MoDOT Safe Systems Intersections

Trey Bebee, I.E. - GBA

Outline

- Project Background
- Research
- Development of Guidelines
- Recommendations and Lessons Learned
- Questions

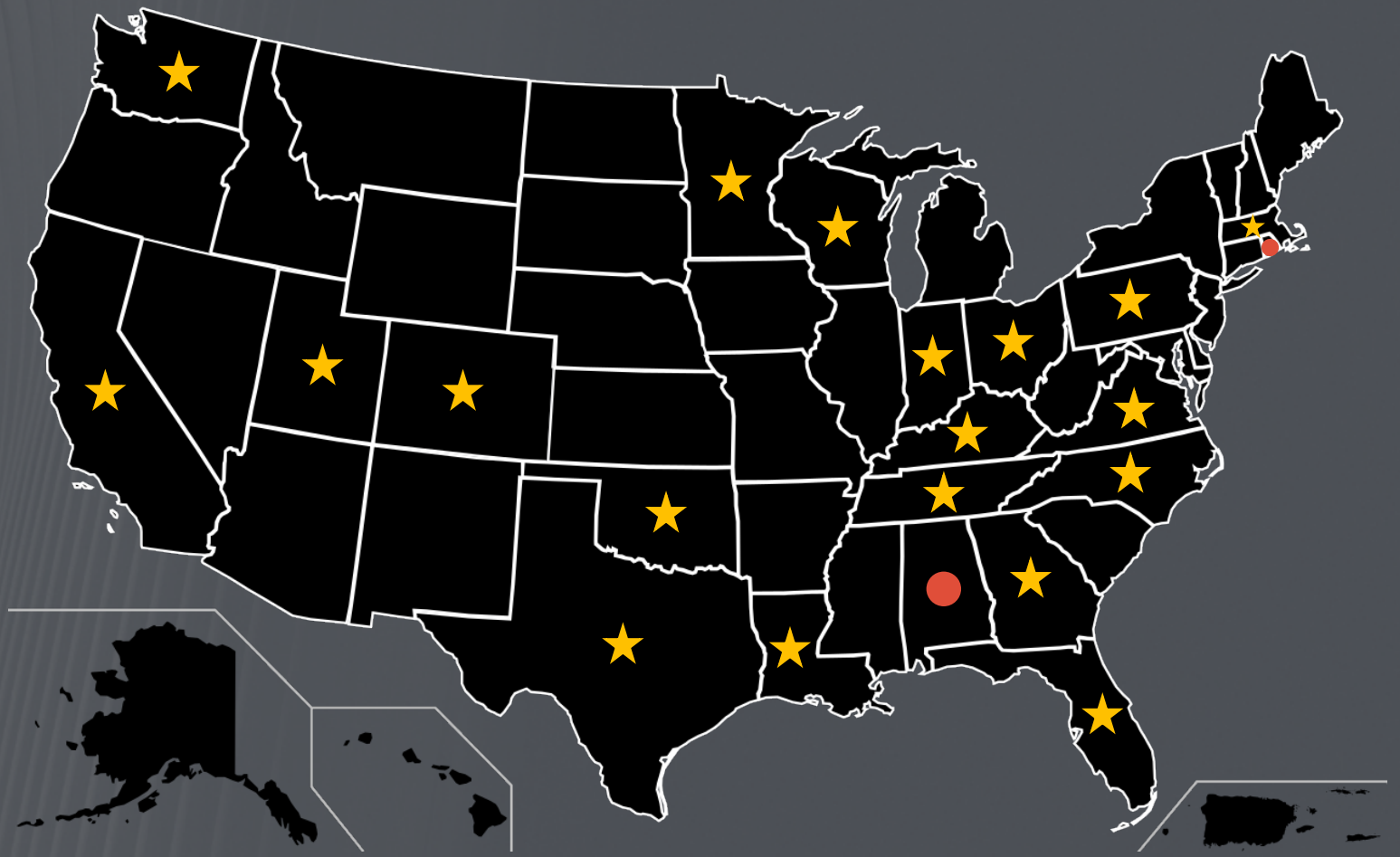
Project Background

What is the Safe Systems Approach?

- Designed to anticipate human error
- Reduce risk of severe crashes
- Intersection strategies can include:
  - Minimizing and modifying conflict points
  - Reducing speed of vehicles
  - Improving visibility
  - Providing space and protection for pedestrians and bicyclists

Guidance In Development

Existing Guidance



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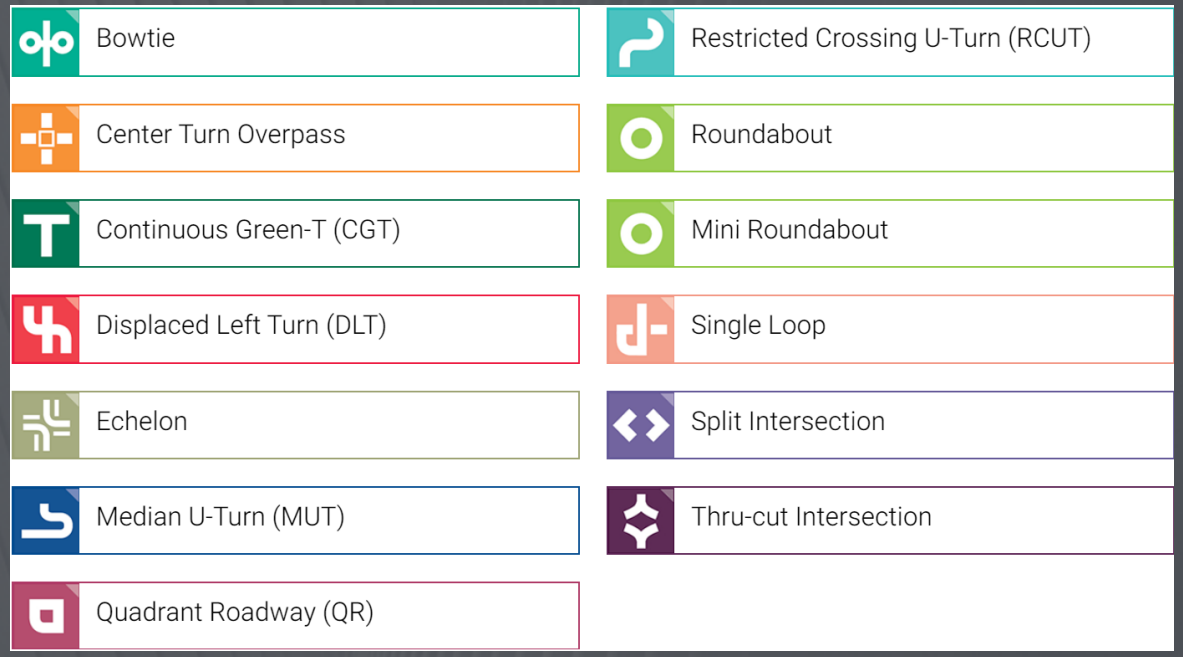
Related Efforts, Tools, and Research

- Capacity Analysis of Planning of Junctions (CAP-X)
- Microsimulation modeling
- Analysis of specific locations or junctions

Research

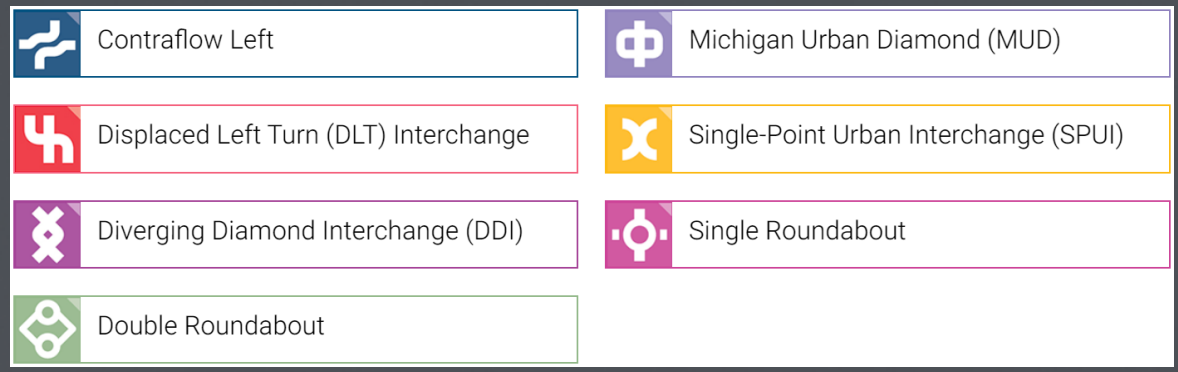
Common Types of Alternative Intersections and Interchanges

Intersections



Virginia Department of Transportation

Interchanges



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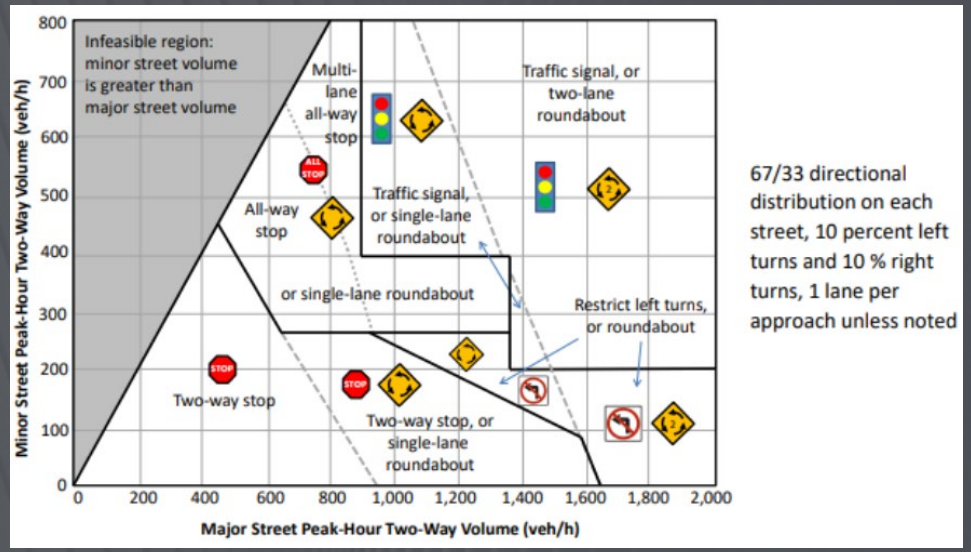
Relevant MoDOT Intersections

- **“Traditional” Stop and Signal Control**
- **Roundabouts**
- **J-Turns**
  - Restricted Crossing U-Turn (RCUT)
  - Superstreet
  - Reduced Conflict Intersection (RCI)
- **Median U-Turns (MUT)**
  - ThrU-Turn
  - Indirect Left
  - Express Left
  - Michigan Left/Loon
- **Displaced Left-Turns (DLT)**
  - Continuous Flow Intersection (CFI)
  - Crossover Displaced Left-Turn (XDLT)

Research Sources

- 2009 Alternative Intersections/Interchanges: Informational Report (AIIR)
- A Safe System-based Framework And Analytical Methodology For Assessing Intersections
- Intersection Informational Guides
- State DOT Guidance Documents
  - FDOT
  - NCDOT
- NCHRP Reports
- University Research Studies

Comparative



67/33 directional distribution on each street, 10 percent left turns and 10 % right turns, 1 lane per approach unless noted

NCHRP Report 825

Table 1 – Potential Intersection Control by total Daily Entering Volume (ADT)

Approximate Combined ADT	Four Way Stop	Signal	Roundabout	Non-Traditional Intersection	Access Management Treatments	Grade Separation
7,500-10,000	X		X		X	
10,000-50,000	X	X	X	X	X	X
50,000-80,000		X	X	X	X	X
>80,000				X	X	X

MnDOT Intersection Control Evaluation

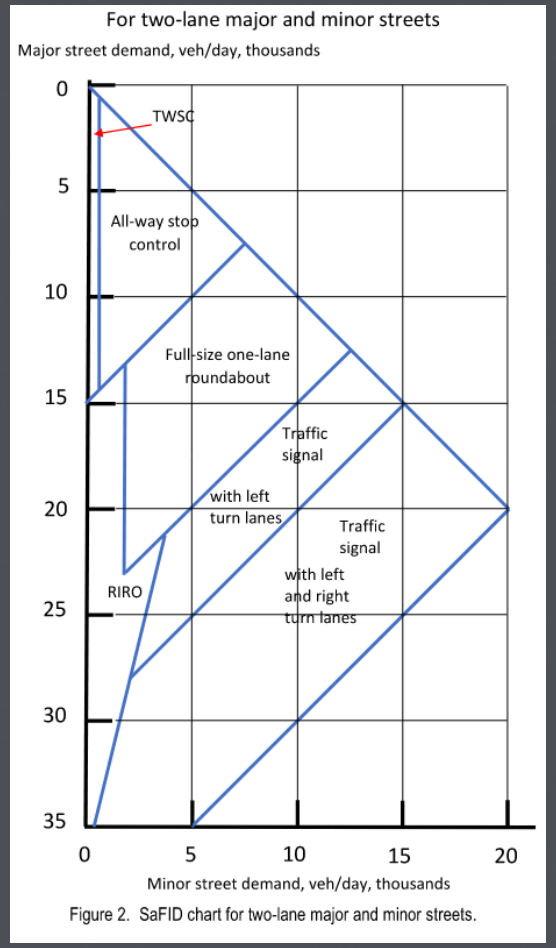
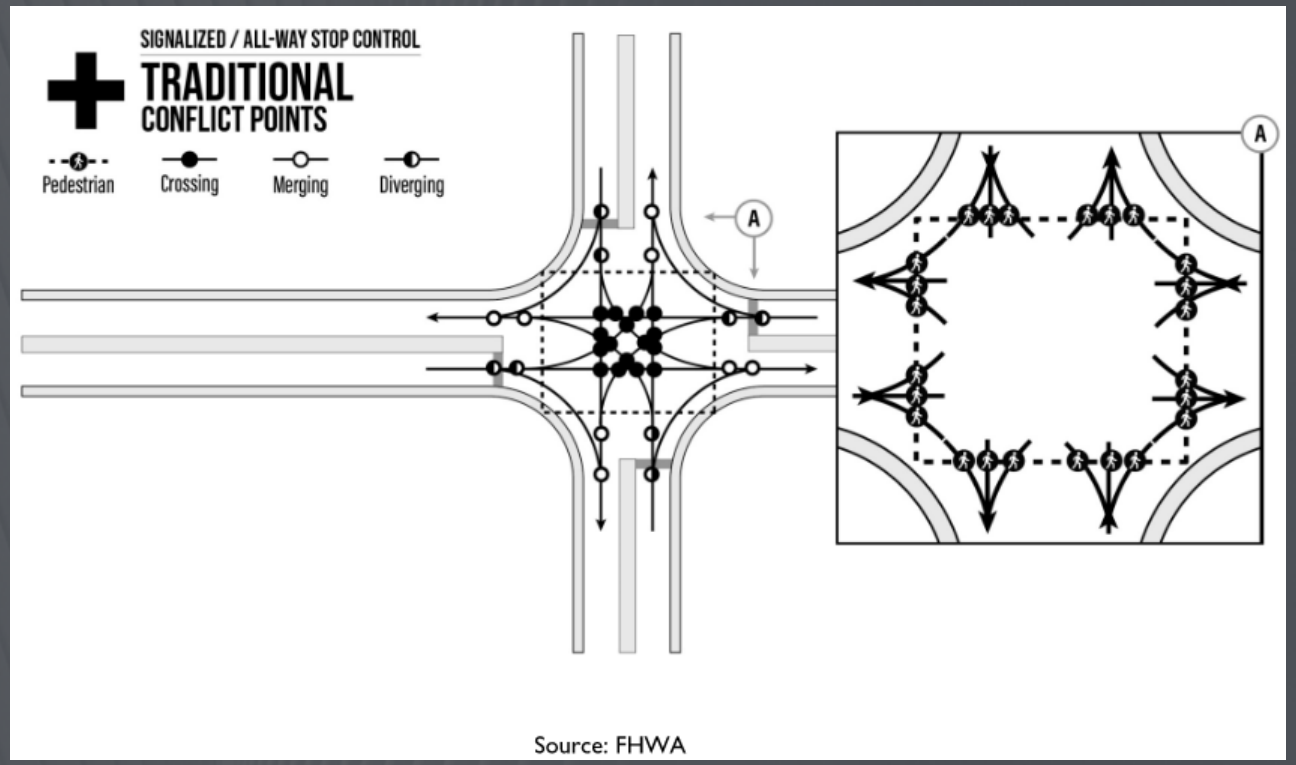


Figure 2. SaFID chart for two-lane major and minor streets.

NC Dot: Selecting Optimum Intersection Or Interchange Alternatives

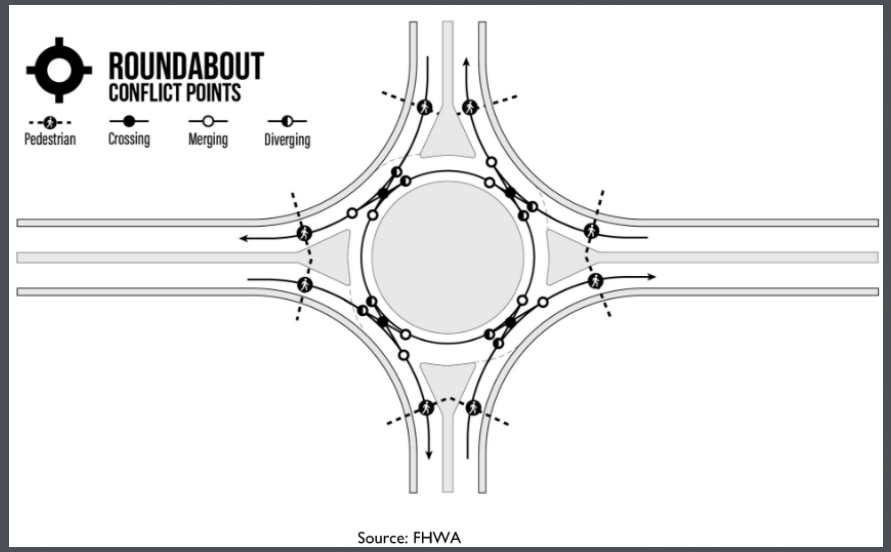
Traditional

- MUTCD Stop and Signal Warrants
- Widely used tools for operational analysis



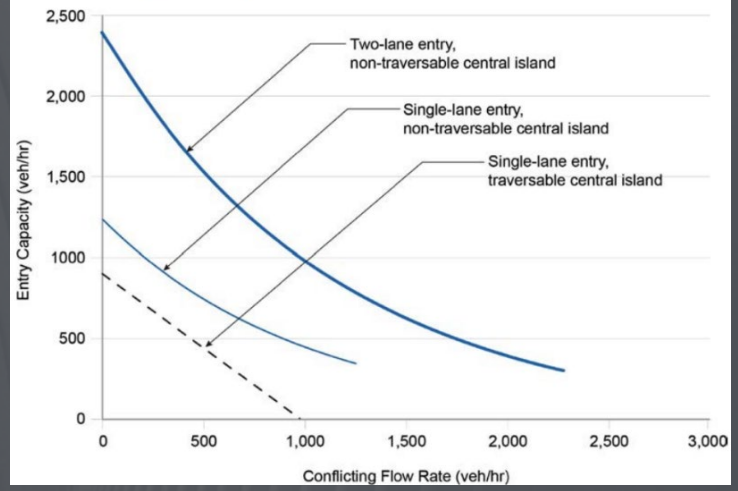
Source: FHWA

Roundabouts



Source: FHWA

Exhibit 8.5. Planning-level practical capacity estimates using peak hour volumes for a given entry.



NCHRP Roundabouts Guide

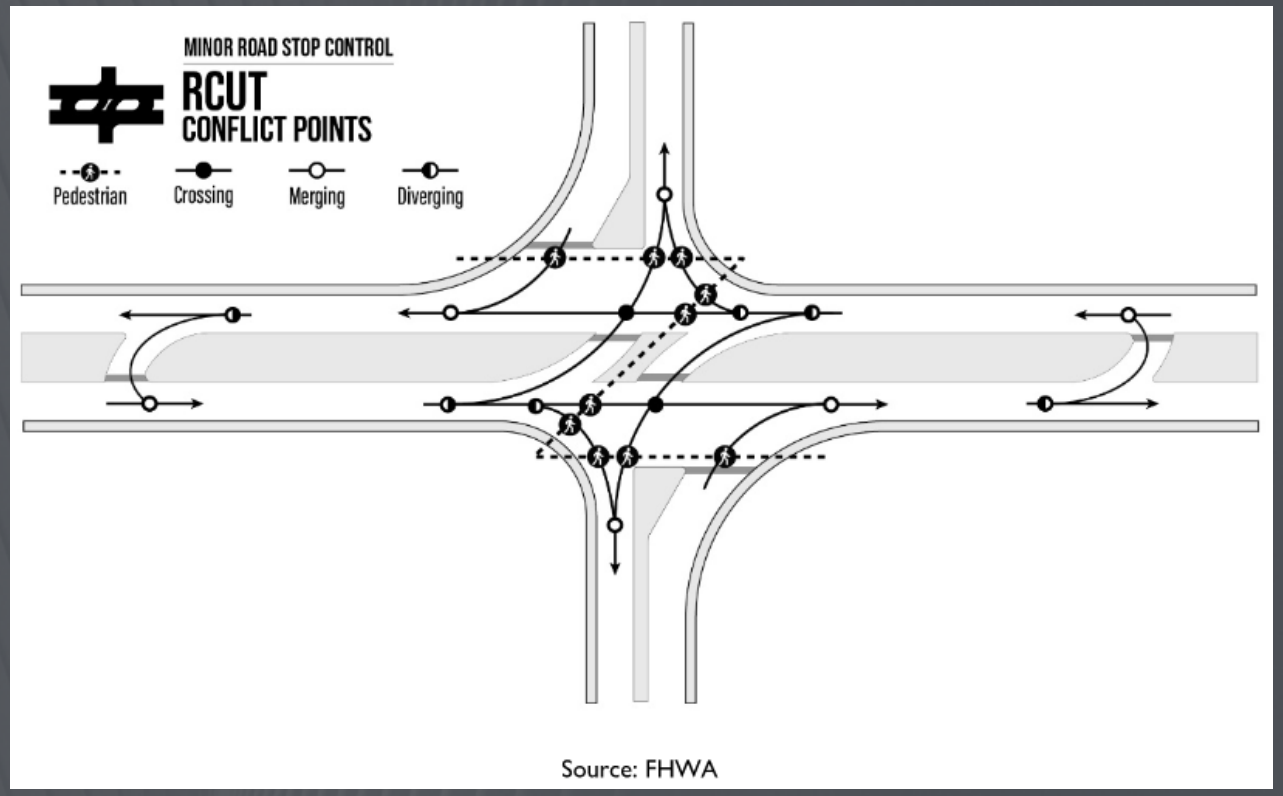
Table 2 - Basic Design Characteristics for Roundabout Categories

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

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

MnDOT Intersection Control Evaluation Manual

J-Turns



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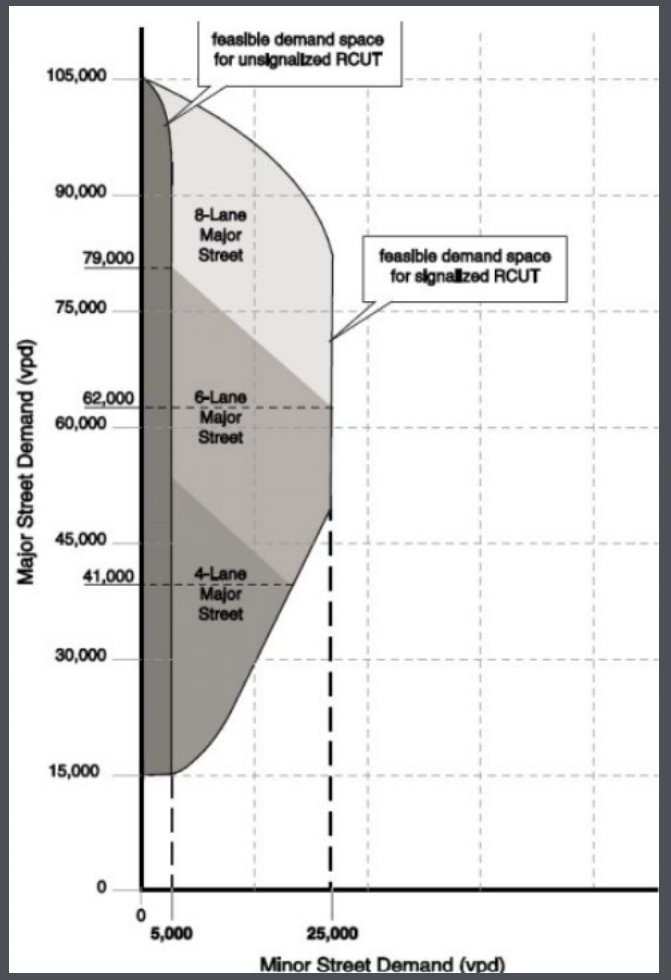


FHWA RCUT Informational Guide

Median U-Turns

TABLE 1 Median U-Turn and Conventional Intersection Capacities

Arterial		Cross	Critical v/c with 180-second cycle			
	Dir.	street	20% turns		40% turns	
ADT	Split	ADT	Med. U-turn	Conv.	Med. U-turn	Conv.
15,000	60	15,000	0.49	0.56	0.61	0.69
		25,000	0.65	0.74	0.83	0.93
	70	15,000	0.58	0.69		
		25,000	0.77	0.91		
20,000	60	15,000	0.57	0.66	0.7	0.81
		25,000	0.73	0.84	0.93	1.05
	70	15,000	0.68	0.81		
		25,000	0.86	1.03		
25,000	60	15,000	0.66	0.76	0.79	0.81
		25,000	0.82	0.94	1.02	1.05
	70	15,000	0.77	0.93		
		25,000	0.96	1.15		
30,000	60	15,000	0.74	0.86	0.88	0.9
		25,000	0.9	1.04	1.11	1.14
	70	15,000	0.87	1.05		
		25,000	1.06	1.27		
35,000	60	15,000	0.63	0.78	0.98	0.99
		25,000	0.79	0.96	1.2	1.23
	70	15,000	0.74	0.95		
		25,000	0.93	1.17		
40,000	60	15,000	0.69	0.85	1.07	1.08
		25,000	0.84	1.03	1.29	1.32
	70	15,000	0.81	0.93		
		25,000	1	1.15		

TRB: E-Circular E-C019

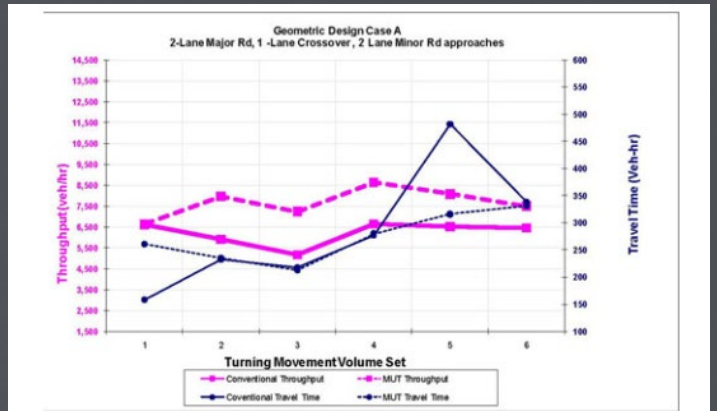
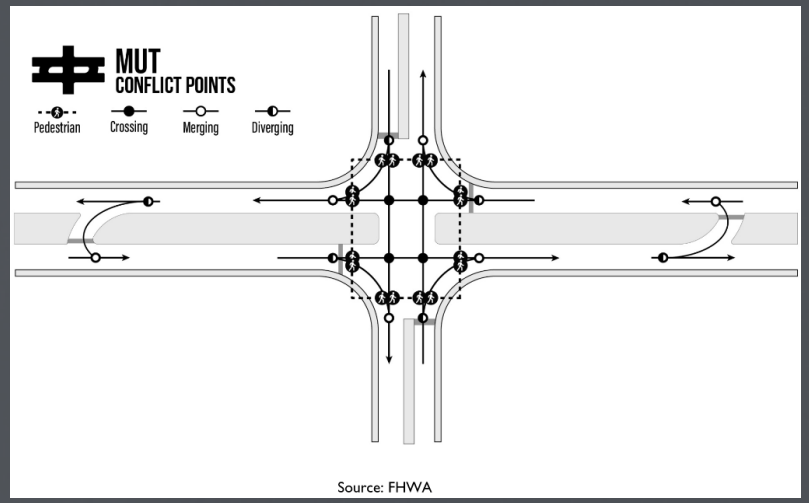
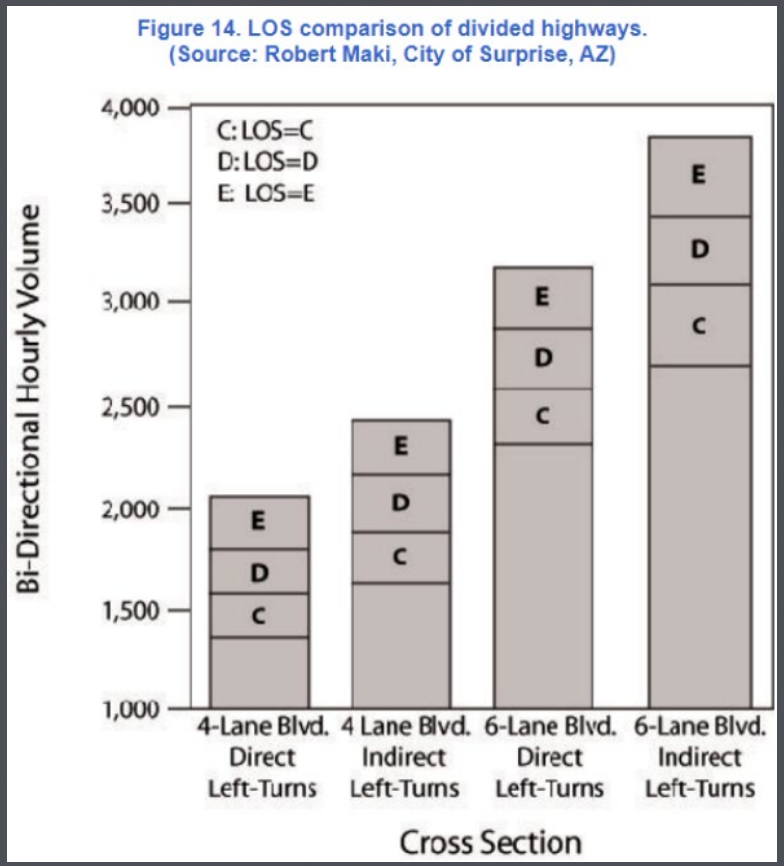


Figure 78. Graph. Throughput and travel time comparisons for geometric design case A.

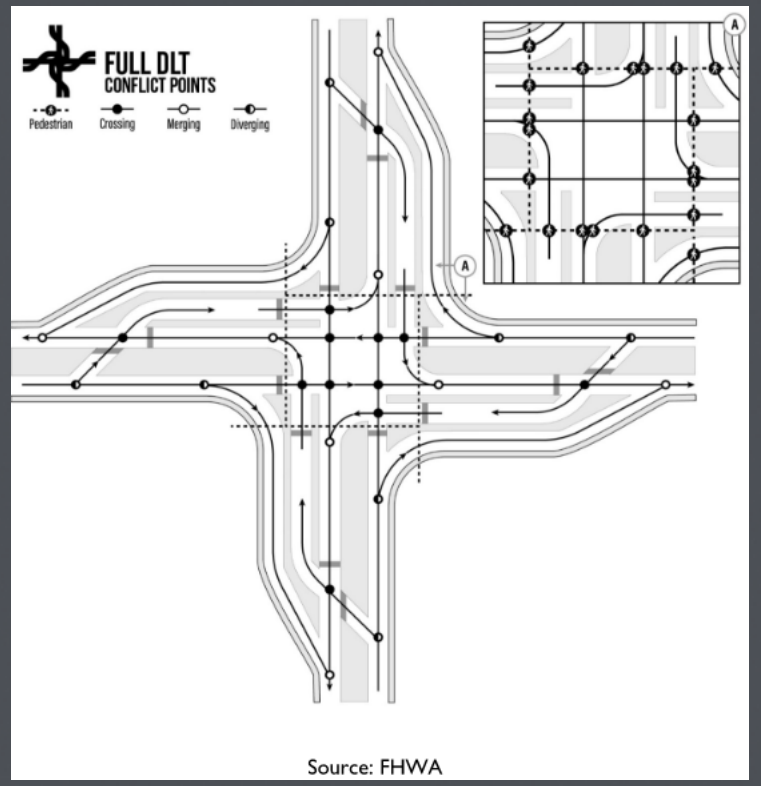
FHWA Alternative Intersections Report





Displaced Left-Turns

- 30 and Gravois Bluffs Blvd in Fenton, MO
- Mathematics or calculation-based criteria



Source: FHWA

Development of Guidelines

Development of Guidelines

Guidance Criteria

- Other Names
- Distinguishing Feature and Key Considerations
- Operational Based Criteria
- Advantages
- Disadvantages
- Pedestrian and Other Nonmotorized User Considerations
- Costs and Maintenance
- Conflict Points (Compared to Traditional)
- High Speed Design Considerations (Roundabouts Only)

Traditional Intersection Quick Reference Table

Other Names	Conventional; Standard		
Distinguishing Features and Key Considerations	• Intersection allows direct movements (left, through, right) on all approaches. • Intersection may operate under traffic signal, all-way stop, or two-way stop control.		
Applicability	• Traditional intersections are considered across a wide range of contexts. • The MUTCD provides clear guidance for when signalized control is warranted.		
Operational Based Criteria		Maximum Major Street Volume (vpd)	Maximum Total Entering Volume (vpd)
	Two-Way Stop Control (One Through Lane)	14,000	
	All-Way Stop Control (One Through Lane)		15,000
	Signalized Intersection with Left-Turn Lanes		30,000
	Signalized Intersection with Left- and Right-Turn Lanes		40,000
Advantages	• This commonly used layout leads to familiarity and intuitiveness for all users.		
Disadvantages	• Safety issues may arise under certain geometric conditions, such as when slip lanes are included or left-turn visibility is obstructed by opposing movements. • Two-way stop control is ineffective at serving high minor roadway volumes. • All-way stop control has the lowest capacity of any intersection type.		
Pedestrian and Other Nonmotorized User Considerations	• One-stage or two-stage crossings may occur depending on the presence of refuge island. • There are no protected movements across the major road under the two-way stop control condition. • Long signal cycle lengths may limit crossing opportunities.		
Costs and Maintenance	• Stop control may be low cost, and signalized control has predictable cost. • Signalized intersections require equipment and timing maintenance.		
Conflict Points	Vehicle-Vehicle - Total	32	
	Vehicle-Vehicle - Crossing	16	
	Vehicle-Vehicle - Merging	8	
	Vehicle-Vehicle - Diverging	8	
	Nonmotorized-Vehicle	24	

Roundabout Quick Reference Table

<table>
<tr><td>Distinguishing Features and Key Considerations</td><td colspan="3">• Direct left-turns are removed from all approaches.
• Roundabouts may be installed as individual intersections or in a series.
• Right-turn bypass lanes may be added.
• All approaches typically operate under yield control.</td></tr>
<tr><td>Applicability</td><td colspan="3">• Where high left-turn or right-angle crashes are being experienced.
• Where there are heavy traffic delays.
• In situations with non-conventional approach geometry (i.e., skewed intersections, more than four legs, etc.).
• May be used as an alternative to traffic signal installation at some intersections.</td></tr>
<tr><td rowspan="8">Operational Based Criteria</td><td>Roundabout Type</td><td>Sum of Entering and Conflicting Flows (vph)</td><td>Maximum Daily Capacity (vpd)</td></tr>
<tr><td>Mini</td><td></td><td>10,000</td></tr>
<tr><td>Urban Compact</td><td></td><td>15,000</td></tr>
<tr><td>Urban Single-Lane</td><td>1,000-1,300</td><td>20,000-25,000</td></tr>
<tr><td>Urban Double-Lane</td><td>1,300-2,300</td><td>40,000-50,000</td></tr>
<tr><td>Rural Single-Lane</td><td>1,000-1,300</td><td>20,000-25,000</td></tr>
<tr><td>Rural Double-Lane</td><td>1,300-2,300</td><td>40,000-50,000</td></tr>
<tr><td>Advantages</td><td colspan="3">• Reduces overall conflict points and eliminates left-turn conflicts.
• Geometry and yield control leads to reduced vehicle speeds and crash severity, especially for fatal/injury crashes compared to signalized control.
• Provides an opportunity for a transitional zone along a corridor, facilitates access management, and provides traffic calming.</td></tr>
<tr><td>Disadvantages</td><td colspan="3">• Cannot provide explicit priority for specific users without supplemental traffic control devices.
• Increase in single-vehicle and fixed-object crashes compared to other intersection treatments.
• Implementation of multi-lane roundabouts may create unique challenges, such as path overlap and higher crash rates.
• Multi-lane roundabouts may require supplemental lane markings and wayfinding signage for correct utilization.
• Roundabouts operating near volume / capacity thresholds lose efficiency or may even gridlock.</td></tr>
<tr><td>Pedestrian and Other Nonmotorized User Considerations</td><td colspan="3">• Splitter islands provide refuge for two-stage crossings.
• Pedestrians only cross one direction of conflicting traffic at a time.
• Multiple options for cyclists to navigate based on skill and comfort level.
• Potential navigation difficulty for pedestrian users with visual impairments.
• Multilane approaches to roundabouts may require additional pedestrian protective measures, such as activated signals, beacons, or raised crosswalks.</td></tr>
<tr><td>Costs and Maintenance</td><td colspan="3">• Comparable (or higher) initial geometric cost to new signalized intersection with turn lanes.
• Some roundabouts may require more right-of-way than a traditional intersection.
• Elimination of traffic signal equipment, maintenance, and power costs.
• May require landscaping maintenance.</td></tr>
</table>

Roundabout Quick Reference Table (Continued)

Conflict Points (Compared to Traditional)	Vehicle-Vehicle - Total	20 (32)
	Vehicle-Vehicle - Crossing	4 (16)
	Vehicle-Vehicle - Merging	8 (8)
	Vehicle-Vehicle - Diverging	8 (8)
	Nonmotorized-Vehicle	8 (24)
High Speed Design Considerations	• Provide a minimum of stopping sight distance to the entry point based on approach operating speed. • Align approach roadways and vertical profiles to make the central island conspicuous with landscaping and sight-blocking amenities. • Extend splitter islands at least 200' upstream to a point at which entering drivers are expected to begin decelerating. • Use landscaping on extended splitter islands and roadside to create a tunneling effect for approaching vehicles. • Provide roadway illumination in transition to the roundabout. • Use proper signage and pavement markings to advise the appropriate speed and path for approaching vehicles.	

J-Turn Quick Reference Table

Other Names	Restricted Crossing U-Turn (RCUT); Superstreet; Reduced Conflict Intersection (RCI)	
Distinguishing Features and Key Considerations	• Allows direct left-turns and through movements from the major roadway. • Through and left movements from the minor road are redirected to a downstream U-turn. • In an unsignalized J-turn, minor road movements are yield controlled. • The primary intersection movements may be signal controlled. • Downstream U-turns may operate under signal, stop, or yield control.	
Applicability	• Where there are low left-turn and through volumes from the minor road. • Where there is a high frequency of right-angle crashes. • Where there are heavy through and left turn volumes on major road approaches.	
Operational Based Criteria	Signalized J-Turn Minor Street Demand Threshold	2,250 vph (25,000 vpd)
	Unsignalized J-Turn Minor Street Demand Threshold	450 vph (5,000 vpd)
	Minor Road Approach Volume Ratio to Total Entering Intersection Volume	Less Than 0.20
	Combined Volume of Through + Merging Movement (From Crossroad or U-Turn Entry)	Less Than 1,800-1,900 veh/hr/ln
Advantages	• Eliminates most crossing conflict points. • Reduces turning and angle crashes, and reduces overall crash severity. • Increases intersection throughput by approximately 30%. • Lower exposure time for large vehicles compared to traditional two-way stop-controlled intersections. • May be implemented as a signalized or unsignalized intersection. • May be a treatment at a single intersection or may be applied to multiple intersections along a corridor.	
Disadvantages	• May require additional right-of-way to construct supplemental turning areas (i.e., loons) or a wider median. • Prioritizes major road movements at cost of minor road movements, which have additional travel distance and time. • Not a suitable treatment at the intersection of arterials, where two roadways have balanced and high traffic volumes.	
Pedestrian and Other Nonmotorized User Considerations	• Z-crossing is the most common pedestrian configuration, which results in non-traditional and indirect pedestrian movements. • Shorter cycle lengths provide more frequent crossing opportunities. • Wider intersection footprint lengthens crossings, but medians may provide refuge for multistage crossing. • Midblock crossings may be provided at U-turn crossovers. • Various bicycle treatments are possible, depending on the intended riding location of users. • Potential navigational difficulty for pedestrian users with visual impairments.	
Costs and Maintenance	• Construction costs are higher than traditional intersections. (FHWA Estimate: 29%-34%) • Additional costs may be associated with right-of-way acquisition or median widening. • Eliminates traffic signal equipment, maintenance, and power costs for the unsignalized configuration.	
Conflict Points (Compared to Traditional)	Vehicle-Vehicle - Total	14 (32)
	Vehicle-Vehicle - Crossing	2 (16)
	Vehicle-Vehicle - Merging	6 (8)
	Vehicle-Vehicle - Diverging	6 (8)
	Nonmotorized-Vehicle	10 (24)

Disclaimer: Information provided as part of this document is intended for policy guidance and initial planning evaluation. Information presented in this document does not supersede detailed requirements set by MoDOT for further analysis of specific projects or proposed improvements.

Median U-Turn (MUT) Quick Reference Table

Other Names	ThrU-Turn; Indirect Left; Express Left; Michigan Left/Loon	
Distinguishing Features and Key Considerations	• Removes direct left-turns from major and minor roads. • Replaces left-turns at the main intersection with downstream U-turns. • The main intersection is signalized, while the downstream U-turns may operate under yield, stop, or signal control.	
Applicability	• Where there is a high proportion of through volumes to left-turning volumes. • Where there are heavy through volumes and moderate left-turn volumes on all approaches. • Where there is a high frequency of right-angle or rear-end crashes. • Where there are corridors with wide medians.	
Operational Based Criteria	Major street volumes of 300-1,900 veh/hr/ln and minor street volumes of 100-500 veh/hr/ln.	
	Left-turning volume < 400 veh/hr/ln and opposing through volume > 700 veh/hr/ln on two opposing approaches.	
	Volume to Capacity Ratio > 0.8 on two opposing approaches.	
	Left-turn approach volume < 20% of total approach volume on all approaches.	
	Cross product of hourly left-turn and opposing through volumes > 150,000 on two opposing approaches.	
Advantages	• Reduces crossing conflict points. • Increases capacity and improves operational efficiency. • Reduces crashes by 20%-50%. • Typically increases throughput by 30%-45%. • Better suited for high minor road through volumes than a J-turn intersection. • May be a treatment at a single intersection or may be applied to multiple intersections along a corridor.	
Disadvantages	• Has a lower overall intersection capacity at high left-turn demands. • Left turns have longer travel times and delays. • No geometric barriers are provided to prohibit left-turn movements at main intersection. • May require additional right-of-way to construct supplemental turning areas (i.e., loons) or a wider median.	
Pedestrian and Other Nonmotorized User Considerations	• Wider footprint lengthens crossings, but major road median may provide a refuge for multistage crossing. • Shorter cycle length leads to more frequent crossing opportunities. • Pedestrian crossing movements may be provided in similar manner to a traditional intersection. • Midblock crossings may be provided at U-turn crossovers. • Various bicycle treatments are possible, depending on the intended riding location of users. • Potential navigational difficulty for pedestrian users with visual impairments.	
Costs and Maintenance	• Generally, more expensive than a traditional signalized intersection. • Additional cost may be associated with right-of-way acquisition or median widening.	
Conflict Points (Compared to Traditional)	Vehicle-Vehicle - Total	16 (32)
	Vehicle-Vehicle - Crossing	4 (16)
	Vehicle-Vehicle - Merging	6 (8)
	Vehicle-Vehicle - Diverging	6 (8)
	Nonmotorized-Vehicle	16 (24)

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Displaced-Left Turn (DLT) Quick Reference Table

Other Names	Continuous Flow Intersection (CFI); Partial Displaced Left-Turn (PDLT); Crossover Displaced Left-Turn (XDLT)	
Distinguishing Features and Key Considerations	• Left-turns cross over to the left side of the roadway at secondary intersections upstream of main junction. • Left-turns and through movements occur simultaneously at the main intersection without conflict. • Main junction and secondary crossovers are signalized.	
Applicability	• Where there are heavy through and left-turning volumes. • Where left-turn queues exceed existing storages. • Where there is high left-turn crash frequency. • At an urban or suburban intersection location.	
Operational Based Criteria	Full DLT Maximum Intersection Volume	12,000 vph
	Partial DLT Maximum Intersection Volume	10,000 vph
	Major street volume > 2,000 veh/hr/ln and minor street volume > 300 veh/hr/ln.	
	Mainline left-turning volumes > 250 veh/hr/ln and opposing through volumes > 500 veh/hr/ln on two opposing approaches.	
	Cross product of hourly left-turns and opposing through volumes exceed 150,000 on two opposing approaches.	
	Volume to Capacity Ratio > 0.8 on two opposing approaches.	
Advantages	• May accommodate high intersection volumes and is a viable alternative to grade separation. • Increases capacity and operational efficiency. • Well suited to accommodate high left-turn volumes. • Intersection delays are typically reduced by 50%-85% for a full DLT (30%-40% for partial). • Throughput is typically increased by 10%-25% for a full DLT (10%-20% for partial).	
Disadvantages	• Unique access management techniques may need to be utilized to provide access to adjacent parcels, such as frontage roads. • U-turn movements are prohibited at intersection. • Footprint of intersection is large relative to other at-grade alternatives. • Challenges regarding navigation and adherence to traffic control devices may arise where right turn bypass lanes are omitted.	
Pedestrian and Other Nonmotorized User Considerations	• Movements are more complex than at standard intersections, and traffic may approach from unexpected directions. • Wider footprint lengthens crossings, but median islands may provide refuge for multistage crossings. • Shorter signal cycle lengths lead to more frequent crossing opportunities. • Channelized right-turn lanes may be hazardous for pedestrians. • Potential navigation difficulty for pedestrian users with visual impairments. • Various bicycle treatments are possible, depending on the intended riding location of users.	
Costs and Maintenance	• Construction costs are higher than traditional intersections. (FHWA Estimate: Approximately 30%) • Significantly cheaper than grade-separated alternatives which may provide equivalent capacity. • More signals and associated equipment than traditional intersection. • Larger right-of-way needs than traditional intersection.	
Conflict Points (Compared to Traditional)	Vehicle-Vehicle - Total	Partial – 30; Full – 28 (32)
	Vehicle-Vehicle - Crossing	Partial – 14; Full – 12 (16)
	Vehicle-Vehicle - Merging	Partial – 8; Full – 8 (8)
	Vehicle-Vehicle – Diverging	Partial – 8; Full – 8 (8)
	Nonmotorized-Vehicle	Partial – 22; Full – 20 (24)

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Recommendations and Lessons Learned

Recommendations and Lessons Learned

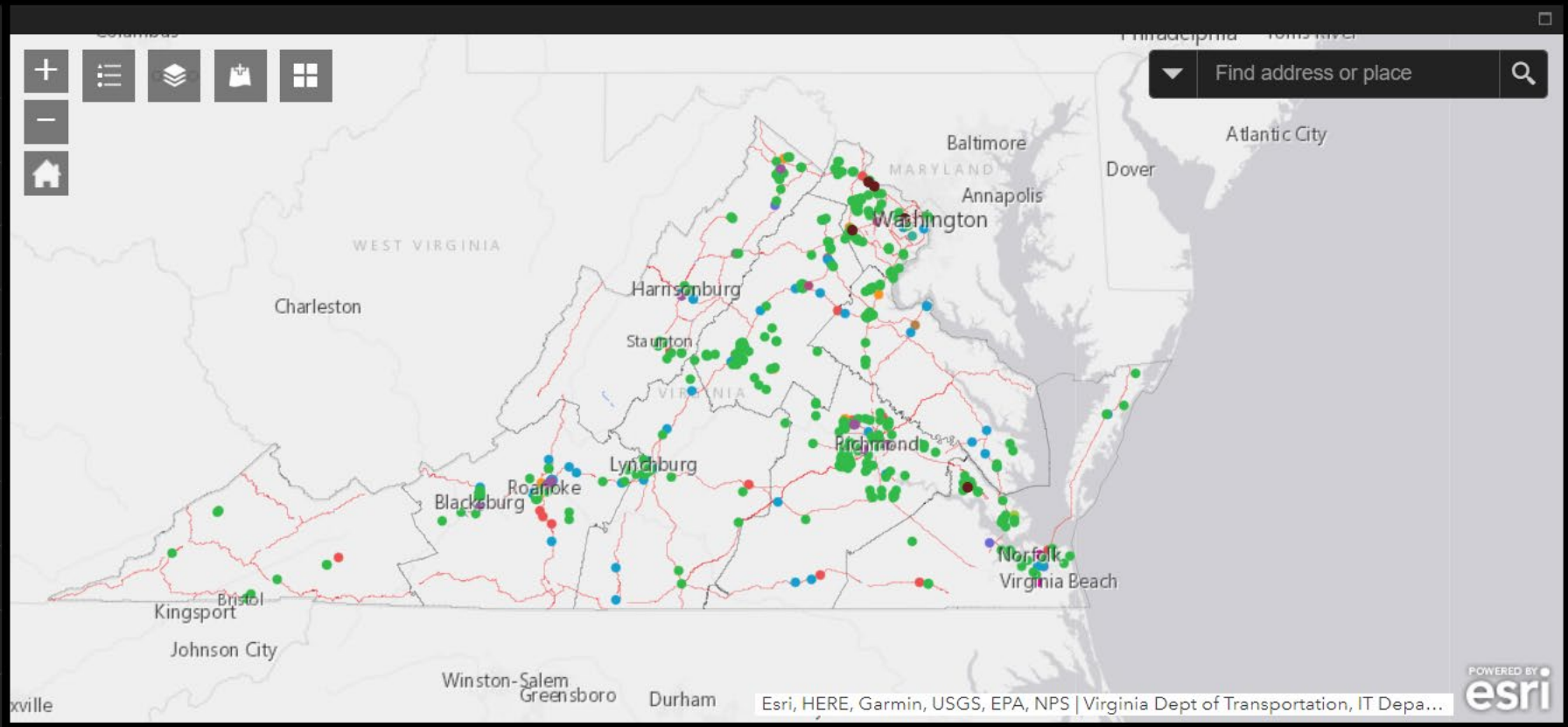
- Older guidance and data
- Small sample sizes
- Public engagement
- Tracking of new projects and existing sites
- Some guidance > no guidance

Innovative Intersections

with Web AppBuilder for ArcGIS

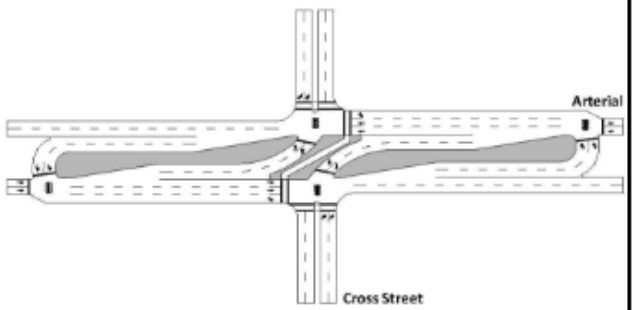
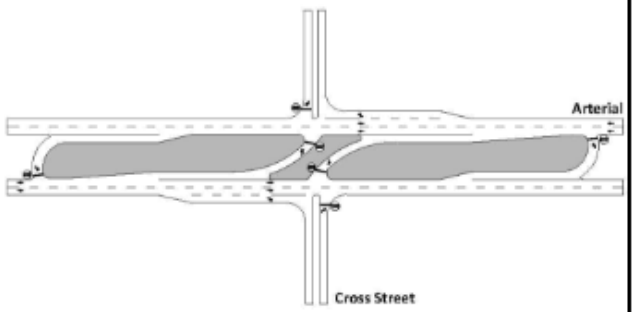
Innovative Intersections - Types

- Continuous Green-T
- Displaced Left Turn
- Diverging Diamond Interchange
- Roundabout
- Restricted Crossing U-Turn (RCUT)
- Tight Urban Diamond
- Single-Point Urban Interchange
- Median U-Turn
- Jughandle
- Quadrant Roadway
- Offset Lefts
- Reversible Roadway
- Thru-Cut



Innovative Intersections - Status

- Open
- In Development

Intersection Control Type			Mode Accommodations			Reference Material[1]	Volume Thresholds	Recommended Stage 1 and 2 Operational Analysis Tool(s)[2]
Intersection Name	Illustration	Description	Vehicles	Pedestrians	Bicycles			
Signalized Restricted Crossing U-Turn (RCUT), or Superstreet		An intersection design that restricts left-turn and through movements from cross street approaches as permitted in conventional designs. Advantages: Fewer signal phases and conflict points (if signalized) than a conventional intersection, enables major street to operate as one-way couplet if signalized Disadvantages: Out-of-direction travel for cross street left and through movements, requires wide median or outside right-of-way at U-turn crossover	Left-turns and through movements from the minor street are required to turn right onto the main road and then make a U-turn maneuver at a one-way, signalized median opening desirably 400 to 800 feet after the intersection. The major street effectively operates as a pair of one-way streets because no movement ever crosses both directions of the major street at once.	Pedestrian crossings of the major road at the RCUT intersection are usually accommodated on one diagonal "Z" path from one corner to the opposite corner, and each crossing is signalized. Direct paths across all four legs are also possible. Increased right turn volumes from the minor street may result in more vehicle-pedestrian conflicts and can be mitigated through prohibiting right turn on red. See NCHRP Report 948: Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges; Chapter 7 for additional guidance on pedestrian treatments. FDOT has published three videos showing different pedestrian treatments at signalized RCUTs.	Ride on street in travel lane or bicycle lane (if available) unless multi-use path is present. Cross street through and left turn movements can use pedestrian crossings to avoid use of U-turn movements Increased right turn volumes from the minor street may result in more vehicle-bicycle conflicts and can be mitigated through prohibiting right turn on red. See NCHRP Report 948: Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges; Chapter 7 for additional guidance on bicycle treatments. FDOT has published three videos showing different bicycle treatments at signalized RCUTs.	FHWA-SA-14-070 NCHRP Report 948 Pedestrian and bicycle facility operations videos FDOT Traffic Engineering and Operations Office, Intersection Operations and Safety website	Not suitable for an intersection of two arterials Minor street demand threshold of 25,000 vpd (or 2,250 vph) See ***Figure A3*** for further details.	CAP-X (planning level), HCS, SYNCHRO, SimTraffic[3]
Unsignalized Restricted Crossing U-Turn (RCUT), or J-Turn			Left-turns and through movements from the minor street are required to turn right onto the main road and then make a U-turn maneuver at a one-way, stop-controlled median opening desirably 600 to 1,000 feet after the intersection.	Unsignalized RCUTs are usually located in rural areas and do not typically have pedestrian facilities. If there is pedestrian demand, accommodations should be provided. See NCHRP Report 948: Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges; Chapter 7 for additional guidance on pedestrian treatments.	Ride on street in travel lane or bicycle lane (if available) unless multi-use path is present. Direct crossings from minor street to minor street can be facilitated with a cut-through in the median island. See NCHRP Report 948: Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges; Chapter 7 for additional guidance on bicycle treatments.		Minor street demand threshold of 5,000 vpd (or 450 vph) See ***Figure A3*** for further details.	

Questions