini.

Snow-plowable reflective pavement markers (with red reflectors for the wrong-way movement) should be considered for use within the DDI for lane lines, wrong-way arrows and where appropriate on edge lines. Structure & Bridge Division approval may be required prior to installing raised pavement markers on bridge decks.

Guide signing is essential to proper operation of the DDI. Given the complex nature of the interchange, consideration should be given to mounting the guide signs for the cross street

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on overhead (butterfly, cantilever, or full-span) structures to safely guide drivers through the interchange and minimize the potential for confusion that results in drivers entering the wrong side of the DDI. If cantilever and/or full-span sign structures are used, they shall not exceed the maximum span lengths specified in the current version of *IIM-S&B-89*.

Raised reflective markers should not be used on or adjacent to edgelines in areas where bicycles might be expected to exit or enter the shoulder across the edgeline.

Additional regulatory and warning signage may be necessary to guide users through the DDI. Examples of signs that should be considered are R4-8 series "Keep Left" signs and W24-1L series reverse curve warning signs. However excessive signing should be avoided to avoid distracting drivers with a "forest of signs" effect.*

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[*]DIVERGING DIAMOND RESOURCES:

1. FHWA DDI Informational Guide
   http://www.virginiadot.org/FHWA-SA-14-067_DDI_Informational_Guide.pdf
   FHWA DDI Brochure
   http://www.virginiadot.org/FHWA-SA-14-039_DDI_Informational_Brochure.pdf

2. "Engineering Policy Guide, Chapter 234.6: Diverging Diamond Interchanges", Missouri Department of Transportation 2014. Online: *http://epg.modot.org/index.php?title=Main_Page*

3. "*Tech Brief: Double Crossover Diamond Interchange.*" Federal Highway Administration. 2009.

4. "*Tech Brief: Drivers' Evaluation of the Diverging Diamond Interchange*." Federal Highway Administration 2008.

5. "Innovative Diamond Interchange Designs: How to Increase Capacity and Minimize Cost." David Stanek. Institute of Transportation Engineers. 2007. Online: *http://tinyurl.com/y9yum2o*

6. "Traffic and Operational Comparison of Single-Point and Diverging Diamond Interchanges." Praveen K. Edara. Transportation Research Board. 2009.

7. "Alternative Intersections/Interchanges: Informational Report", Federal Highway Administration, 2010. Online: *http://www.fhwa.dot.gov/publications/research/safety/09060/*

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SINGLE POINT URBAN INTERCHANGE (SPUI)

The SPUI, another variant of the compressed diamond interchange, was developed in 1970 to improve traffic capacity and operations while requiring less right-of-way than the diamond interchange. The turning movements of the major road ramps and all the movements of the minor road are executed in one central area that is either on the overpass or underpass.

Some of the key design characteristics that need to be considered when designing a SPUI are skew angle; number of through, left-, and right-turn lanes; median width; and islands. Generally, the bridge of a SPUI has a span length from 160 to 280 ft. depending on various geometrics of the crossing. The bridge structure of a SPUI has a large deck and is more expensive to construct in comparison to a TUDI, which is relatively easy to design and construct.

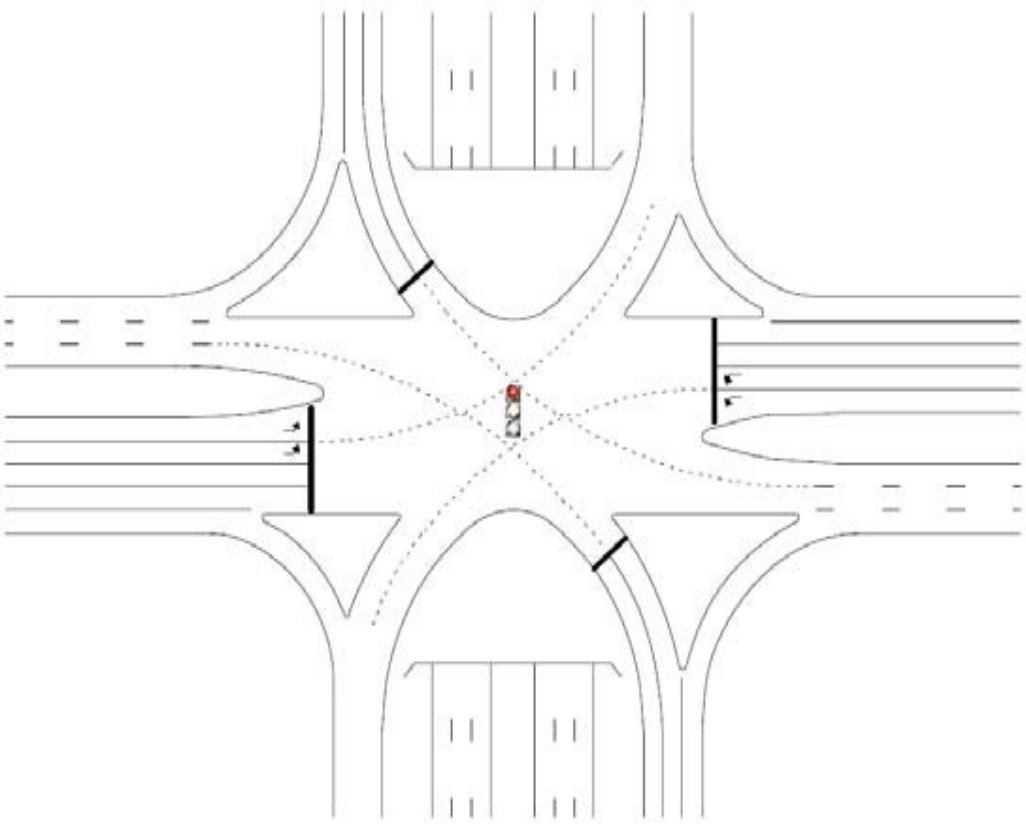

FIGURE A3-20 TYPICAL SINGLE POINT URBAN INTERCHANGE CONFIGURATION*

* Added 10/20

DOUBLE ROUNDABOUT INTERCHANGE

The Double Roundabout Interchange, alternatively referred to as a roundabout interchange, uses the concept of roundabouts at the grade-separated interchange. In effect, the minor street through movements navigate through roundabouts. There can be two types of raindrop interchanges—double and single. The double roundabout version uses two roundabouts at the ramp terminals. The single roundabout type has a single large roundabout designed over the arterial and serves as the overpass for the turning movements

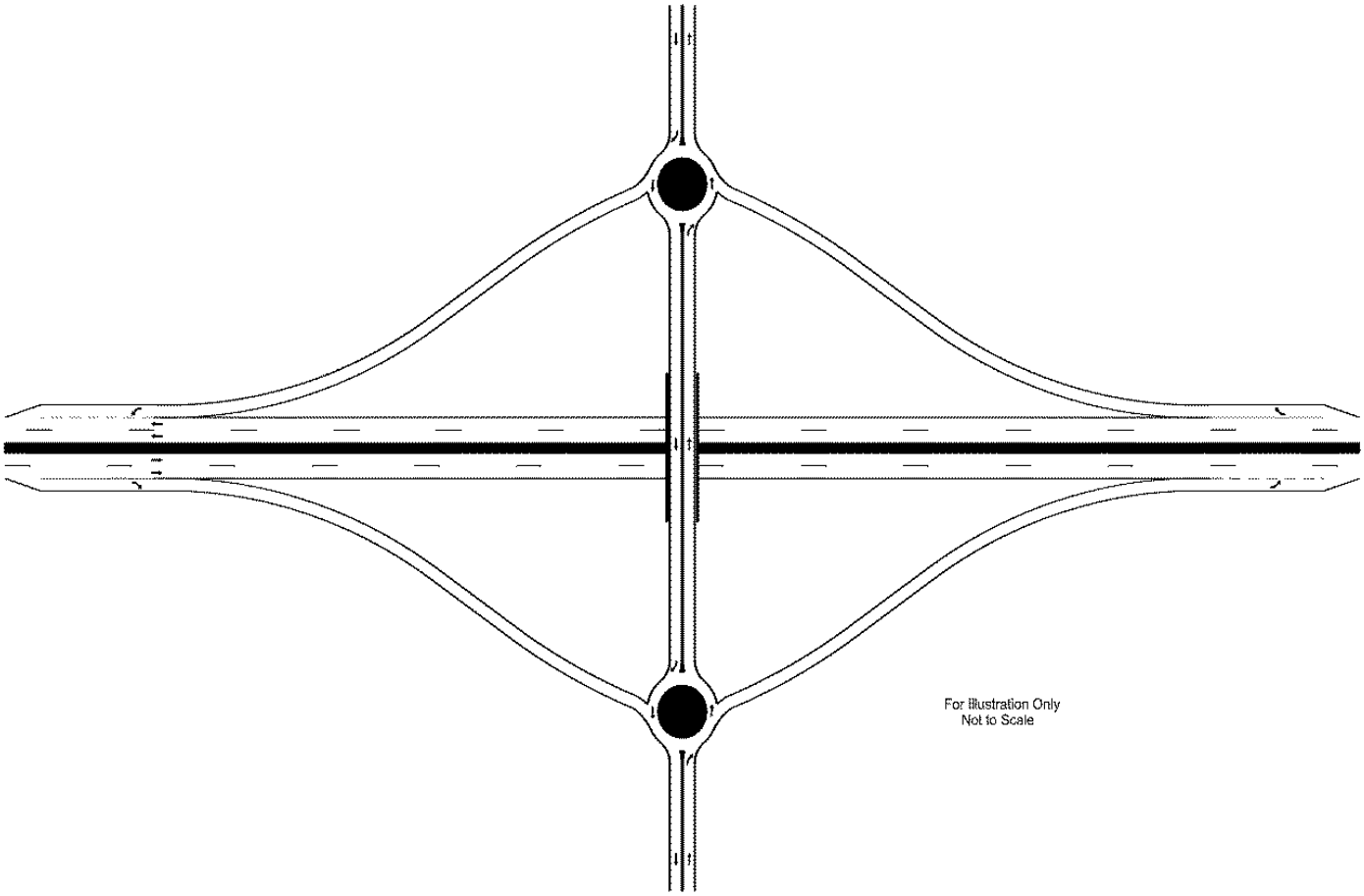

FIGURE A3-21 TYPICAL DOUBLE ROUNDABOUT INTERCHANGE CONFIGURATION*

For more information on the above mentioned Innovative Interchange Designs see: *https://safety.fhwa.dot.gov/intersection/alter_design/*

* Added 10/20