Results from Designing an Interchange Instead of an Intersection

- "Parclo A"
- Just south of downtown Raleigh

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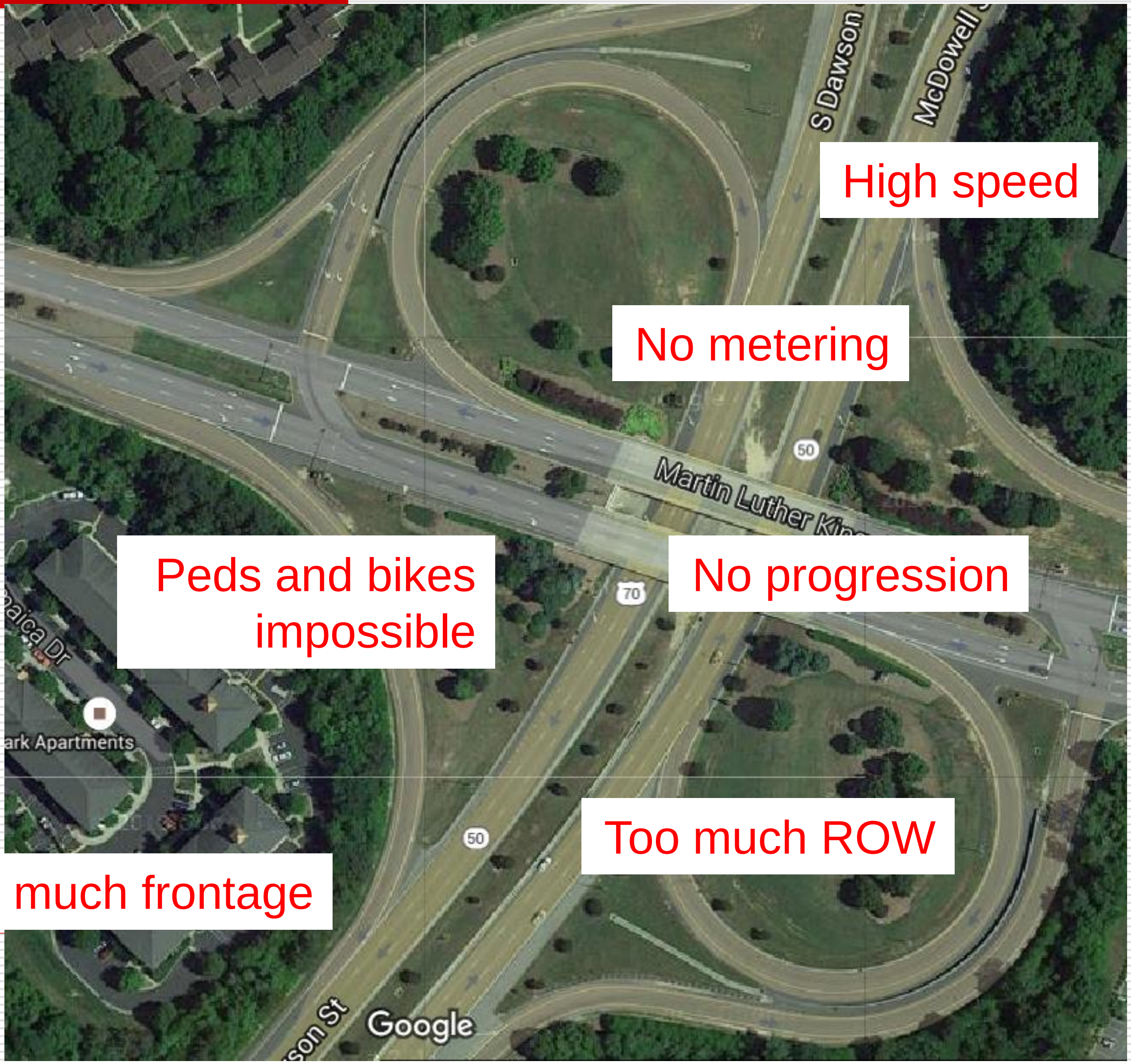

Grade-Separated Intersection Alternatives

NCDOT Webinar

Presenters: Thomas Chase
Chris Cunningham

NCDOT Moderators: Joseph Hummer

09/14/2020

Definition

Grade-separated intersections consist of:

- Two or more arterials
- Elevation of at least one movement
- Interrupted flow for through movements on each arterial

Why not an Interchange?

Safety: Interchange designs for crossing arterials may result in higher speeds and less pedestrian/bicycle accessibility.

Operations: Interchanges are ideal for high through demand on one arterial while GSI can accommodate balanced demand or heavy turning movements.

Context Sensitive: GSI designs can utilize the existing network and have compact low speed ramps to minimize Right of Way need.

Introduction

Why not an Interchange?

Frontage: Interchange designs with free flowing ramps limit frontage and access in suburban/urban areas

Metering: Uncontrolled movements on interchange designs may overload downstream signals

Poor progression: Signalized intersections at interchange often are critical intersection on the corridor while GSI can often utilize two phase signals and allow coordination options to limit ramp spillback

Existing Designs

DISCLAIMER

All designs and drawings shown are not standards or typicals. These designs and drawings are meant to communicate the core design concepts and many components are adaptable to specific project needs.

Echelon Intersection

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Center Turn Overpass

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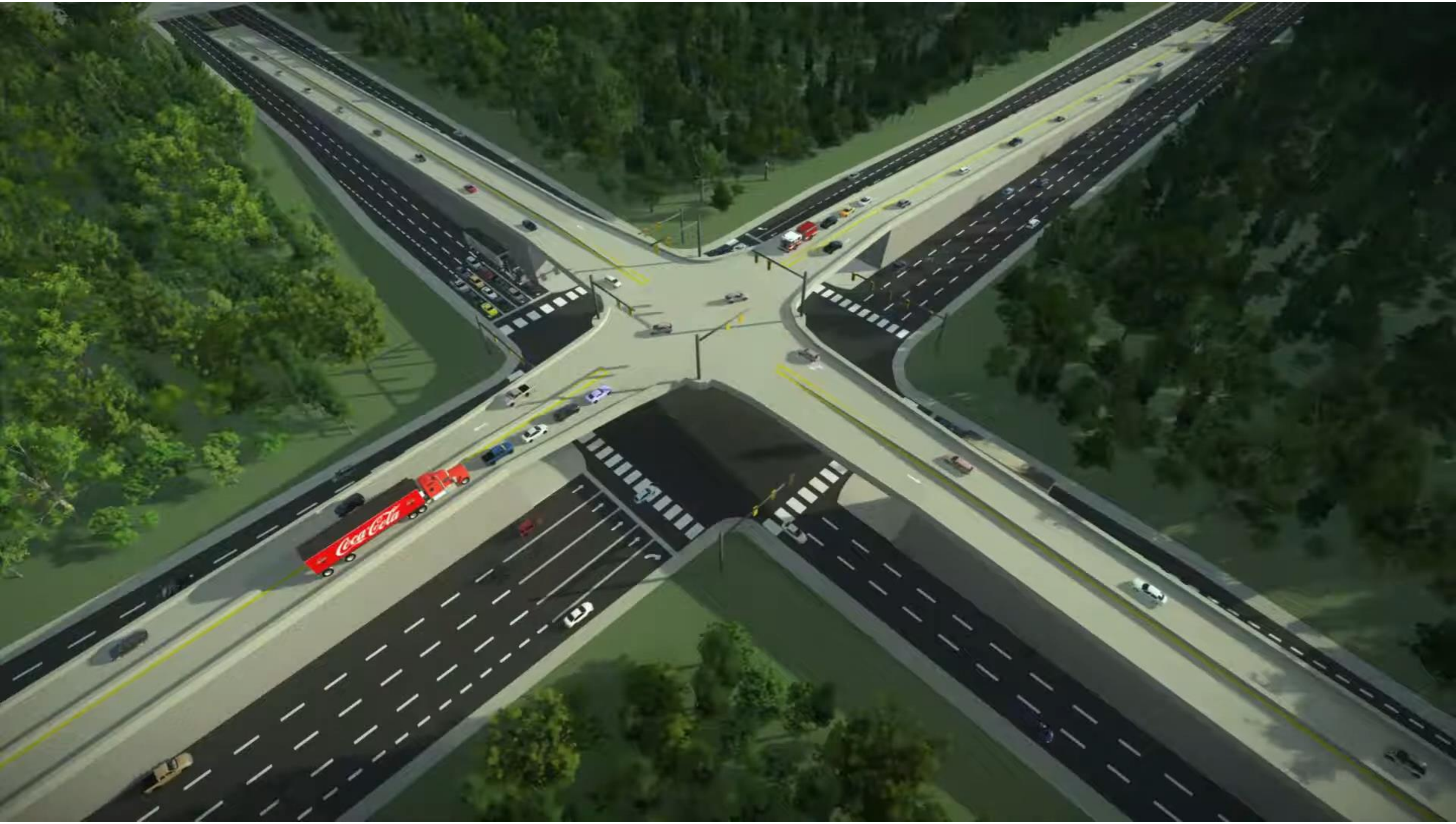

Grade Separated Quadrant Intersection

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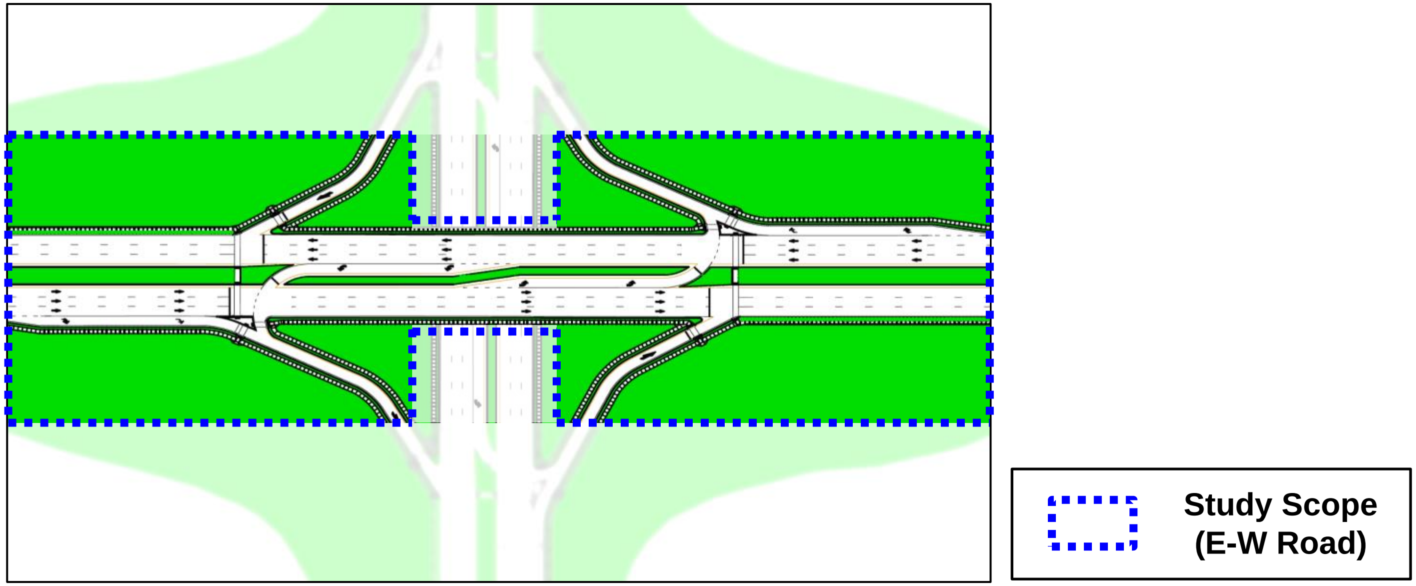
Hillsborough St & Hillandale Rd - Durham

Scope of Study Designs

- In order to provide an engineer or planner the most flexibility during concept or design stages of a project, our study provides the operational and safety analysis results only for one of the two roads (e.g. East-West road) that could intersect.



Study Scope: East-West Road (example: Direct Left - Downstream)

Direct Left - Downstream

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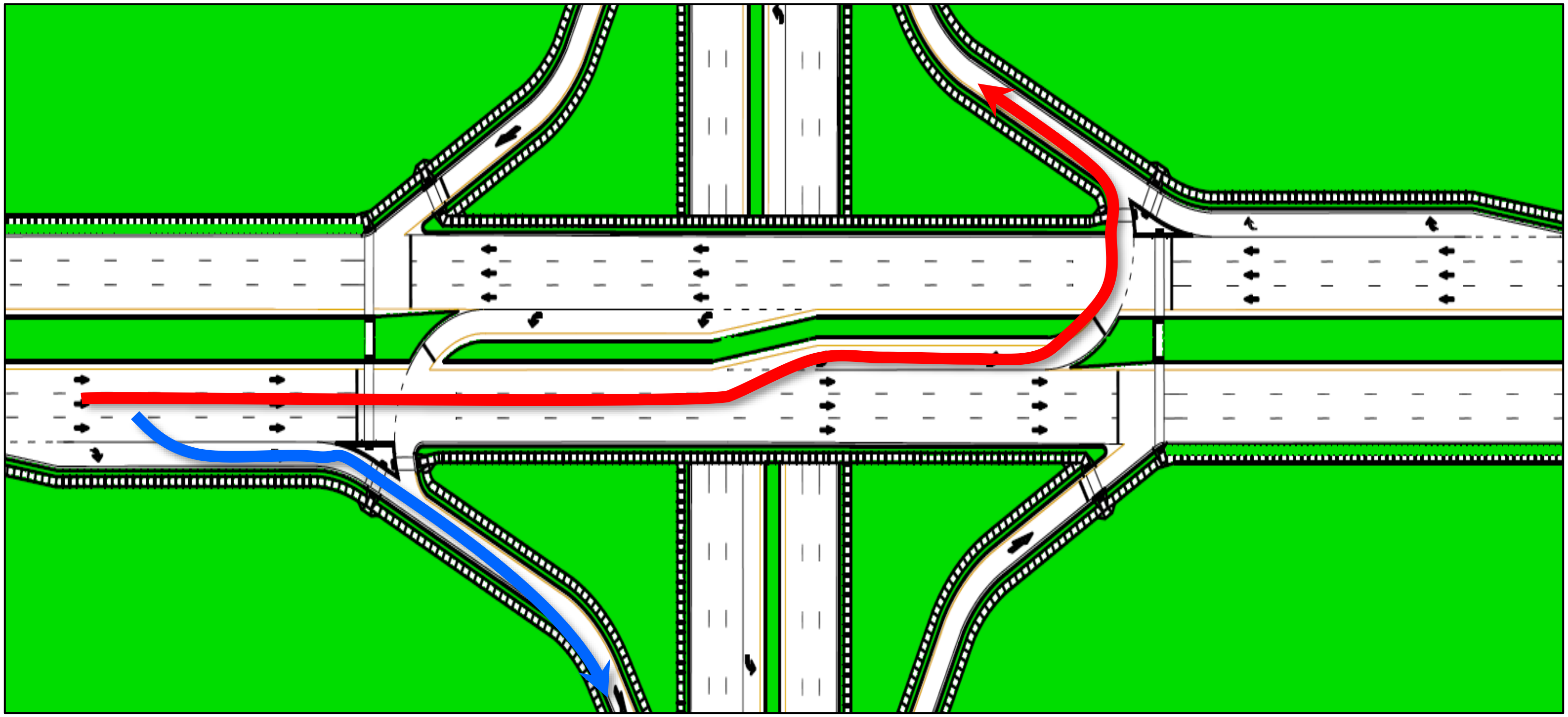

The left turn is

- separated downstream of the signal on the major road
- conflicting with opposing left turn and opposing through

Note: For illustration purposes, major & minor roads designs are same; however, they could be any combination of designs for the major and minor.

Direct Left - Upstream

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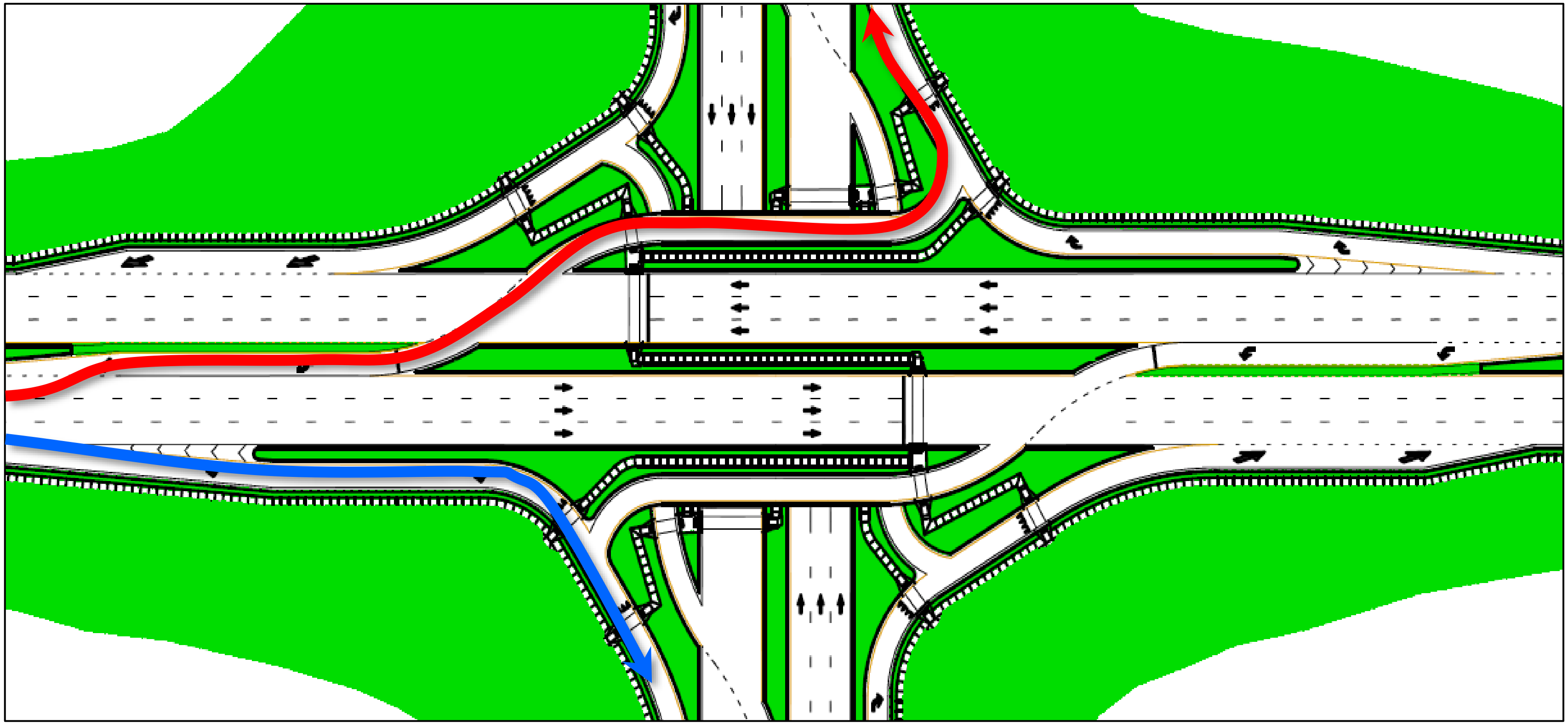

The left turn is

- separated upstream of the signal on the major road
- conflicting with opposing through

Note: For illustration purposes, major & minor roads designs are same; however, they could be any combination of designs for the major and minor.

RCI: RCUT U-turn then Right

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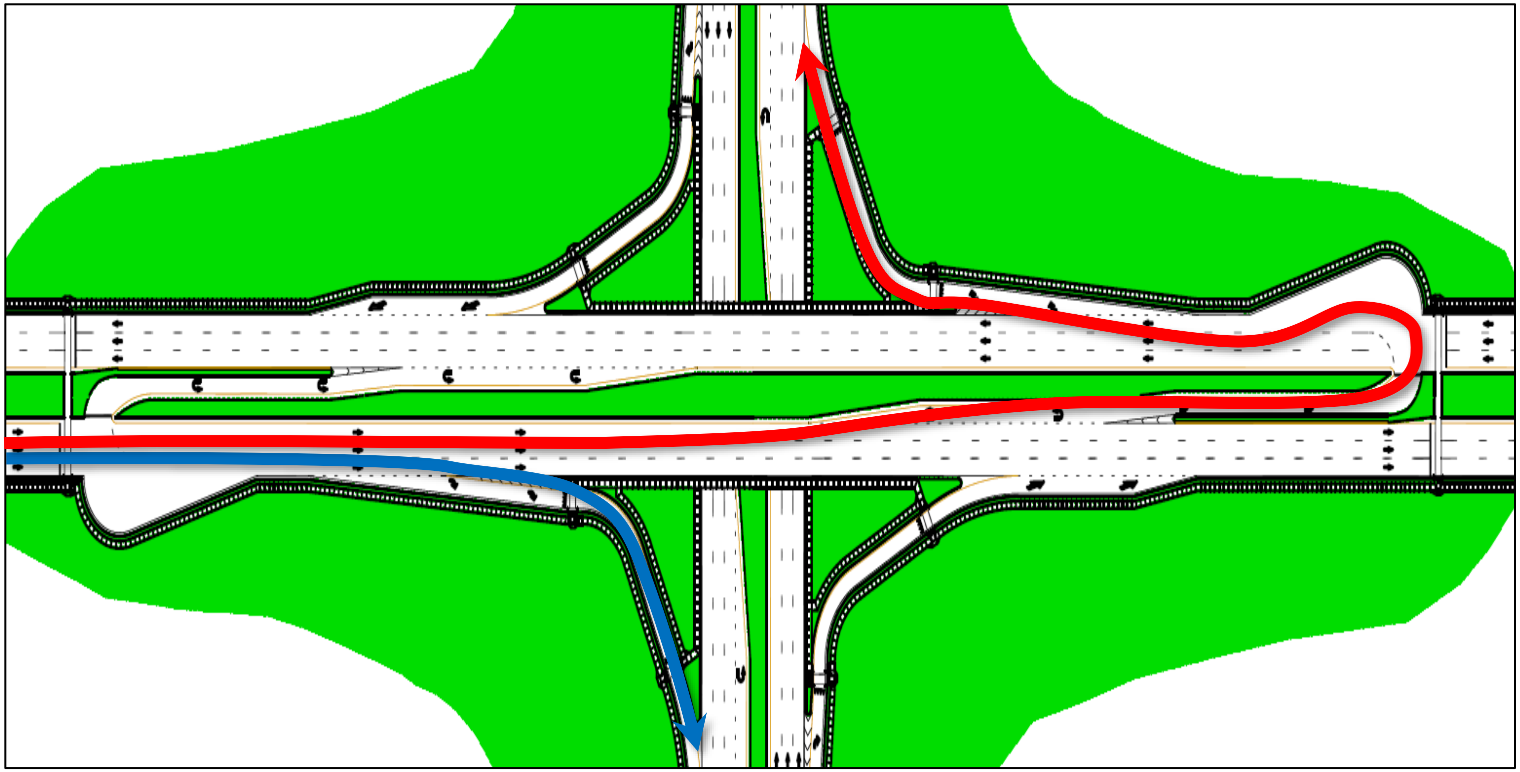

The left turn is

- separated downstream of the signal on the major road
- conflicting with opposing U-turn and opposing through at U-turn point on the major road

Note: For illustration purposes, major & minor roads designs are same; however, they could be any combination of designs for the major and minor.

RCI: RCUT Right then U-turn

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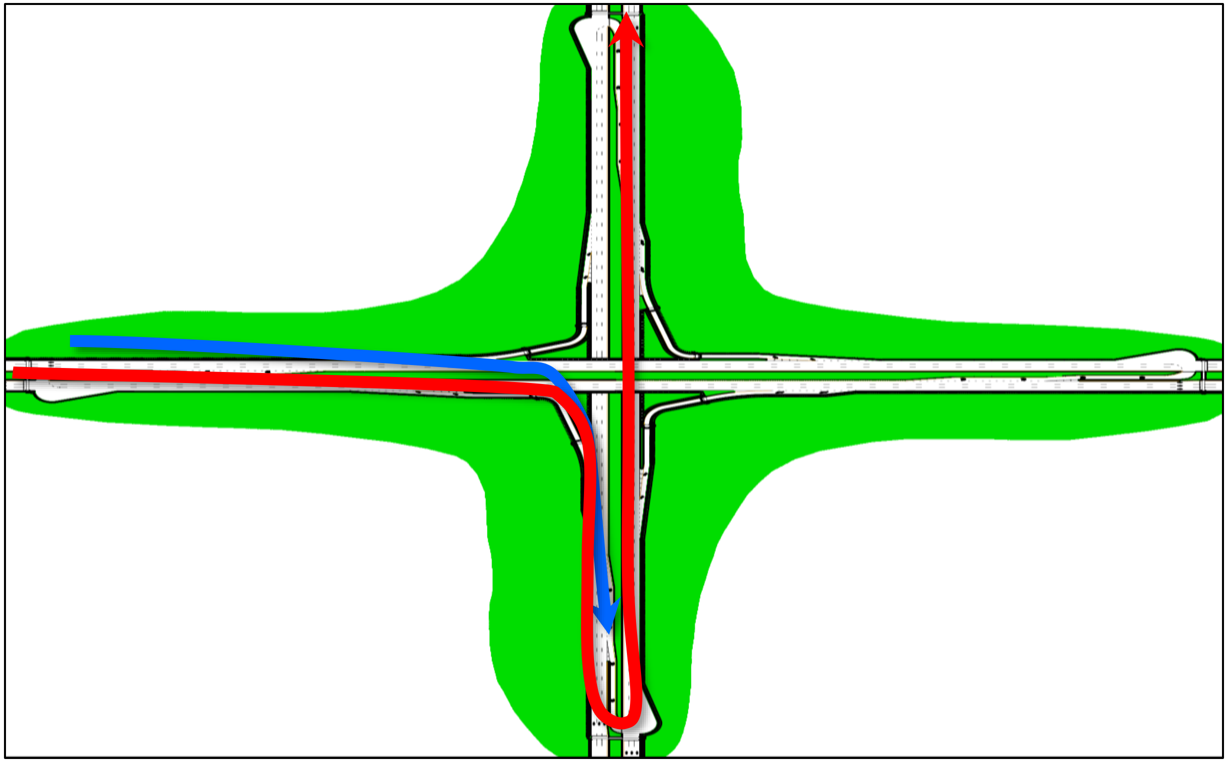
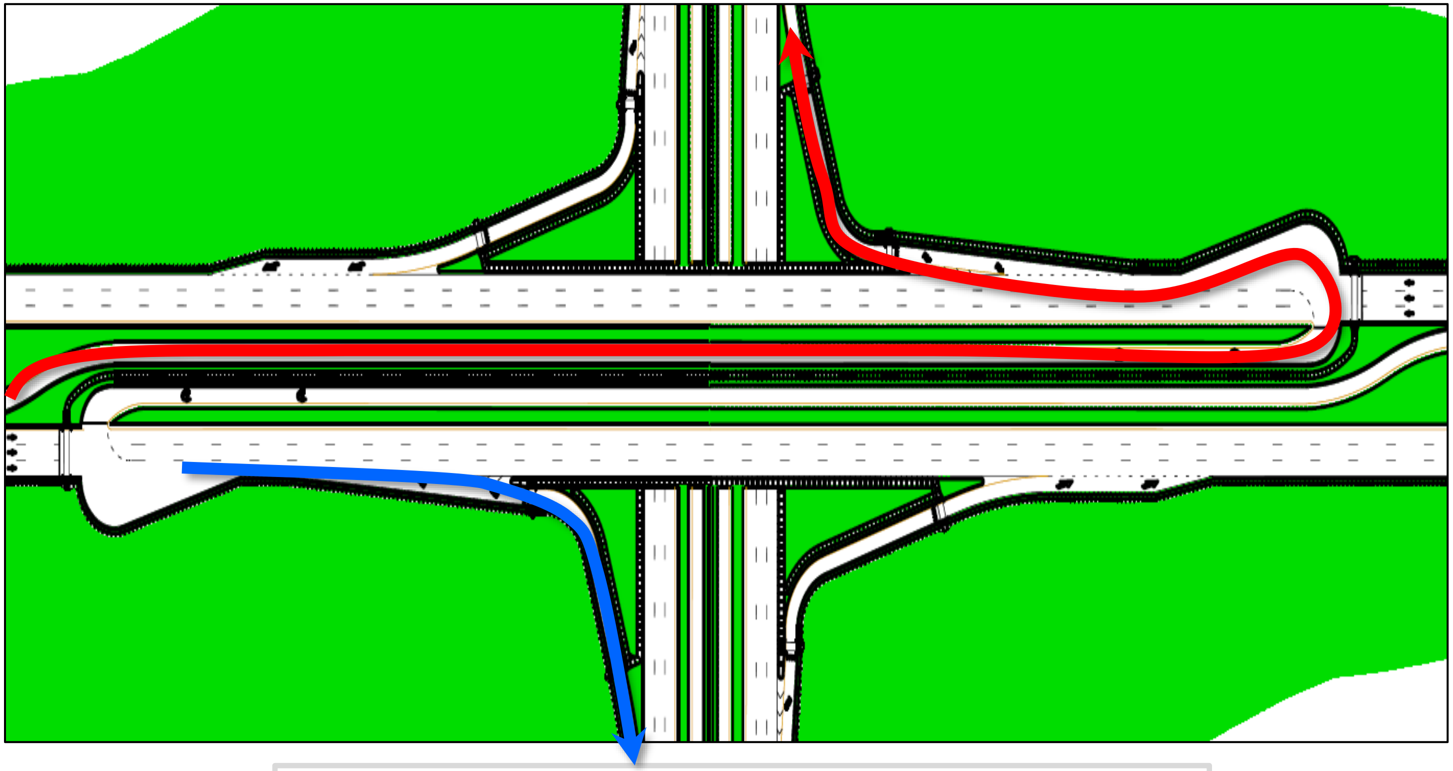


The left turn is

- separated downstream of the signal on the major road and then detoured to the minor road
- conflicting with opposing U-turn on the major road and the opposing through at U-turn point on the minor road

Note: For illustration purposes, major & minor roads designs are same; however, they could be any combination of designs for the major and minor.

RCI: Contra-RCUT



The left turn is

- separated upstream of the signal on the major road
- conflicting with opposing through at U-turn point on the major road

Note: For illustration purposes, major & minor roads designs are same; however, they could be any combination of designs for the major and minor.

Combined Movements: Single Point Left

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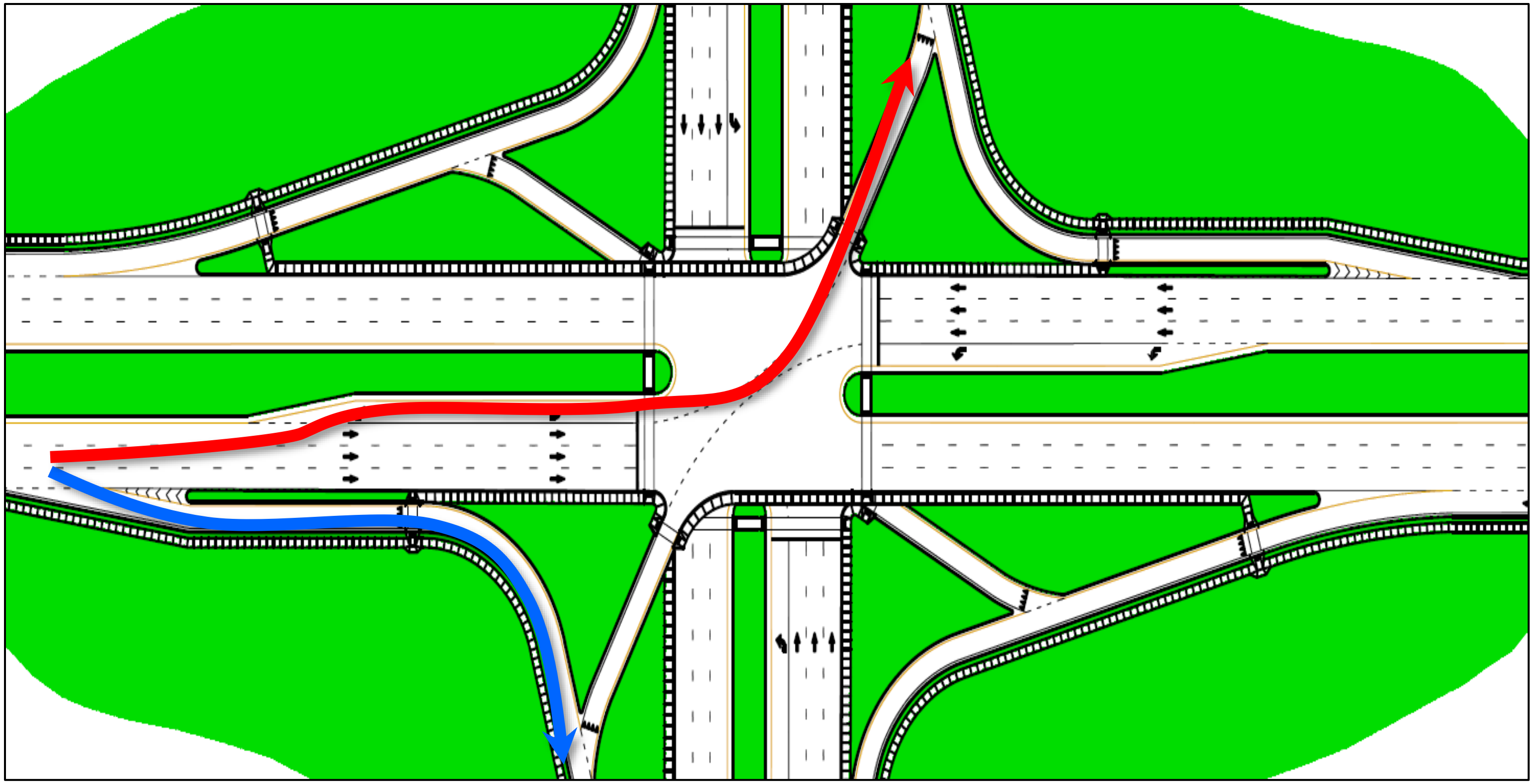
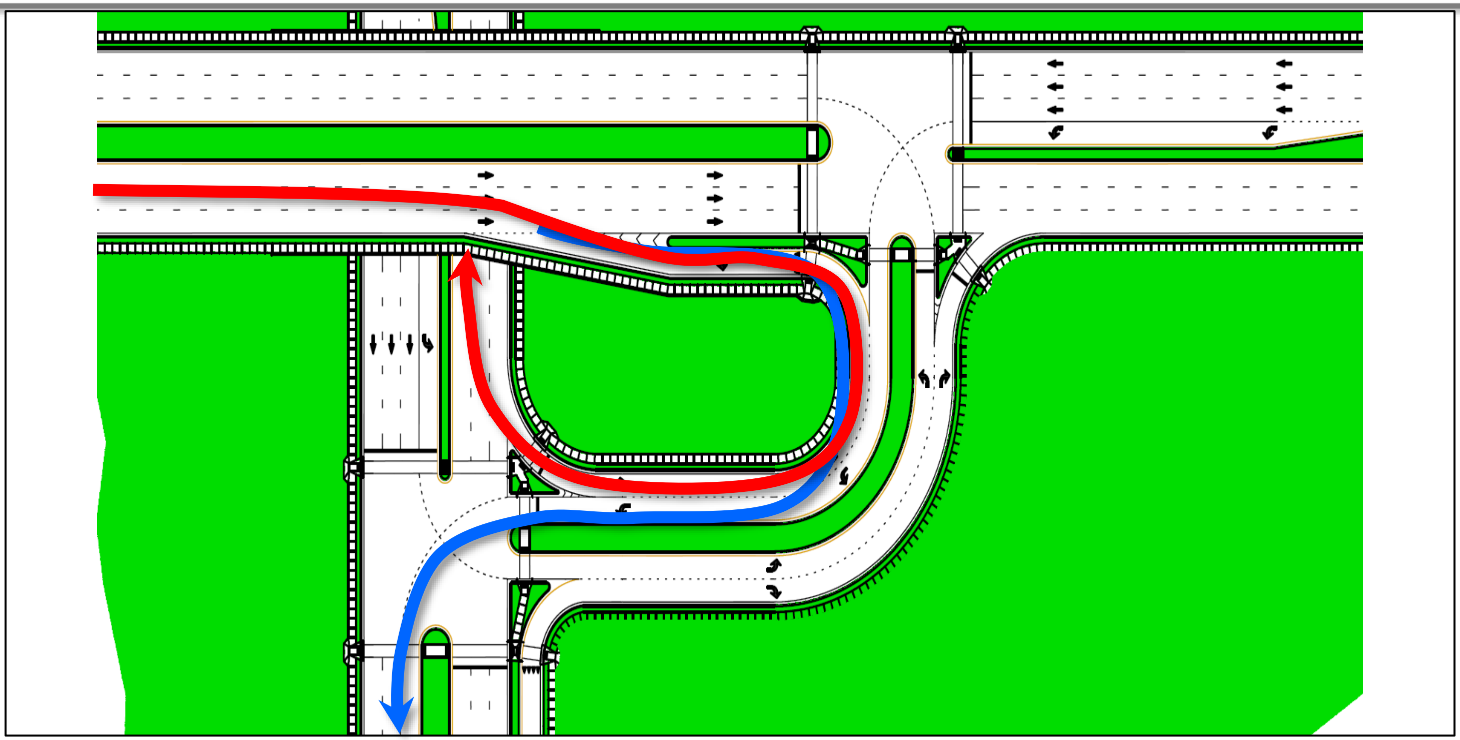


The left turn is

- separated at the signal on the major road
- conflicting with the opposing through on the major road

Note: For illustration purposes, major & minor roads designs are same; however, they could be any combination of designs for the major and minor.

Combined Movements: Quadrant (SE shown)



The left turn is
- separated upstream of the signal on the major road and then move to the right turn ramp
- not conflicting with any movement

* There are three signal phases on major & minor roads

Note: For illustration purposes, major & minor roads designs are same; however, they could be any combination of designs for the major and minor.

Operational Analysis - Summary

- Critical Movement Analysis can help select a subset of feasible GSI designs and lane configurations
- ITRE modified CAP-X is a starting point for analysis of newer GSI
- During Microscopic modeling, be sure to analyze the GSI “network” rather than isolated sections
- Develop detailed signalization options for simulation
- Turning movement patterns heavily impact GSI design selection, consider each peak and off-peak
- Overall, a project-based alternatives analysis is recommended for these cases in applications.

Safety Analysis - Summary

- For new intersection designs, CMFs are not yet available
- Current practice is to measure number of conflict points, VJuST uses weighting factors
- Proposed Movement-Based Safety Performance Functions enable safety screening with planning-level data
- MB-SPF need daily turning movement data
- Definition of conflict point order based on geometry
- MB-SPF has preliminary validation underway but many planned improvements
- MB-SPF method can be applied to existing designs as well for planning-level comparison

Patent Landscape

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Process

- Patent search performed by UNC's Innovate Carolina
- Keyword search: Iterative search based on provided list

Findings

- Search found both international and US patents
- Previous Center Turn Overpass patent is expired- No expected issues
- Echelon and single point over single point have active US patents

Disclaimer

- A landscape is only a search, not legal opinion

Other Design Considerations

Pedestrian and Bicycle Accommodations

- Lower speeds expected on GSI compared to interchanged designs
- Protected turns possible at all studied designs
- Crosswalk Pathing Impacts:
  - Direct Left Downstream: Diamond style needs additional signals for direct crossing
  - Direct Left Upstream: Contraflow vs Crossover median sidewalks
  - RCUT and Quadrant Designs: Long crossing distances for non-through crossings

Other Design Considerations

Frontage and Driveway Impacts

- Tight Quadrants retain access on up to 6 frontages, All others up to 4

Constructability

- All GSI have major impacts to maintenance of traffic during elevation

- Contraflow and Contra RCUT need concurrent (E/W or N/S) intersection control changes

- Quadrant only needs two intersections and can be used as interim control

Other Design Considerations

Queue Storage

- Storage constraints follow at-grade limitations
- Consider paired movements and ramp queues for spillback

Convertibility to Interchange

- Studied designs utilize standard structures with some modification for contraflow or crossover designs
- Conversion to interchange-style requires new structures for Center Turn Overpass and Echelon

Other Design Considerations

Longitudinal Impact

- Direct left downstream allows very tight intersection and ramps
- Quadrant affects only two of four approaches
- U-turns accommodating right turn to u-turn need additional offset from ramp

Bridge Width Impact

- Single point and crossover designs require additional width to separate opposing movements
- Depending on the location of the quadrant intersections, left turn bay may extend onto bridge

Mini-Roundabout Crash Modification Factors (CMF) Development

Srinivas S. Pulugurtha, The University of North Carolina at Charlotte
Jim Dunlop, North Carolina Department of Transportation

Tuesday, March 8, 2022

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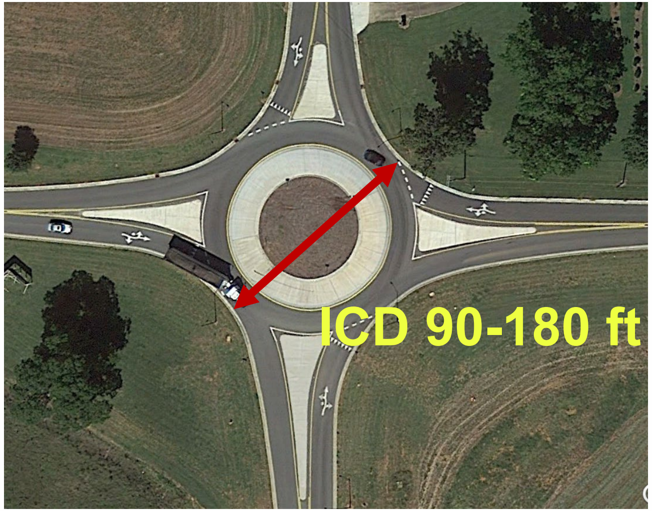
Outline

- Introduction
- Research question
- Methodology
  - Mini-roundabout identification and selection
  - Data collection and processing
  - Before-after analysis - naïve and Empirical Bayes (EB) methods
- Results
- Conclusions

Introduction



Single-lane roundabout
Inscribed circle diameter (ICD) 90-180 ft
Typical daily service volume 20,000 VPD
Source: AASHTO, 2018 (Green book)

Mini-roundabout
Inscribed circle diameter (ICD) 45-90 ft
Typical daily service volume 15,000 VPD
Source: AASHTO, 2018 (Green book)

Introduction (Cont.)

Single-lane roundabout

Mini-roundabout

Large trucks and buses can use the traversable central island to maneuver around the mini-roundabout

Source: NCDOT (2019) Roundabouts
https://www.youtube.com/watch?v=eZyccYCsyZM

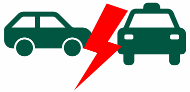
Source: Michael Alexandar (2013); Tollgate & MacPhail Mini-Roundabout, Bel Air, MD
https://www.youtube.com/watch?v=3KLbr1awEbk

Mini-Roundabout

- Featured design to -
  - Reduce traffic speeds
  - Reduce delay
  - Reduce emissions
  - Lower right-of-way impacts
  - Enhance safety
- Common in the United Kingdom and many European countries

Mini-roundabout at Hickory Ridge Rd, Harrisburg, NC

Mini-Roundabout (Cont.)

- Installed in several states
- Three locations in North Carolina on non-neighborhood roads
- More locations with mini-roundabouts are envisioned in North Carolina as the cost of a mini-roundabout is 1/3rd to half of a full-sized roundabout and has fewer right-of-way impacts
- FHWA recommends mini-roundabouts at speed limit ≤35 mph but …
- Lack of documented evidence pertaining to safety benefits associated with mini-roundabouts at approaches with speed limit ≥35 mph
- **Safety benefits?** 

Is it safe and cost effective to convert a stop-controlled intersection to a mini-roundabout?

Before

TWSC

After

Mini-roundabout

Before

AWSC

After

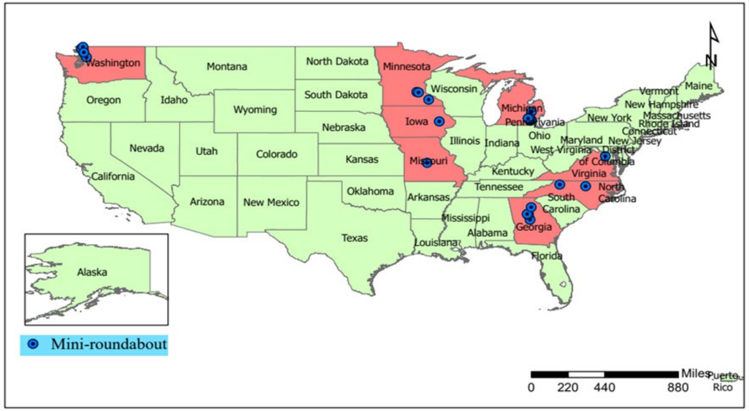
Mini-roundabout

Project/Study Objectives

- Identify mini-roundabout installations in the United States
- Collect before and after crash data at the mini-roundabout installations
- Quantify safety benefits of mini-roundabout installations by developing **crash modification factors (CMFs)**
- Examine the effect of traffic characteristics, geometric characteristics, and on-network and off-network characteristics on mini-roundabout safety effectiveness and after period crashes

Identification and Selection of Mini-Roundabouts

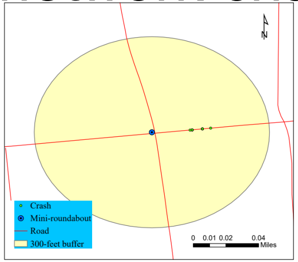
- Identified over 70 mini-roundabouts in the United States
- Selected 25 mini-roundabouts with speed limit ≥35mph, fully traversable, crash and traffic volume data availability, at least one year after period
- Eight states: Georgia, Iowa, Michigan, Minnesota, Missouri, North Carolina, Virginia, & Washington State



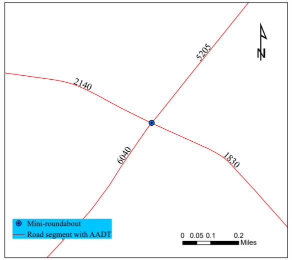
Selected mini-roundabouts

Data Collection – Mini-Roundabouts & Reference Intersections

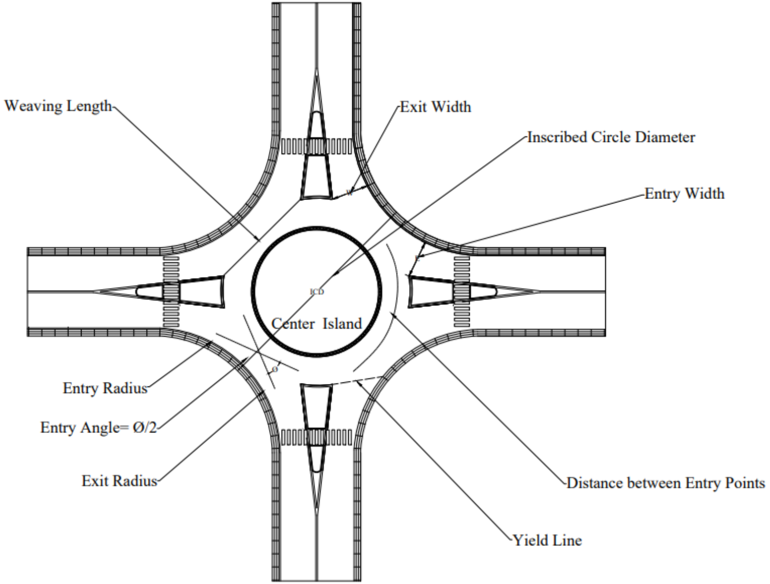
- Crash data (before-after)
- Traffic volume (before-after)
- Inventory data including geometric, on-network and off-network characteristics



Extracting crash data



Extracting traffic volume



Capturing geometric details

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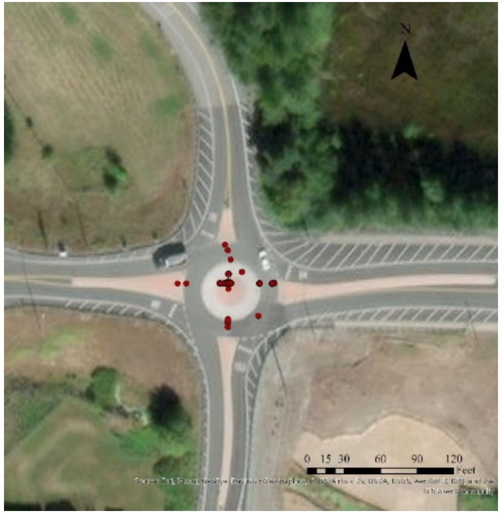
Data Processing

- Each contacted state has its own crash database management software and formats
- Processed using database management software such as Microsoft Access, Tableau, and ArcGIS Pro
- Captured traffic volume data at major streets and cross-streets
- Collected and also processed reference intersection data (649 intersections) based on control type



Extracting crash data

Analysis

- Methods
  - Naïve before-after
  - Empirical Bayes (EB) before-after
- 15 two-way stop-controlled/one-way stop-controlled intersections (TWSC/OWSC) converted to mini-roundabouts
- 10 all-way stop-controlled (AWSC) intersections converted to mini-roundabouts
- Crashes for the year 2020 were not considered (during the pandemic)

Analysis (Cont.)

- Safety performance functions (SPFs) from the Highway Safety Manual (HSM) were used for TWSC/OWSC intersections
- Calibration factors were computed for SPFs available in the HSM
- Developed jurisdiction-specific SPFs for AWSC and OWSC (ramp) intersections
- Analyzed total crashes, FI crashes, and PDO crashes

Results

Before control type	Built year	Crash severity	Before period: # of years	Before period: Crashes per year	Before period: Crash rate for 10,000 AADT	After period: # of years	After period: Crashes per year	After period: Crash rate for 10,000 AADT	After crashes / Before crashes	After crash rate / Before crash rate	Odds ratio (EB method)
TWSC	2016	Total	5	7.2	4.15	3	4.67	2.94	0.65	0.71	0.66
		FI	5	1.8	1.04	3	0.00	0.00	0.00	0.00	0.00
		PDO	5	5.4	3.11	3	4.67	2.94	0.86	0.95	1.04

Before

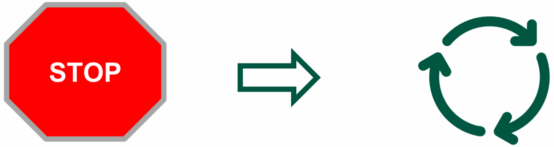
After

TWSC before and mini-roundabout after at Carver St & Broad St, Durham, NC (© Google Street View)

Results (Cont.)

Crash severity type	Naïve: Odds ratio based on crashes/year (standard error)	Naïve: Odds ratio based on crash rate (crashes per year/traffic volume) (standard error)	EB: Odds ratio (standard error)
15 TWSC/OWSC converted to mini-roundabouts			
Total	0.99 (0.10)	0.85 (0.09)	0.83 (0.08)
FI	0.53 (0.12)	0.44 (0.10)	0.41 (0.09)
PDO	1.15 (0.13)	0.99 (0.12)	1.09 (0.12)

TWSC/OWSC intersection



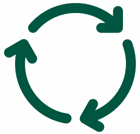
Mini-roundabout

Results (Cont.)

Crash severity type	Naïve		EB
	Odds ratio based on crashes/year (standard error)	Odds ratio based on crash rate (crashes per year/traffic volume) (standard error)	Odds ratio (standard error)
10 AWSC converted to mini-roundabouts			
Total	3.51 (0.34)	3.04 (0.34)	3.25 (0.27)
FI	1.96 (0.39)	1.67 (0.35)	1.74 (0.26)
PDO	4.06 (0.44)	3.53 (0.43)	3.83 (0.31)

AWSC intersection

⇨



Mini-roundabout

Results (Cont.)

of intersections where the treatment is effective and not effective using naïve and EB methods

Prior control type	Crash severity type	Naïve				EB	
		Crashes per year		Crash rate (crashes per year/traffic volume)			
		# of intersections where treatment is effective	# of intersections where treatment is not effective	# of intersections where treatment is effective	# of intersections where treatment is not effective	# of intersections where treatment is effective	# of intersections where treatment is not effective
TWSC /OWSC	Total	7	7	8	6	8	7
	FI	10	4	11	3	12	3
	PDO	3	10	6	7	6	9
AWSC	Total	0	10	0	10	1	9
	FI	1	8	1	8	1	9
	PDO	0	10	1	9	1	9

Results (Cont.)

Recommended CMFs for mini-roundabout

Crash severity type	CMF	Standard error	Confidence interval	Lower limit	Upper limit	Statistical significance
TWSC/OWSC intersection						
Total	*0.83*	0.08	± 1.96	0.67	0.98	Significant at α=0.05
FI	*0.41*	0.09	± 1.96	0.23	0.59	Significant at α=0.05
PDO	1.09	0.12	± 1.96	0.86	1.32	Not significant
AWSC intersection						
Total	*3.25*	0.27	± 1.96	2.72	3.78	Significant at α=0.05
FI	*1.74*	0.26	± 1.96	1.23	2.25	Significant at α=0.05
PDO	*3.83*	0.31	± 1.96	3.22	4.44	Significant at α=0.05

Results (Cont.)

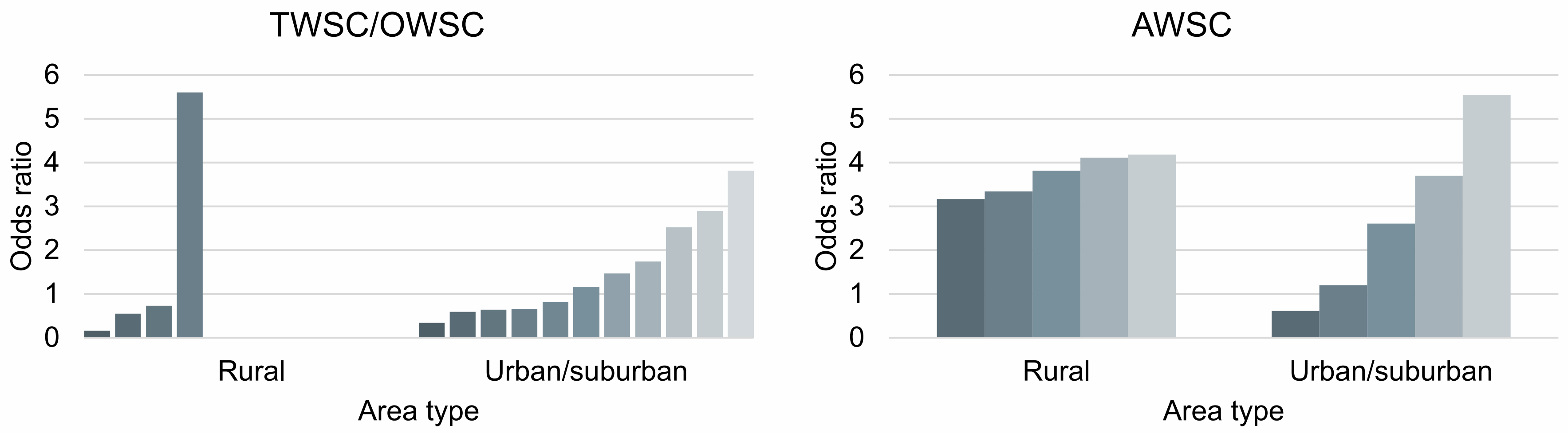
Correlation analysis summary

Variable	Odds ratio - TWSC/OWSC intersection converted to mini-roundabout			Odds ratio – AWSC intersection converted to mini-roundabout			Crashes per year (after period) -all mini-roundabouts		
	T	FI	PDO	T	FI	PDO	T	FI	PDO
Total crashes per year (before period)	N						P		
FI crashes per year (after period)		P							
PDO crashes per year (before period)			N						P
Cross-street AADT (before period)							P		P
Cross-street share (before period)									P
Cross-street AADT (after period)							P		P
Speed limit major street							P	P	P
Speed limit cross -street							P	P	P
Entry width (maximum)						N			
Entry width (minimum)				N		N			
Entry width (average)						N			
Weaving length (minimum)							N	N	N
Entry angle (maximum)							P	P	P
Entry angle (minimum)							N	N	N

Note1 : T, FI, and PDO are total, fatal & injury, and property damage only crashes
Note 2: P/N indicates statistically significant positive/negative Pearson correlation (r) at a 90% confidence level; blank cell indicates no statistically significant correlation (r); maximum, minimum and average is the maximum, minimum and average values considering all approaches

Results (Cont.)

Odds ratio vs. area type



Scatter plot between odds ratio and area type of stop-controlled intersections converted to mini-roundabouts

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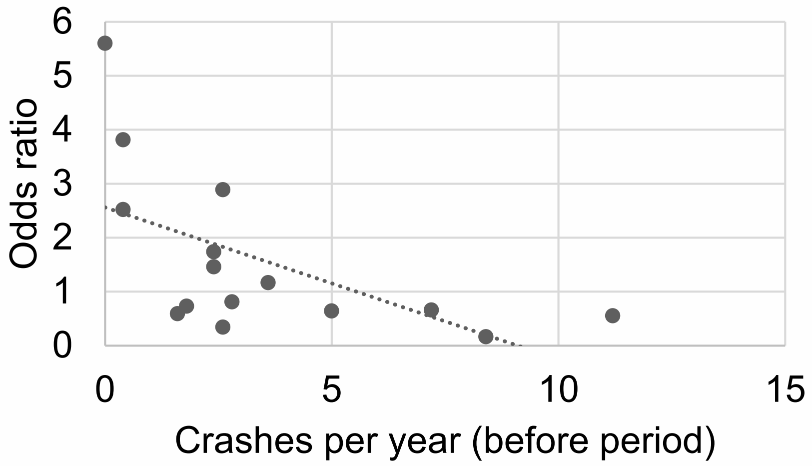
Results (Cont.)

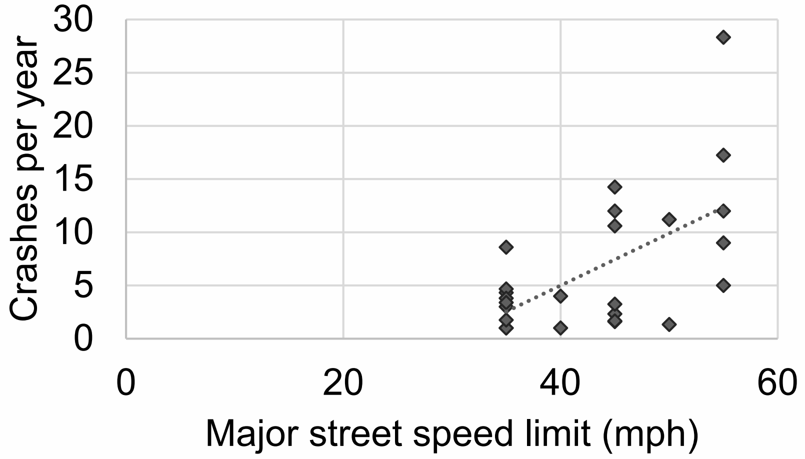
Odds ratio vs. crashes per year (before period)

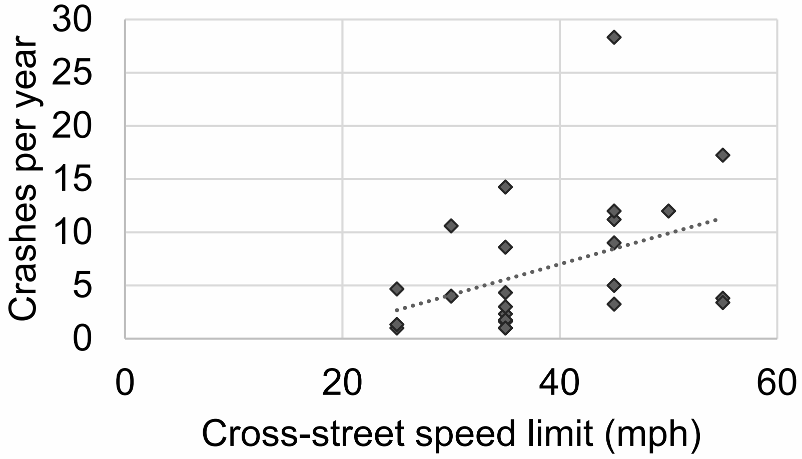


Scatter plot between odds ratio and crashes (before period) for TWSC/OWSC intersections converted to mini-roundabouts

Results (Cont.)

Crashes per year vs. speed limit

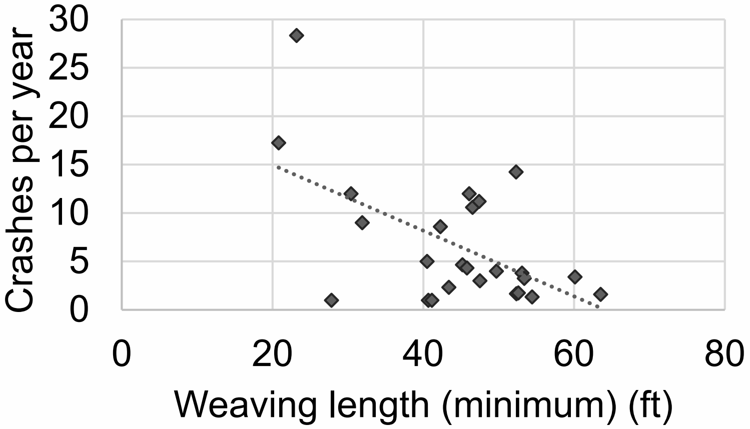


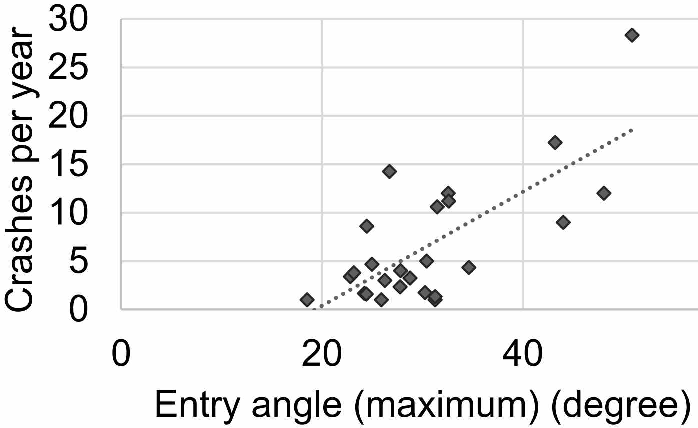


Scatter plots between the number of crashes in the after period and speed limits of major street and cross-street

Results (Cont.)

Crashes per year vs. mini-roundabout geometric feature





Scatter plots between the number of crashes in the after period and weaving length (minimum of all approaches) and entry angle (maximum of all approaches)

Conclusions

- Mini-roundabouts installed at intersections with speed limit ≥35 mph
- Crash, traffic volume, and geometry data was collected for 25 mini-roundabouts to conduct before-after analysis
  - Eight states (Georgia, Iowa, Michigan, Minnesota, Missouri, North Carolina, Virginia, and Washington)
- Before period crash data for five years and after period crash data for one to five years was analyzed (depending on the construction year and crash data availability)

Conclusions (Cont.)

- TWSC/OWSC intersections converted to mini-roundabouts
  - Reduction in the total number of crashes
  - Reduction in the number of FI crashes
  - Increase in the number of PDO crashes
- AWSC intersections converted to mini-roundabouts
  - Increase in the number of total crashes, FI crashes, and PDO crashes

Conclusions (Cont.)

- Crashes in the before period, cross-street traffic volume, speed limit at major street and cross-street, and intersection skewness have a statistically significant influence on after period number of crashes
- Recommended CMFs for converting a TWSC/OWSC intersection to a mini-roundabout are **0.83** for **total crashes**, **0.41** for **FI**, and **1.09** for **PDO** crashes
- Recommended CMFs for converting an AWSC intersection to a mini-roundabout are **3.25** for **total crashes**, **1.74** for **FI**, and **3.83** for **PDO** crashes

Limitations and Scope for Future Work

- Number of intersections converted from TWSC/OWSC and AWSC to mini-roundabouts are relatively limited
- CMFs of signalized intersections converted to mini-roundabouts are unknown (not many samples)
- Safety effectiveness of AWSC intersections, with high crash history, converted to mini-roundabouts should be further studied in the future

Limitations and Scope for Future Work (Cont.)

- Before-after analysis by crash type e.g., angle crashes, rear-end crashes, etc. when converted to mini-roundabouts would provide insights for large-scale implementation
- Analysis using larger sample size and comparing CMFs with mini-roundabouts installed at intersections with speed limit <35 mph by area type merits further investigation

Link to the Final Report

- https://connect.ncdot.gov/projects/research/RNAProjDocs/RP2020-32_Final%20Report.pdf