RESEARCH & DEVELOPMENT

Groundwork for the Second Edition of the Alternative Intersection and Interchange Informational Report

Institute for Transportation Research and Education (ITRE)
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16. Abstract

The Alternative Intersection and Interchange Informational Report (AIIR) First Edition was published in 2010 by the Federal Highway Administration. It was the first national, public-sector, comprehensive guidebook on the alternative designs which were starting to be built in many states and some other countries. The AIIR contained operational data from simulation experiments and suggested methodologies for planners and engineers to evaluate alternative designs during project processes.

Although it is now considered out of date by many agencies, the AIIR First Edition has been employed by various agencies as a valuable resource for planning and designing AIIs. In North Carolina, the NCDOT has given freedom to transportation professionals to explore new alternatives to conventional roadway designs, and many more AII designs have emerged since 2010. These new AII designs may involve different traffic patterns, which may introduce confusion and create safety hazards for drivers. In addition, it is anticipated that with more AIIs being installed in the central business areas in the near future, there is a need of incorporating methodologies to assess the pedestrian and bicycle quality of service and safety performance at AII designs.

The primary objective of this research is to initiate the process of compiling the AIIR Second Edition that covers a wider range of alternative intersection and interchange (AII) designs, including three facility categories: at-grade intersection, grade-separated intersections, and service interchanges. This report crafted an annotated outline for the forthcoming AIIR second edition based on a state-of-the-practice literature review and expert interviews on AII designs. Specifically, for each AII design, this report presented high-level descriptive information in a standardized format, including salient geometric design features, operational and safety issues, access management, costs, construction sequencing, environmental benefits, and applicability. Finally, this report features a collection of case studies that illustrate the utilization of diverse AII designs in the context of mobility enhancement or safety improvement projects across different land-use scenarios.

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Alternative at-grade intersections, Alternative grade-separated intersections, Alternative service interchanges, Rotary, Left-over, U-turn, Assessment	

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Second Edition of the Alternative Intersection and Interchange Information Report - Annotated Outline

Executive Summary

This document will contain 5 Chapters, covering: 1) general concepts and operational features; 2) three AII categories covering specific details of each AII design; 3) and real-world case studies.

- Chapter 1: Introduction
  - High-level overview of AIIs, including those with separate guidebook, to help see the overall picture of AIIs and how to consider them through direct (high level) comparison.
  - Expert discussions
  - Description of the structure of the document

- Chapters 2- 4: Detailed AII design, planning, operation, and construction considerations for AIIs that do not currently have separate guidebooks.
  - At-grade intersections
  - Grade-separated Intersections
  - Interchanges

- Chapter 5: Case Studies
  - Urban CBD One-Way Couplet Town Center Intersections
  - Urban Quadrant Roadway Intersections
  - Suburban Median U-Turn Intersections
  - Suburban Grade-Separated Intersections
  - Rural Restricted Crossing U-Turn Intersections
  - Suburban Alternative Corridor

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Chapter 1 – Introduction

Scope of the Guide

- Description of the intent of the publication
  - This guide is intended as a basic reference for the consideration of intersection and interchange design alternatives.
  - The guide includes a framework for planning level considerations related to design selection and should supplement rather than replace any established local or state intersection and interchange design selection processes.
- Who are the audiences and what challenges do they have?
  - Agencies who have designed very few AIIs
  - Agencies who do not have a good grasp on the full plethora of options for AII design.
  - The general public and business owners who must be educated on the trade-offs of these designs compared to traditional designs that are more likely to be accepted with no other information.
- How to use the guide
  - Understanding the basic concept of alternative *intersections* vs. grade separated intersections vs. alternative *interchanges*.
  - Understanding the “family” of treatments (standard, rotary, and diverted) that can be considered for each AII type and how they can be used during the planning process to reduce conflicts and/or increase efficiency.
  - Understanding how to choose appropriate designs based on the constraints imposed at the site (such as right-of-way, utilities, nearby intersections, etc.)
  - Have a more complete understanding of the trade-offs when considering AII vs. standard designs.
  - Understand how to compare and contrast the designs to find the most suitable for meeting the objectives of a project.
  - Better communicate these trade-offs with the public using various performance metrics, visuals, etc.
  - Provide simple case studies using the alternative intersection assessment methodology.
  - Other extreme could be a dedicated website providing website such as that done by VDOT.

Organization of the Guide

- Description of overall layout and components of guide

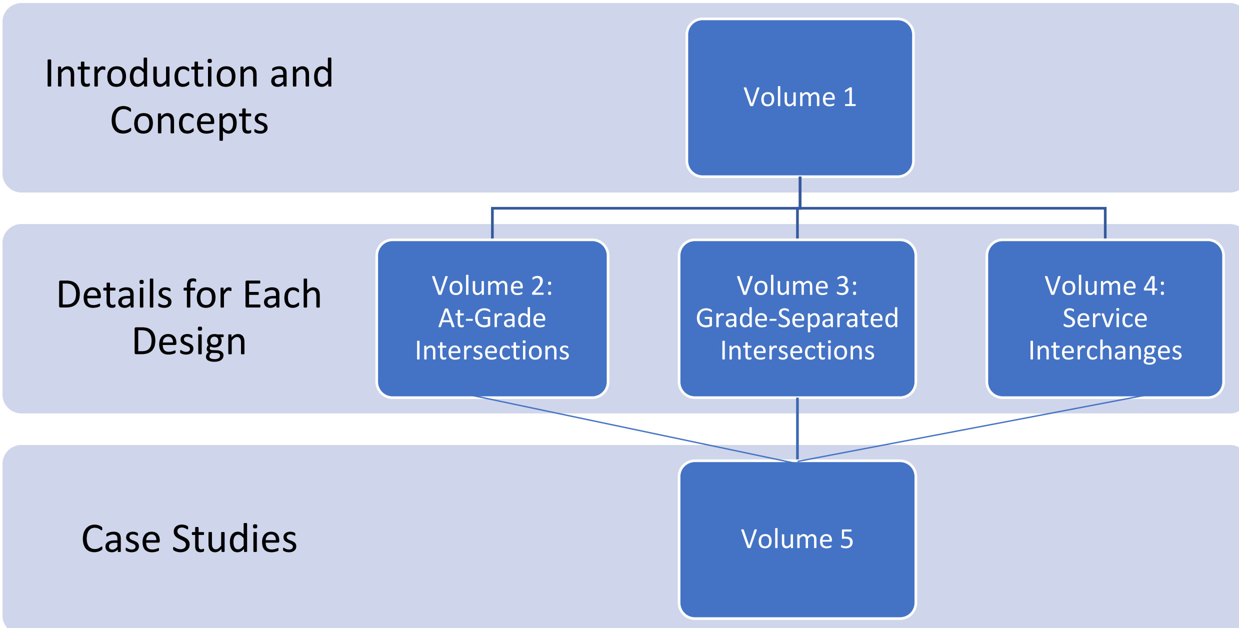

Figure 1-1 Overall layout of the guide

1.1. Overview of Alternative Intersections and Interchanges

- The goal of this section is to provide the user with a better understanding of the differences in the three categories of AII design – especially grade separated intersections which are often confused with service "interchanges" because they have grade separation.
- Consistent format provided to explain when one alternative is more appropriate than another to consider (i.e. heavier volumes at an existing intersection with limited right-of-way or nearby intersections may make it more appropriate to consider a grade separated intersection).

1.1.1. AII Design Discussion

- In Chapter 1, we will compare and contrast conventional designs against all known AII designs.
- Three different types of AIIs
- Differentiation b/w the types
- Chapters 2-4 will only focus on AII design that do not currently have standalone guidebooks

<u>At Grade Intersections</u>

- Definition and Description: two surface streets (arterial or secondary) crossing at grade
- Pros and Cons
  - Improved operational and/or safety performance
  - Potential out-of-direct travel, rerouting downstream can have lower public acceptance

- Applicability
  - Right-of-way requirements
  - Traffic demand and turning volumes

<u>Grade-Separated Intersections</u>

- Definition and Description: two surface streets (arterial or secondary) crossing with grade separation, includes control on both streets
- Pros and Cons
  - Improved operational and/or safety performance
  - Potential out-of-direct travel
  - High construction costs
- Applicability
  - Right-of-way requirements
  - Traffic demand and turning volumes

<u>Service Interchanges</u>

- Definition and Description: uninterrupted facility (freeway/highway) crossing a surface street (arterial or secondary) with grade separation
- Pros and Cons
  - Improved operational and/or safety performance
  - Potential out-of-direct travel
  - High construction costs
- Applicability
  - Right-of-way requirements
  - Traffic demand and turning volumes

1.1.2. Comparison Table

- Summary tables in this section are used to introduce the three design types and the "family" categories. The goal is to:
  - 1) provide a means for understanding/considering the options of the AII design
  - 2) compare common performance metrics used in the decision-making process at the "planning level".
- This is the first "high level" introduction to ALL possible intersection and interchange design options.
  - Chapter 1 will include ALL AII designs for overall planning purposes; however, chapters 2-4 will not cover standard designs OR any AII that has a standalone guidebook already in place.
  - Current standalone guidebooks include:
    - Alternative Intersections: CFI/DLT, RCUT, MUT, Quadrant
    - Grade Separated Intersections: None
    - Service interchange: DDI
- 37 total possible designs (standard and AII) in three categories. Note: There are actually many more possible designs when mixing and matching takes place (for instance, a grade separated intersection could have two different AI types on the N/S and E/W directions).
  - 17 at-grade intersection
  - 10 grade-separated intersection
  - 10 service interchange designs

- **Error! Reference source not found.**
    - Details for each
  - Summarizes movements that are redirected for each design to improve safety and efficiency
  - Provides the number of critical phases that is typical for that design
  - Provides the coordinability of a particular AII with other nearby intersections
    - The criteria for progression are provided below for reference to the panel

Table 1-1 Comparison of Redirected Movements, Critical Phases, and Coordinability for Various Intersection and Service Interchange Designs

Type	Family		Design Type	Mainline		Side Street		# Crit. Phases*
				Left	thru	left	thru	
At-grade Intersections	Standard		AWSC					
			TWSC					
			Signalized 3 Approach "T"					3
			Signalized 4 Approach					4
			Offset T				X	3
			Continuous Green T					3
			Split Intersection/One Way Couplet					2
	Rotary		Roundabout					
			Hamburger	X		X	X	2
	Diverted	Loop	Jughandle	X				2
			Quadrant	X		X		2
		Upstream	CFI (Partial)	X				3
			CFI (Full)	X		X		2
			PFI (Partial)	X				3
			PFI (Full)	X		X		2
			Synchronized Split-phasing	X	X	X	X	3
		U-Turn	MUT (Partial)	X				2
			Thru-Cut				X	3
			MUT (Full)	X		X		2
			Bowtie / Teardrop	X		X		2
			RCUT			X	X	2
			Rev. RCUT	X			X	2
Grade-Separated Intersections	Standard / Direct Left Turn		Center Turn Overpass					2
			Echelon					2
			Single Point					2
			Direct LT Downstream (Diamond)					2
	Diverted	Loop	Quadrant	X		X		3
		Upstream	Contraflow					2
			CFI	X		X		2
		U-Turn	RCUT U-turn then Right	X		X		2
			RCUT Right then U-turn	X		X		2
			Contra-RCUT	X		X		2
Interchanges	Standard		Diamond					3
			Tight Urban Diamond					3
			SPUI					3
	Rotary		Double Roundabout	X		X		

			Single Roundabout	X	X	X		
	Diverted	**Loop**	Parclo	X				2
		Left-over	DDI	X	X			3
			CFI	X				2
		U-Turn	MUT	X		X		2

Note: X = Rerouted movement
*Additional details available in chapters 2-4 overviews

1.2. Planning, Design and Implementation Considerations

1.2.1. Performance-Based Design

- Definition and Description
  - "Performance-based design" tries to achieve a balance of safety for all users with efficient traffic flow within the context of project costs, availability of right-of-way, and effects on roadside development.
- Performance considerations
  - Existing and expected future traffic operational efficiency
  - Existing and expected future crash frequency and severity
  - Quality of service for pedestrians, bicycles, transit buses and trucks
  - Accessibility for persons with disabilities
  - Community impacts and quality of life
  - Providing access to existing properties and accommodating potential future development
  - Operational flexibility during emergencies, incidents, and maintenance activities
  - Project location, and right-of-way, etc.

1.2.2. Process/Lifecycle

- Identify Potential Alternatives
  - High-level summary table[1]
  - Details of each alternative design will be discussed in Chapters 2-4
- Preliminary and Final Alternative Selection
- Design
- Construction
- Maintenance

1.2.3. Naming of AII Designs

- Naming Conventions in Practice (for engineers and planners)
  - i.e. "How we distinguish b/w the types as transportation professionals
  - AII Terminology
    - "Alternative" is anything in lieu of a standard 4-critical phase intersection
    - May keep guidebook name the same, because they are used in practice, but provide new naming conventions for use with public
  - Take family approach to similar designs (see Table in 1.1.2)

[1] *Hummer, J. Developing, Using, and Improving Tables Showing the Safest Feasible Intersection Design. ITE Journal, 2020*

- Naming Conventions in Public Use
  - Public engagement is very important and can help them sell the designs
    - "Revitalization" is an important word to communicate, especially in urban areas.
    - Public acceptance is key. Political support too
    - not much literature, but some anecdotal information possible
  - Maybe a section on public facing information and what to consider
    - Expert Interview: *Another label to consider not using is "conventional intersection" which can be used against us just like "alternative" or "unconventional". The term "all-movement" is better than conventional IMHO.*
  - Evaluation of Names and Why (*Expert Interview*)
    - "Superstreet" might be misleading public as super highway…
    - RCI is not a synonym for RCUT. NCDOT label the RCUT geometry as "the most common RCI design".
    - "RCI" has a positive nomenclature
    - We can't use CFI term anymore....because it isn't actually continuous
      - "The way I describe CFI is that the displaced lefts can be coordinated to continuously flow in the same phase as the adjacent throughs and rights."
    - We could point out that the names are for technical differences and not necessarily to be used for the general public

1.3. General Design Considerations

1.3.1. Geometric Design Considerations

- Design elements: # Lanes, shoulder, median widths, right-of-way availability
- Design vehicle
- Queue storage length
- Distance traveled
- Speed management an overall consideration in design

1.3.2. Access Management Considerations

- Driveway and land-use impacts should be included.
  - New vs. existing design
  - Urban vs. rural vs. suburban
- How many turns a driver must make as the driver out of the driveway to go through the intersection?
- Safety a big consideration/justification for median designs (volumes, lanes, driveways. etc.)

1.3.3. Accommodation of Pedestrians, Bicyclists, and Transit Users

- Pedestrian crossings and sidewalks
  - Pedestrian expectation? Short and long term.
  - Pedestrian "types" (i.e. in an urban area you may expect more visually impaired or disabled peds.
  - One-stage or Multiple-stages crossing at the main intersection
  - Use of midblock crossings at secondary intersections
- Bicycle lanes

  - AADT (see NACTO guide[2])
  - One-way vs. Two-way bicycle lane[3]
  - Left side vs. Right side
  - Buffered vs. Shared
- Pedestrian/bicycle signals
  - Coordination of pedestrian/bicycle signals to minimize number of stops
  - Coordination dependent on dominant modality (or weighted in some fashion)
  - Some designs more optimal for coordination for multiple modes (i.e. designs with less critical phases)
- Transit stops/ bays
  - Near side vs. Far side vs. Mid-block
    - Far side stops tend to be safer and more efficient[4]
  - In-lane vs. Pull out

1.3.4. Traffic Signalization Treatments

- Signal warrants (based on MUTCD? Or need updated guidelines since there are re-routed demands)
  - More of a question towards DOTs/FHWA- what is the guidance?
- Primary operational benefit is reducing the number of critical phases (2 or 3 phase)
- Overhead vs. side mounted guidance[5]
  - Mast arm signal has considerably better safety performance than pedestal signal
  - The placement of traffic signal heads on span wires or mast arms will be particularly advantageous for heavy vehicles, giving them additional time to decelerate and come to a full stop
  - Near-side pole placements may be considered where there may be limited sight distance or at a particularly wide intersection with a high number of rear-end or angle collisions
- Progression opportunities
  - Progression opportunity can be expressed as the percent of the links of the arterials to fit (?) without interrupting the bandwidth
  - Reduced cycle length or use of half-cycle
  - Will an AII promote or interrupt signal progression?

1.3.5. Signing and Marking

- Advance warning signs
- Informational signs and pavement markings at intersection approaches
- Number of signs
- Location to display the signs
- Text vs. Graphic
- Overhead vs. Roadside

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[2] NACTO (2014). U*rban Bikeway Design Guide, 2nd ed.* Island Press. Retrieved from https://www.perlego.com/book/2984936/urban-bikeway-design-guide-second-editions-pef (original work published in 2014).
[3] NACTO (2017). Designing for All Ages and Abilities: Contextual Guidance for High-comfort Bicycle Facilities. https://nacto.org/wp-content/uploads/2017/12/NACTO_Designing-for-All-Ages-Abilities.pdf
[4]Furth, P., SanClemente, J. Near Side, Far Side, Uphill, Downhill: Impact of Bus Stop Location on Bus Delay. https://journals.sagepub.com/doi/epdf/10.1177/0361198106197100108
[5] FHWA. Signalized Intersections: Informational Guide. https://www.fhwa.dot.gov/publications/research/safety/04091/11.cfm

- Lighting (location Urban/Sub/Rural?)

1.4. Alternative Intersection Assessment Methodology

1.4.1. Operational Performance

- Performance-Based Practical Design instead of bandwagon
- Operations
  - Performance Measures
    - Travel time, delay, queue length, average speed, etc.
    - FHWA Traffic signal timing manual
- Secondary Considerations
    - LT Phasing (Protected, Permissive, etc.)
    - RT Phasing tradeoffs (good? Bad?)
    - Dual/ Tri- LT lanes at superstreet
- Evaluation Considerations (tools and specific methodology)
    - CAP-X Critical Movement Analysis
    - HCM/deterministic
    - Simulation modeling
- Signal Progression
  - Performance Measures
    - Number of stops
    - Corridor travel time or speed
  - Secondary Considerations
    - LT Phasing (lead-lag, etc.)
    - Overlap phasing (twice per cycle left)
  - Evaluation Considerations
    - Design for Progression (number of stops, spacing, speed, etc.)
    - Simulation modeling

1.4.2. Safety Performance

- Safety System for Intersections
- Conflict Points
  - The number and type of conflict points is one of the simplest methods for estimating the safety performance of an AII design
  - VDOT Junction Screening Tool (VjuST)[6]
  - ITRE conflict diagram for each AII design
- Safety CMFs
  - The CMF Clearinghouse contains a listing of values for a limited number of AII designs[7].
  - Some States have Planning-level guidance that summarize safety recommendations such as NCDOT's SAFID (Safest Feasible Intersection Design)[8]
- Movement Based Safety Performance Functions
  - Should be ready by time guide is written and can consider

[6] *https://www.virginiadot.org/innovativeintersections/#junctionscreening*
7 https://www.cmfclearinghouse.org/
[8] *Hummer, J. Developing, Using, and Improving Tables Showing the Safest Feasible Intersection Design. ITE Journal, 2020*

    - AII designs tend to re-organize traffic flows, so movement-based safety performance analysis, instead of intersection overall performance, tends to be more appropriate (*NCDOT 2022-13*)
- Ped/Bike Safety
    - Flag method for pedestrian and bicyclist safety performance assessment[9]
    - Planning-level guidance POFID and BOFID tables[10] Multimodal Considerations
- Vehicular
    - Heavy vehicle effects
    - Location of transit stops on traffic operations
- Pedestrian and Bicycles
    - NCHRP 07-25 Design Flag Assessment[11] (Table 1-3)
        - The "Design Flag" method is a surrogate for quantitative performance measures that can help identify potential safety, accessibility, operational, or comfort issues for pedestrians and bicycles.
        - Red Flag: warranting attention because specific design elements present direct safety concerns for pedestrians or bicyclists
        - Yellow Flag: which may need attention because design elements negatively affect user comfort (i.e., increasing user stress) or the quality of the walking or cycling experience.

Table 1-2 Design Flags for Pedestrian and Bicyclist Assessment

Flag #	Design Flag	Applicable Mode	Measure of Effectiveness	Yellow-Flag Threshold	Red-Flag Threshold
1	Motor Vehicle Right-Turns	Pedestrian	Vehicle Turning Speed & Vehicle Volume	<=20 mph AND <= 50 veh/h	> 20 mph OR > 50 veh/h
2	Uncomfortable/Tight Walking Environment	Pedestrian	Effective walkway width	< 5 ft if traffic present on one side; <10 ft if traffic present on two sides	N/A
3	Nonintuitive Motor Vehicle Movements	Pedestrian	Vehicle acceleration profile	Vehicle decelerating	Vehicle accelerating or free-flowing
4	Crossing Yield- or Uncontrolled Vehicle Paths	Pedestrian & Bicycle	Vehicle Speed & Vehicle Volume	<=20 mph AND <= 50 veh/h	> 20 mph OR > 50 veh/h
5	Indirect Paths	Pedestrian & Bicycle	Out-of-direction travel distance	90 ft (ped) 450 ft (bike)	135 ft (ped) 675 ft (bike)
6	Executing Unusual Movements	Pedestrian & Bicycle	Local Expectation	The path does not match the expectation	N/A
7	Multilane Crossings	Pedestrian & Bicycle	Number of lanes without refuge	2 – 3 lanes (ped) 4 – 5 lanes (bike)	>3 lanes (ped) >5 lanes (bike)
8	Long Red Times	Pedestrian & Bicycle	Delay	30 seconds	45 seconds

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[9] *NCHRP Report No. 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges*
[10] *Hummer, J. Developing and Using Tables Showing the Pedestrian Optimum and Bicyclist Optimum Feasible Intersection Designs ITE Journal, 2021*
[11] *National Academies of Sciences, Engineering, and Medicine. Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges. Washington, DC: The National Academies Press, 2021. https://doi.org/10.17226/26072*

9	Undefined Crossings at Intersections	Pedestrian & Bicycle	Path Markings	Unmarked crossing	N/A
10	Motor Vehicle Left-Turns	Pedestrian & Bicycle	Vehicle Turning Speed & Vehicle Volume	<=20 mph AND <= 50 veh/h	> 20 mph OR > 50 veh/h
11	Intersection Driveways and Side Streets	Pedestrian & Bicycle	# of Access points in Area of Influence	1-2 (peds) 1-2 (oneway bikes)	>2 (peds) >2 (oneway bikes) >0 (twoway bikes)
12	Sight Distance for Gap Acceptance Movements	Pedestrian & Bicycle	Sight Distance	N/A	Less than required for vehicle speed
13	Grade Change	Pedestrian & Bicycle	% grade	+3% to +5% OR -3% to -5%	<–5% OR >+5%
14	Riding in Mixed Traffic	Bicycle	Vehicle Speed & Vehicle Volume	25-35 mph OR 3,000 – 7,000 vpd	>35 mph OR >7,000 vpd
15	Bicycle Clearance Times	Bicycle	Vehicle Speed and Clearance Zone Length (feet)	<=35 mph and 36–72 ft OR > 35 mph and 24–60 ft	<=35 mph and >=72 ft OR > 35 mph and >=60 ft
16	Lane Change Across Motor Vehicle Travel Lane(s)	Bicycle	Vehicle Speed & Vehicle Volume	25-35 mph OR 3,000 – 7,000 vpd	>35 mph OR >7,000 vpd
17	Channelized Lanes	Bicycle	Vehicle Speed & Channelization Length	25-35 mph AND <= 50 ft	>35 mph OR >50 ft
18	Turning Motorists Crossing Bicycle Path	Bicycle	Motor Vehicle Lane Configuration	Exclusive Turn Lane	Shared Thru & Turn Lane
19	Riding between Travel Lanes, Lane Additions, or Lane Merges	Bicycle	Motor Vehicle Lane Configuration	Motor vehicle lanes remain parallel or diverge	Motor vehicle lanes merge
20	Off-Tracking Trucks in Multilane Curves	Bicycle	Turn Angle	Curve at 60 degrees or less	Curve at greater than 60 degrees

1.4.3. Development Considerations

- Driveway and ped issues at constrained environments (CFIs for instance)
- GSIX vs. interchange in suburban/urban environments. (i.e. frontage)
- Access Management in the Vicinity of Interchanges[12]
- Side street with U-turn
- Quadrant opportunities for more access
- Median project
- Intersections in corridor context (for instance, a one-way pair tied into a RCUT still acts like a one-way pair)

1.5. Construction and Implementation

1.5.1. Right of Way

- U-turn and embankments,
- Ramps for grade-separated intersection, interchanges
    - Right-of-way restrictions in urban area

[12] NCHRP Research Report 977: *Access Management in the Vicinity of Interchanges, Volume 1: Practitioner's Guide*. DOI: 10.17226/26501

Figure 1-2 Illustrations of urban grade-separated intersections

- Requirements for separating directional traffic / physical barriers
- Is the facility an overpass or underpass?
- Are there nearby detour routes?
- Loons vs. wide median for downstream u-turns (i.e., Loons may be more suitable for urban designs)

Figure 1-3 Illustration of Loon U-turn and Median U-turn

1.5.2. Constructability and Sequencing

- Whether the interchange is new construction, whether additional structures are needed, or if the interchange is a true retrofit design using existing structures?
  - Retrofit designs
    - What are the traffic demands of the facility
    - Is additional cross-section width necessary to accommodate future traffic?
      - Can the interchange be closed?
      - Is the existing pavement going to be used or replaced?
      - When are the best times to switch traffic between various stages of the project?
- Sites that have not been built
  - Similar to other (existing) designs (e.g., PFI vs. CFI)
- Consider crossing movements such as DDI / leftovers

- Detailed concept of sequences[13]

1.5.3. Maintenance

- Lighting (High-mast systems)
- Pavement markings (need to be inspected and maintained more frequently than conventional designs to make sure the lanes are easily seen)
- Trash on the road (Pedestrian crossing / bicycle lanes)
- Snow removal (Many snowplows are designed to push snow to the right (outside of the street), which may result in snow piling in the "median" of an AII design)
- Curved channelized lanes to help drivers become familiar with the crossed-over nature of the arterial and reduce unintentional wrong-way maneuvers

1.6. Other Considerations

1.6.1. Human Factors

- Driving confusion on left turn treatments
  - Standard, rotary, and AIIs with upstream diversion are likely to have the highest acceptance rates for the public because they are less likely to drive "out of direction" or incur significant additional travel time (see Table 1-1 in Section 1.1.2)
  - Quadrant Roadway Intersections are generally easy to understand particularly when using side-mounted decision point signs and providing lane information on the junction sign[14]
  - Drivers who are familiar with alternative intersection designs were more ready for any intersection in a corridor to be non-traditional because of their prior experience, but they may still be confused when approaching an intersection because there are many different alternative intersection types[15]
  - Both familiar and unfamiliar groups wanted more signs and to have them earlier[16]
    - More adequate signing (directional guidance) in advance of the decision point
    - Advanced warning of the unusual movements to be made in advance of the main intersection.
    - Pavement markings were useful, especially if they were placed early
    - Overhead signs superior to side mounted signs since the visual path was more consistent with expectation
- Public acceptance? Reduced usage due to extra travel distance?
  - Public's main concerns are driver confusion and fear of the unknown. Survey results highlight education as important, and that public opinion generally improves once an alternative intersection is constructed[17]

[13] *FHWA DDI or CFI Informational Guidance*
[14] *FHWA/NC/2019-26: Roadway Signing and Marking of Unconventional Grade Separated Intersection Designs*
[15] *NCDOT Design Consistency for Corridors*
[16] *NCDOT Design Consistency for Corridors*
[17] *Shumaker, M.L., Hummer, J.E., Huntsinger, L.F. Barriers to implementation of unconventional intersection designs: A survey of transportation professionals. Public Works Management and Policy, Vol.18(3), 2012, pp.244-262.*

    - Engineers should provide additional guidance signs upstream of the decision point for intersections with non-traditional movements in order to offset low driver situation awareness and high cognitive workload, and to support timely lane changing behavior[18]

1.6.2. Economic Impacts

- Impacts to Business
    - Access management
        - Access management, particularly around an AII often involves restricting or eliminating movements to the nearby land uses[19]
        - AII projects can create access benefits for one side of the street but restrict the other side[20]
        - There is no direct evidence of negative economic impacts due to access management installations[21]
    - Business may or may not good during construction; will be good after construction.
        - Owners of businesses along treatment corridors viewed access management techniques in a more positive light than the perceptions of those on comparison sites.[22]
        - Work zone should be done quickly. After construction business will be infill after the construction.
        - Construction of RCUTs is associated with an increase in sales among businesses in their vicinity[23]
    - Business reactions varied greatly depending on the ability to make direct left turns from the arterial.[24]
        - In general, more business managers feel superstreets negatively impact business growth and operations.
        - Access and confusion were identified as key problems in retaining the number of regular customers and attracting new customers near superstreets

1.6.3. AII Corridor

- If an AII design affect the corridor signal progression
    - Corridor Treatments: RCUT, MUT (promote signal progression)
    - Spot Treatments: CFI, QRI (high capacity so can accommodate busy intersections)
- Coordination between the main intersection and secondary intersections
- Design consistency when applying AIIs along a corridor
    - Any issues navigating any of the specific AII combinations?

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[18] *FHWA/NC/2019-26: Roadway Signing and Marking of Unconventional Grade Separated Intersection Designs*
[19] *Lau, T., Perrin, J. Alternative Intersection/Interchanges in Commercial Areas Application, Misconceptions and Benefits.*
[20] *Lau, T., Perrin, J. Alternative Intersection/Interchanges in Commercial Areas Application, Misconceptions and Benefits.*
[21] *Cunningham, C., Miller, M., Findley, D.J., Smith, S., Cater, D., Schroeder, B., Katz, D., Foyle, R.S. Economic Effects of Access Management Techniques. Report No. FHWA/NC/2009-12, North Carolina Department of Transportation, Raleigh, NC, 2010.*
[22] *Cunningham, C., Katz, D., Smith, S., Cater, D., Miller, M., Findley, D.J., Schroeder, B., Foyle, R.S. Business Perceptions of Access Management Techniques. Public Works Management & Policy, Vol.20(1), 2013, pp. 60–79.*
[23] *Schneider, H., Barnes, S., Pfetzer, E., Hutchinson, C. Economic Effect of Restricted Crossing U-Turn Intersections in Louisiana. Report No. FHWA/LA.17/617, Louisiana Department of Transportation and Development, Baton Rouge, LA, 2019.*
[24] *Ott, S.E., Fiedler, R.L., Hummer, J.E., Foyle, R.S., Cunningham, C.M. Resident, Commuter, and Business Perceptions of New Superstreets. Journal of Transportation Engineering, Vol. 141, Issue 7, 2015, https://doi.org/10.1061/(ASCE)TE.1943-5436.0000754*

  - Intersection pair has a significant impact on the occurrence of failure movements[25]
- Spacings between adjacent intersections
  - Minimum spacing to allow drivers making decisions safely
  - Optimal spacing is a tradeoff between queue storage and extra travel distance
- One-way pairs vs. RCUTs
  - A one-way pair tied into a RCUT still acts like a one-way pair

1.6.4. Public Communication and Acceptance

- Socioeconomic factors
  - Respondents who are younger, male, highly educated, who travel more often or for farther distances, and who rate their own driving ability highly, are more likely to accept and be confident using alternative designs.[26]
- Impacts on travel demand
  - Will commuters avoid using AII designs and detour/switch to other routes?
    - Many drivers have the perception that these intersections are unsafe, are confused by them, or may have difficulty navigating them without additional support. Likewise, many specific user groups (e.g., trucking companies or local business owners) may be concerned about how these innovative intersections will impact their operations.[27]
- Factors that may affect public acceptance
  - Modality / bike, ped, transit users (be more specific, such as additional ROW available?)
  - Accessibility
    - AI guide[28]
  - Transit stops
    - Transit stop located at Upstream downstream or midblock?
    - Transit stop on mainline or side street?
    - DDI guidance
    - NCHRP Access management
  - Safety
    - Lighting (general information, DDI guide)
    - Speed
    - Traffic calming (speed limit, geometric/curvature, lane width, signal progression)
    - Road diet (cross-reference to multimodal facilities)
    - Refuge island
    - Short crossing
    - Separated facilities for bike lane
- Public Communication
  - Working with the community to better support commuters
    - Information sharing via social media such as NextDoor
    - Public meeting for information sharing
  - Naming Conventions- consistent for engineers, careful of how to present to public

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[25] *NCDOR Research Project 2019-31*

[26] *Adsit, S.E., Konstantinou, T., Gkritza, K., Fricker, J.D. Public Acceptance of and Confidence in Navigating Intersections with Alternative Designs: A Bivariate Ordered Probit Analysis. Journal of Transportation Engineering, Part A: Systems, Vol. 148, Issue 9, 2022, https://doi.org/10.1061/JTEPBS.0000696*

[27] *Rodgers, M.O., Gbologah, F., Abdella, K.E., Bodiford, T. Public Involvement/Education on Alternative Intersection/Interchange Designs. Report No. FHWA-GA-20-1726, Georgia Department of Transportation, Atlanta, GA, 2020.*

[28] *FHWA DDI Informational Guidance*

        - Provide some names
        - The importance of naming them for acceptance
        - One or two examples of how names were changing (superstreet)
    - Outreach or communication by area types
        - Urban area may need more communication than suburban area
        - Commuter area vs. CBD or other non-commuter areas
    - Tool for Public Engagement
        - Website (e.g., *VDOT: https://www.virginiadot.org/innovativeintersections/*)
        - Poster illustrating important facts about the particular innovative intersection
        - Flyers (Georgia DOT: trifold brochure, flyer that would contain much of the same information as the trifold brochure but could more easily be included in handouts or documents)
        - Simulation animation (Georgia DOT: basic VISSIM™ simulation of the intersection operating at moderate traffic)
        - Promotional/Example Materials (Georgia DOT: A video derived from the simulation showing the perspective from each approach and the "driver's eye" perspective showing how to navigate through the intersection)

1.7. Decision Making

- Identifying what the needs at the intersection are and what elements of AI design can help eliminate or enhance that.
- Site-specific applicability
    - Under what conditions should an AII design be recommended?
        - Traffic flow
        - Existing/ potential right-of-way limitation
        - Crash history
    - Summary matrix to help initial design selections
- Flowchart of decision-making process
    - The project development network (PDN) may be helpful but is NC specific[29]
    - Describe the process using non-prescriptive language

[29] https://connect.ncdot.gov/projects/Project-Management/Documents/NCDOT_ProjectDeliveryNetwork.pdf

Chapter 2 – Alternative At-Grade Intersections

2.1 Overview

- Conceptual Description- two surface streets (arterial or secondary) crossing at grade
- Goal: Operational efficiency by removing signal phases and safety benefits by reducing conflicts and/or severity
- Possible Design Types you could consider (including AII with standalone guidebooks)
  - Typical at-grade intersection designs (**Bold** – traditional design; *Italic* – AI designs that have been included in AIIR 1st edition or FHWA/NCHRP reports):
    - **AWSC**
    - **TWSC**
    - *Roundabout*
    - **Signalized 3-leg T-intersection**
    - **Signalized 4-leg intersection**
    - *CFI/DLT*
    - *Median U-Turn*
    - *RCUT*
    - *Quadrant*
    - PFI
    - Split Intersection
    - Bowtie
    - Hamburger
    - Synchronized Split-phasing
    - Offset T
    - Continuous Green T
    - Jughandle
- Consider urban/rural environments
- Crash Modification Factors[30]

  - MUT CMF

Study Name	Summary CMF (range)	Crash Type	CMF	Stars	Applicable Conditions
Al-Omari et al., 2020	0.633	All		5	Urban and Suburban
	0.651	All		5	Urban and Suburban
		K/A/B/C	0.7732	5	Urban and Suburban
		A/B/C	0.7548	5	Urban and Suburban
		O	0.5984	5	Urban and Suburban
		Angle	0.6825	5	Urban and Suburban
		Rear-End	0.5258	5	Urban and Suburban
Kay et al., 2022		K/A/B/C	0.438	3	Not Specified
		K/A/B/C	0.686	3	Not Specified
		All	1.325	3	Not Specified
Elvik and Vaa, 2004		A/B/C	0.85	3	Urban
		O	0.93	3	Urban
Abdel-Aty et al., 2014	0.5	All		2	Rural
		K/A/B/C	0.66	2	Rural
		Run off road	0.4	2	Rural
		Run off road K/A/B/C	0.58	2	Rural

[30] FHWA. Crash Modification Factors Clearinghouse. https://www.cmfclearinghouse.org/

- RCUT CMF

Study Name	Summary CMF (range)	Crash Type	CMF	Stars	Applicable Conditions
Sun and Rahman, 2019	0.42 - 1.07	All	0.8	4	All
Al-Omari et al. 2020	0.7632	All		2	Urban and Suburban
		K/A/B/C	0.5669	2	Urban and Suburban
		Angle	0.5854	2	Urban and Suburban
		Head on	0.0667	2	Urban and Suburban
		Rear End	0.7511	2	Urban and Suburban
		O	0.8414	1	Urban and Suburban
Mishra and Pulugurtha, 2021	0.301	All		n/a	Rural
		K/A/B/C	0.212	n/a	Rural
	0.689	All		n/a	Suburban
		K/A/B/C	0.689	n/a	Suburban
Ulak et al., 2020	1.169	All		3	Urban and Suburban
		K/A/B/C	0.955	3	Urban and Suburban
Hummer and Rao, 2017	0.85	All		3	Suburban
		K/A/B/C	0.78	3	Suburban
Hummer et al., 2010	0.54	All		3	Rural
		K/A/B/C	0.37	3	Rural
		Left Turn All	0.41	3	Rural
		Angle, Right Turn All	0.25	3	Rural
Edara et al., 2013	0.652	All	0.652	3	Rural

- CFI CMF

Study Name	Summary CMF (range)	Crash Type	CMF	Stars	Applicable Conditions
Zlatkovic, 2015	0.877	All		3	All
Cunningham et al., 2022	0.878	All		n/a	All
		K/A/B/C	0.861	n/a	All
		O	0.882	n/a	All
		Angle	0.706	n/a	All
		Rear end	0.868	n/a	All

- High-Level comparison table

Table 2-1 Comparison of Alternative At-grade Intersections with Traditional Designs

AII Design	Operations (Conflicts + Critical Phases)	Progression Quality	Safety (Veh Conflict Points)	Unusual Maneuvers	Wrong Way Potential	Right of Way	Structures (Bridge Size)	Crossing Pedestrians	Bicycle Accessibility
AWSC	N/A		**	*****	*****	*****	N/A	*****	****
TWSC	N/A		**	*****	*****	*****	N/A	**	**
Roundabout	N/A		*****	****	*****	***	N/A	***	**
Signalized 3-leg T-intersection	***	***	*****	*****	*****	*****	N/A	***	****
Signalized 4-leg intersection	*	**	**	*****	*****1	*****	N/A	***	****
CFI/DLT	***	****	***	**	***	***	N/A	**	***
Median U-Turn	****	****	****	***	***	***	N/A	***	****
RCUT	****	****	*****	***	***	***	N/A	**	***
Quadrant	****	***	****	***	***	*	N/A	****	****
Offset T	***	***	****	****	*****	****	N/A	*	***
Continuous Green T	***	***	*****	****	*****	****	N/A	**	****
Jughandle	***	***	**	***	*****	***	N/A	**	***
Hamburger	****	****	****	***	***	**	N/A	*	**
PFI	****	****	***	**	***	***	N/A	**	***
Split Intersection	***	***	***	***	*****	***	N/A	**	**
Bowtie	****	****	*****	***	*****	***	N/A	***	**
Synchronized Split-phasing	****	****	***	**	***	****	N/A	*	***

Notes:

1. Operations indicates the type and number of conflicting critical movements
2. Progression Quality: Blank cell refer to no progression (0 star)
3. Unusual Maneuvers: Motorized traffic approaching from or leaving to an unexpected direction
4. Crossing Pedestrians and Bicycle Accessibility refer to NCHRP 07-25 (Table 1-3)

2.1.1. Displaced Left-turn (Continuous Flow Intersection)

Key Features

- left-turn vehicles cross to the other side of the opposing through-traffic in advance of the main intersection
- Left turns and opposing through movements occur simultaneously at the main intersection

Applicability

- Moderate to heavy traffic volumes in all directions
- Opposing legs have similar through traffic volumes
- Heavy left-turn traffic volumes
- Limited number of driveways or access points near the intersection

Operational Performance

- Distance Traveled: Minimal extra travel distance
- Traffic Signalization
  - ✓ No more than 3 critical movements and shorter cycle lengths possible
  - ✓ Setback crossovers for more left turn storage
  - ✓ Consider merge vs stop vs signalized for right turn
- Progression
  - ✓ Elimination of left-turn phases and synchronization of the main intersection and crossover traffic signals allows good progression

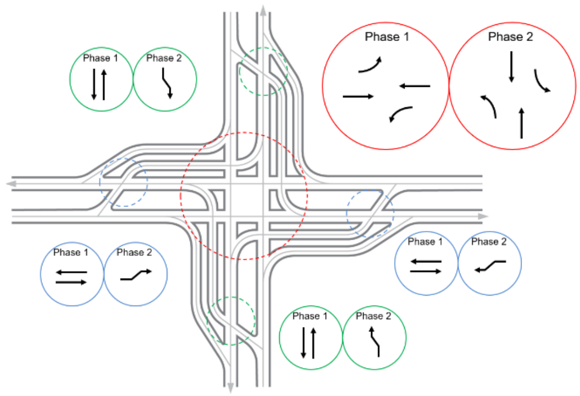
Safety Performance

- Number of Conflict Points
  - ✓ A total of 28 conflict points
  - ✓ Crossing conflicts are more dispersed in the interchange
- Overall CMF between 0.71 and 0.89
- Sight Distance/Other Safety Benefits
  - ✓ Left turns have reduced opposing movements

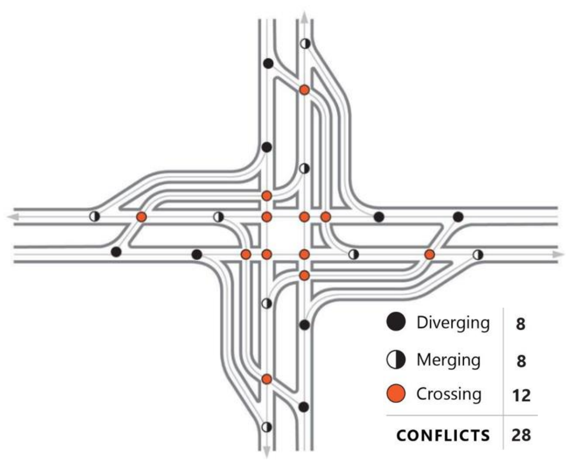
Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ Wide structure is needed to support the displaced/crossover lanes
  - ✓ Multiple raised medians needed with openings to positively direct traffic
- Multimodal design
  - ✓ Location of ped crosswalks
- Access Management Considerations
  - ✓ Consider right-in and right-out configuration

NC 16 and Huntersville Rd., Charlotte, NC



Typical Phasing Scheme at a DLT Intersection



Number of Conflict Points at a DLT Intersection

2.1.2. Median U-Turn Intersection

Key Features

- Left-turn vehicles from one or both roads make U-turns at dedicated median openings to complete the desired movement

Applicability

- Moderate to heavy through traffic volumes and low to moderate left-turn traffic volumes
- On median-divided highways

Operational Performance

- Distance Traveled: Extra travel distance to left-turn traffic on both major and minor streets
- Traffic Signalization
  - ✓ Two zones with 2 critical movements
  - ✓ Shorter cycle lengths feasible
  - ✓ U-turns on ramps may be stop or signal
- Progression
  - ✓ Good one-way progression with two closely spaced signals

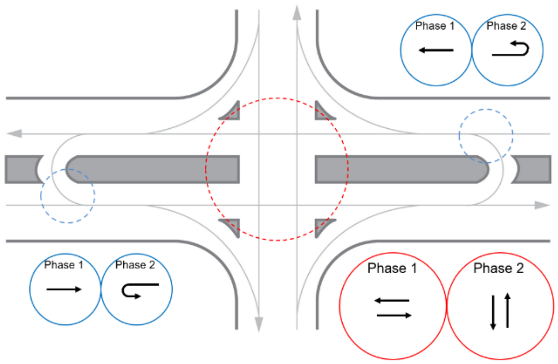
Safety Performance

- Number of Conflict Points
  - ✓ A total of 16 conflict points
- Overall CMF between 0.5 and 0.65
- Sight Distance/Other Safety Benefits
  - ✓ Intersections have reduced complexity

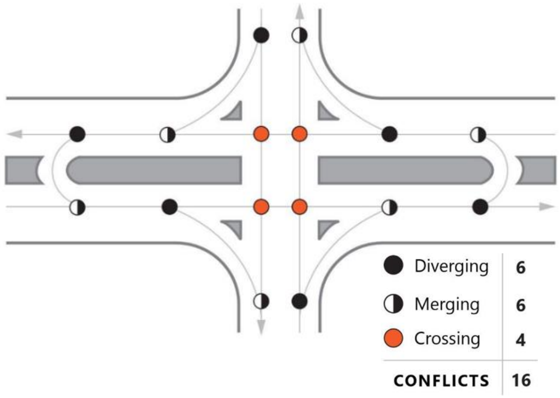
Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ May use existing or widened shoulder (a.k.a. loon) for U-turn to reduce median width
  - ✓ Need to provide sufficient turn bays prior to U-tun crossover to accommodate deceleration and storage
- Multimodal design
  - ✓ Ped crossing can be one-stage or two-stages depending on crossing distance and green time
- Access Management Considerations
  - ✓ Driveways should not be allowed in close proximity to the main intersection

Poplar Tent Road and Derita Road, Concord, NC



Typical Phasing Scheme at a MUT Interchange



Number of Conflict Points at a MUT Intersection

2.1.3. Restricted Crossing U-Turn Intersection

Key Features

- All side street movements begin with a right turn
- Side street left-turn and through vehicles turn right and make a U-turn at a dedicated downstream median opening to complete the desired movement

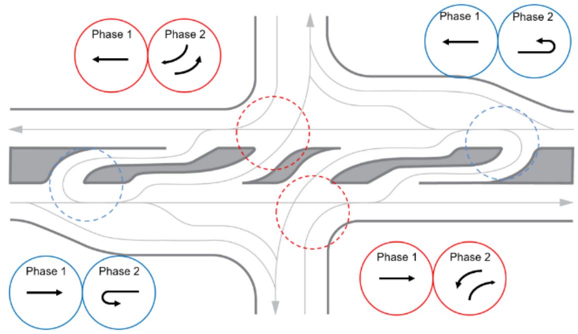
US 401 and Young St. Signalized RCUT Intersection, Wake Forest, NC

Applicability

- With heavy through and / or left-turn traffic volumes on the major street; and low through and left-turn traffic volumes on the side street
- On median-divided highways

Operational Performance

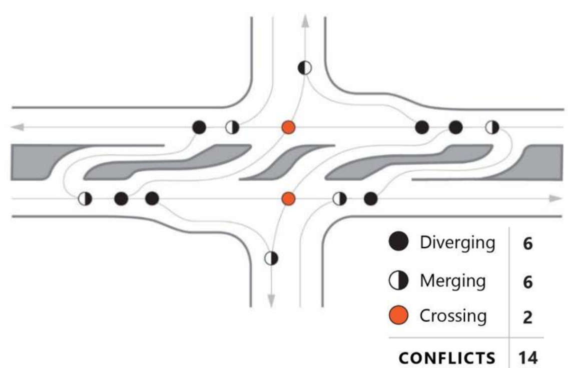
- Distance Traveled: Moderate extra distance traveled for minor street through and left turn traffic
- Main intersection and median U-turns can be designed as signalized, stop controlled or yield controlled
- Traffic Signalization: All signalized zones have 2 critical movements
- Short cycles possible
- Good two way progression due to independent operation of the throughs



Typical Phasing Scheme at a RCUT

Safety Performance

- 14 conflict points total, with large benefits to angle collisions since only 2 crossing conflicts
- Overall CMF between 0.3 and 0.96
- Separated conflict points makes it simpler due to fewer movements for the driver to monitor



Number of Conflict Points at a Grade Separated RCUT (U-turn then Right-turn)

Geometric Design and Implementation Considerations

- Extended intersection area compared to more compact designs
- A large enough vehicle path at the U-turn crossover to accommodate trucks
- Access Management Considerations
  - ✓ Driveways should not be allowed in close proximity to the main intersection

2.1.4. Quadrant Roadway Intersection

Key Features

- Intersection design with one main intersection and two secondary intersections that are linked by a connector road in any quadrant of the intersection
- Left-turn vehicles from all four legs of the main intersection use the secondary intersections and connector road to complete left-turn movements
- When all three intersections are signalized, traffic signals are timed to operate together

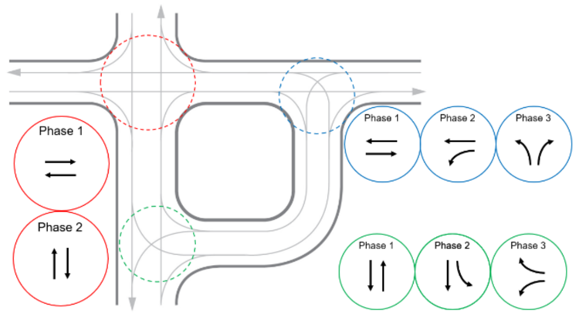
Dixie Hwy and Ross Road, Fairfield, OH

Applicability

- Heavy through and left-turn traffic volumes on the major and side streets
- At locations with an existing roadway that can be used as the connector roadway

Operational Performance

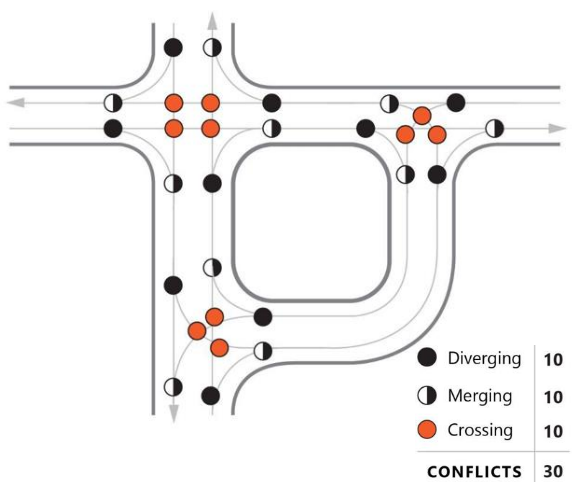
- Some extra distance traveled for diverted turning movements
- Traffic Signalization:
  - ✓ Main intersection has 2 critical movements; two sub-intersections with 3 critical movements each
  - ✓ Shorter cycle lengths than a counterpart 4-leg intersection
- Progression:
  - ✓ Good one-way progression on each roadway



Typical Phasing Scheme at a QRI

Safety Performance

- 30 conflict points total, can potentially reduce angle collisions with only 6 turning crossing conflicts.
- Separated conflict points makes it simpler due to fewer movements for the driver to monitor



Number of Conflict Points at a QRI

Geometric Design and Implementation Considerations

- Requires ROW or network connections for quadrant connector
- Consider right turns- signalized, channelized, merge, yield
- Opposite quadrant movements have large out of distance travel for pedestrians
- For larger connectors- access may be possible on the connector itself

2.2 Parallel Flow Intersection

Introduction:

A parallel flow intersection (PFI) is an intersection where left turns bypass the main intersection by first turning onto a cross street frontage road. Left turn movements are then able to proceed in the same signal phase as the cross street through movement. This increased efficiency is accomplished by arranging for left turns to occur just prior to the main intersection using a frontage road along the cross street. And unlike many unconventional intersection designs, the parallel flow intersection provides for intuitive direct left turns nearly from the same stop bar location as a traditional signal.

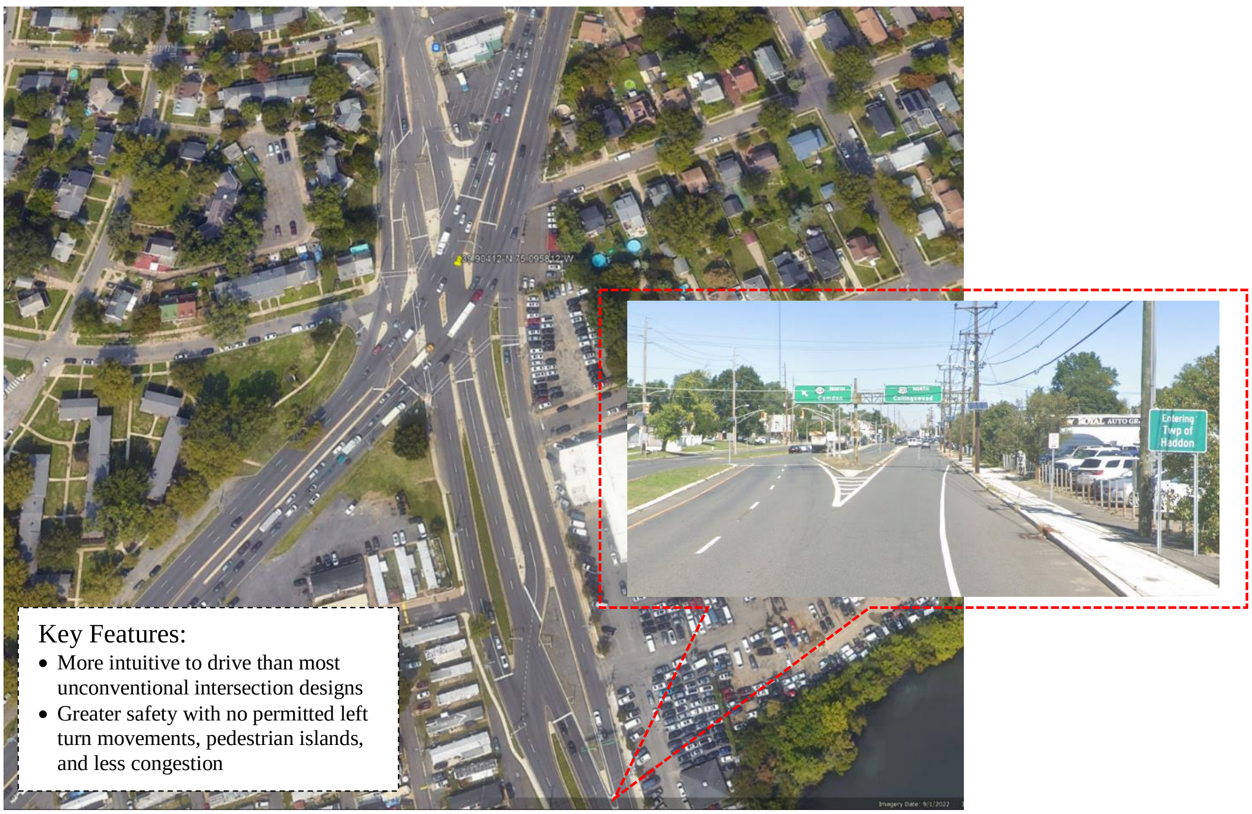
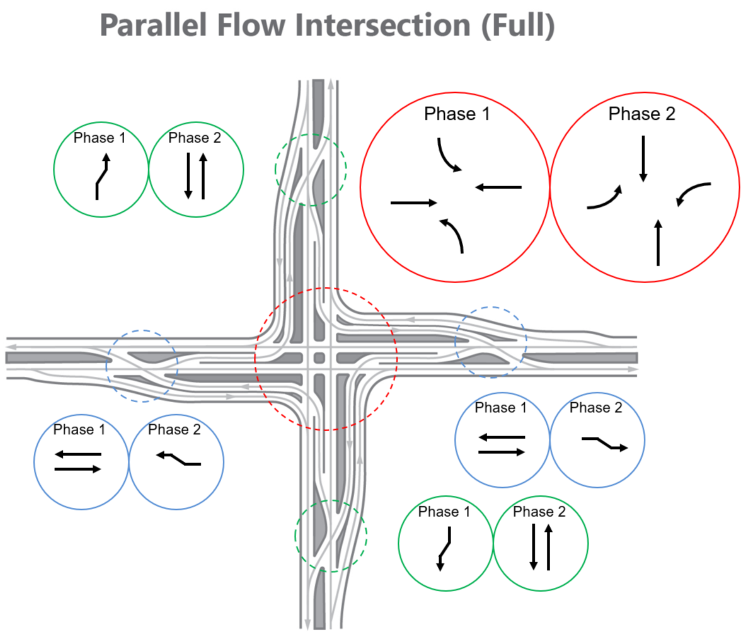


Figure 2-1 SR 168 at US Highway 130 in Haddon Township, New Jersey

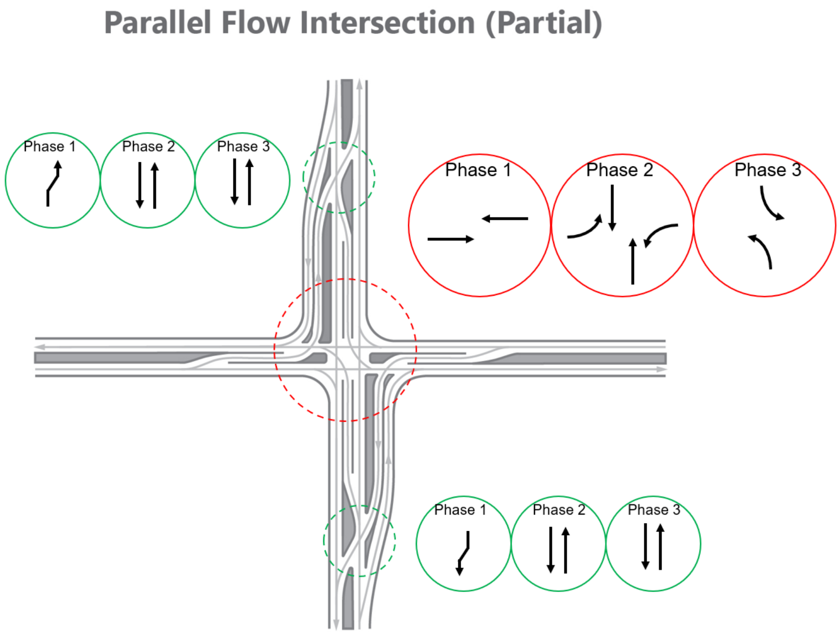
2.2.1 Operational Performance

- Distance Traveled
    - Minimal Extra Distance Traveled because diverted movement is upstream of the main intersection.
- Traffic Signalization
    - Full PFI operates as two phase
        - Parallel RT lane is required to achieve two phase operations

    - Partial PFI can be two or three phase depending on left turn treatment at main intersection
        - Most likely a protected left turn, which means 3-phase
- Progression
    - Good one-way progression due to two/three phase signals
- Vehicle + Multimodal based on simulation/field
- Traffic Signalization Treatments
    - Estimated number of critical phases
    - Cycle length/progression
    - Potential for longer clearance at secondary intersections because of the skewed intersection configuration.
- Control type (signalized, stop, yield for certain movements)



(a)



(b)

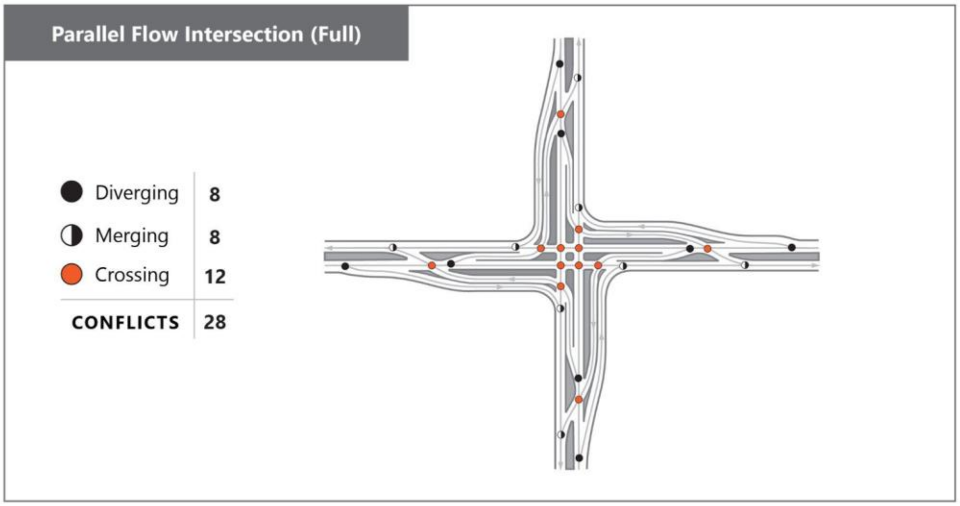
Figure 2-2 Typical Phasing Scheme at PFI (a) Full PFI; (b) Partial PFI

2.2.2 Safety Performance

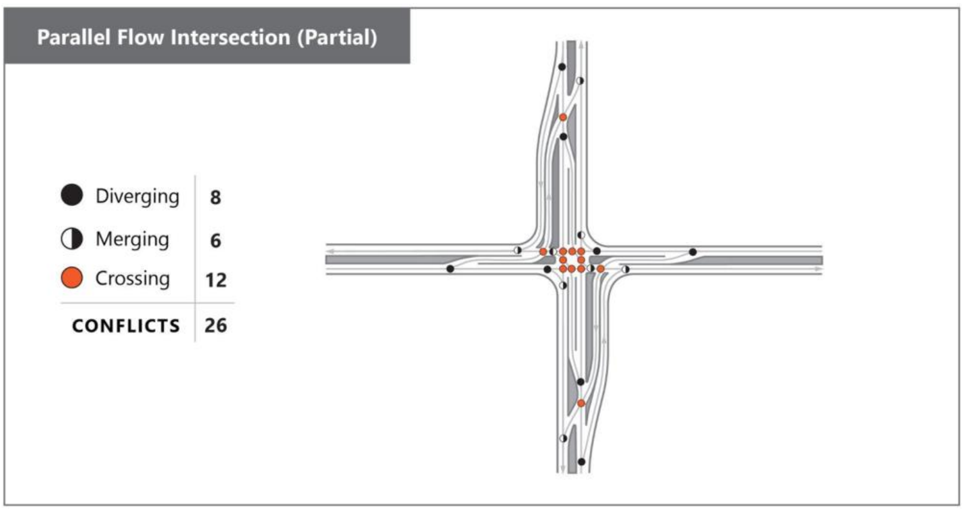
CONFLICTS

A Full PFI has 28 conflict points with 12 crossing conflicts, partial has 26 with 12 crossing conflicts

- Has two fewer conflict points than Full/Partial CFI
- Partial PFI: RTOR Sight Distances improved with earlier separation of non-conflicting RT on opposing approach.



(a)



(b)

Figure 2-3 Number of Conflicts at PFI (a) Full PFI; (b) Partial PFI

CRASHES

- Crash findings should be similar to a CFI
  - Research has been sporadic with negative and positive findings
  - Most recent study found a 12.2% decrease in overall crashes[31].
  - The right turn treatment was the most significant consideration for safety at a CFI.
    - This is discussed more in 2.2.3; however, the default geometric treatment for the right turn should have it run parallel to the diverted left turn (see diagram above). Findings for CFI's showed an even more significant decrease in this case with a reduction in crashes of approximately 30%.

[31] Cunningham et al. (2022). *Development of a Crash Modification Factor for Conversion of a Conventional Signalized Intersection to a CFI*. https://connect.ncdot.gov/projects/research/RNAProjDocs/2020-29%20Final%20Report.pdf

        - In contrast, when right turns were made at the main intersection, crashes were found to increase by 15.6%.

OTHER CONSIDERATIONS

- Incident Response is complex with the offset movements/channelized lanes

2.2.3 Geometric Design and Implementation Considerations

- Geometry
    - Compared to CFI, Major cross-section is narrow, minor cross-section is wide
    - Compared to CFI, the left turn bay length is limited by the crossover location,
    - Right turn storage is limited by parallel section or crossover length depending on phasing
    - If ROW is limited, one option used at CFIs is to have the right turn take place at the main intersection in lieu of it running parallel to the left turn.
        - This treatment should be used sparingly based on the safety findings (noted earlier).
        - If used, a NO RTOR should be strongly considered.
    - Crossover alignment important to reduce wrong way opportunities
- Multimodal design (offset approaches)
    - Typical: Multistage crossing, ped refuge needed
    - Alternative: offset crossing, midblock crossing
- Access Management Considerations
    - Frontage impact is shifted compared to CFI- outbound legs can consider RIRO driveways or on street parking (though unlikely due to travel lane ROW needs)
    - Raised island or median barriers due to crossover/parallel sections

2.2.4 Signal, Signing, Marking and Lighting

- Many of the design features are also in CFI, that manual may have applicable signal, signing, marking and lighting configurations for various movements/configurations
- Compared to CFI, PFI left diverges similar location to traditional so advanced LA signage is not likely required (entry into the left turn is similar to a standard tapered turn pocket)
- Compared to CFI, PFI Right diverges earlier and may need advanced LA signage
- Additional guide/wrong way signage recommended for parallel sections
- Crossover markings (CFI) dotted lane extension markings
- Keep clear is not needed unlike CFI
- Lighting (CFI) needed for both main and crossover intersections
- Signal heads (CFI) – Angular arrow signal display for crossover

2.2.5 Construction and Maintenance

- Consider findings from the CFI manual that may apply to PFI, but little is known about the specifics for PFI
- Right of way needs are greater on the crossover approaches
- Law Enforcement Needs
- Utilities (moving/burying)
- Construction Sequencing (traffic organization during construction phases)
- Maintenance of Traffic
    - Run Traditional and convert all at once
    - Convert Major or Minor first

  - Close/restrict movements
- Maintenance
  - Snow removing
  - Temporary lane closure impact
  - Lane marking quality

2.2.6 Multimodal Considerations

- Multimodal access – bike, ped, Transit (crossing types)
- Pedestrian Flags
  - Peds may have passed the channelized RT lane, so RTOG vehicle may conflict with peds.
  - Nonintuitive motor vehicle movements, since LT vehicles arrive from an unexpected direction.
  - Pedestrian may cross yield or uncontrolled vehicle paths as there may have uncontrolled channelized RT lanes.
  - Typically need multiples lanes to warrant a PFI.
  - Multi-stage crossing
- Bicycle Flags
  - Bicyclists may cross yield or uncontrolled vehicle paths as PFIs may have uncontrolled channelized RT lanes.
  - Bicyclists may cross channelized lanes, depends on actual intersection configuration.
  - May have channelized/dedicated RT lanes so motorists may cross bicycle path.
- Bike lane doesn’t need realignment for downstream right merge unlike CFI
- Ped-vehicle control
  - Signalized but multistage
- Pedestrian phasing
- Heavy Vehicles – accommodate in channelized lanes/turning radius

2.2.7 Applicability

- Area types (urban/suburban/rural)
  - Works well in rural/suburban locations where ROW is available and driveway access is not restricted.
  - Urban locations will be challenging b/c of the right-of-way needed to divert the lanes.
    - The right turn lane could reduce that footprint, but there are (potentially) significant trade-offs (noted in Safety and Geometrics sections)
- Facility limitations- Cross-section width can be an issue with median needed to accommodate crossover

2.2.8 Other Considerations

- Patent US7135989B2- Active, includes both Full and Partial PFI design and signal timing
- Lighting (location Urban/Sub/Rural?)

2.3 Split Intersection

Introduction:

A split intersection is an at-grade variant of the diamond interchange. Compared to a conventional four-leg intersection or road crossing, the arterial road is split into separate carriageways by 200 to 300 feet, allowing a queue of left turning vehicles behind a completed turn into the crossroad without any conflict to oncoming traffic. On the crossroad, the four-leg intersection is being replaced by two intersections. The beginning one-way traffic at the fourth leg makes the intersections reduce the number of conflicts similar to a three leg T-intersection to improve traffic flow.

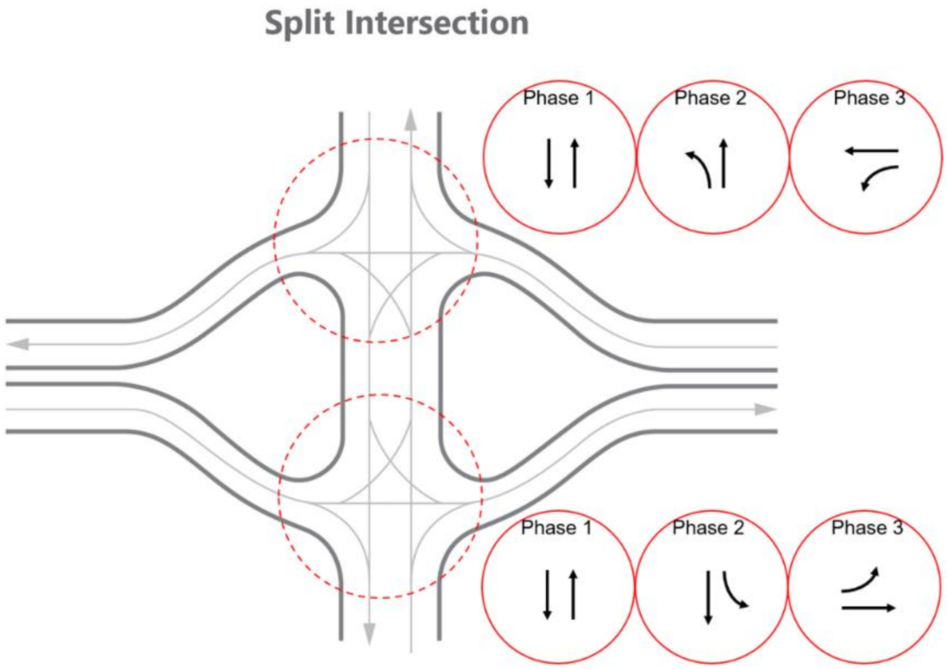
Figure 2-4 Lake Woodlands Drive at Grogans Mill Road in The Woodlands, Texas

A town center intersection (TCI) is similar to a split intersection; however, both the arterial road and the crossroad are split into separated one-way streets. The resulting grid, most often implemented in the central business district of a city, reduces conflicts to two directions per intersection.

Figure 2-5 San Elijo Road at Elfin Forest Road in San Marcos, California

2.3.1 Operational Performance

- Distance Traveled
    - Slight change in alignment, Extra distance/movements for U-turn
- Traffic Signalization
    - Estimated number of critical phases
        - No more than 3 critical movements
    - Cycle length/progression
        - Shorter cycle lengths than a counterpart 4-leg intersection
    - Control type (signalized, stop, yield for certain movements)
        - Two (split) or four (couplet) signalized zones
- Progression
    - Split Intersection: Coordination between 2 three phase intersections
    - One-way Couplet: 4 two phase intersections
    - Good one-way progression



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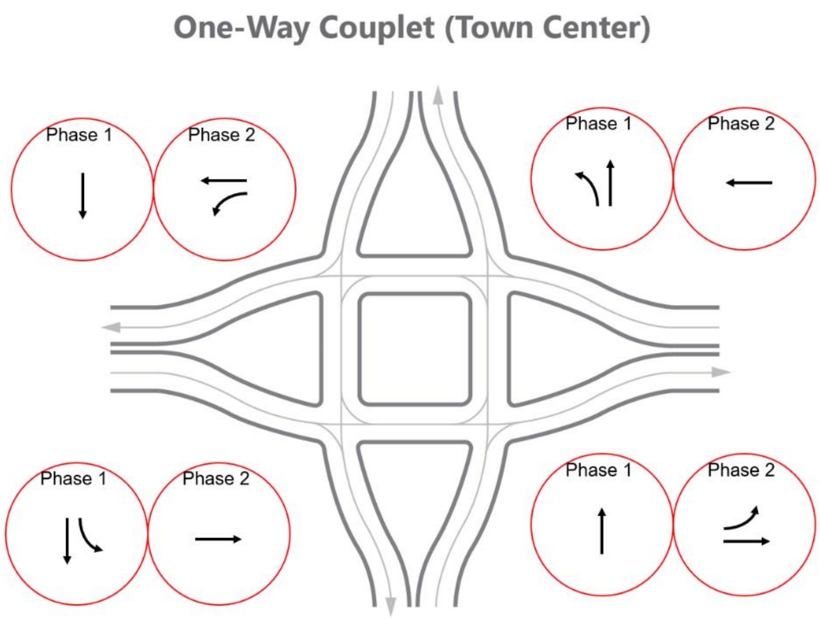
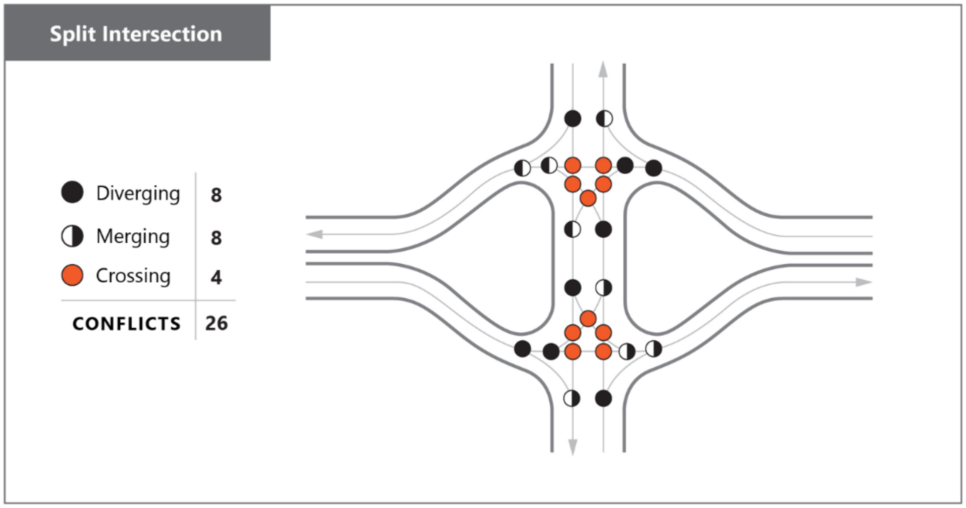


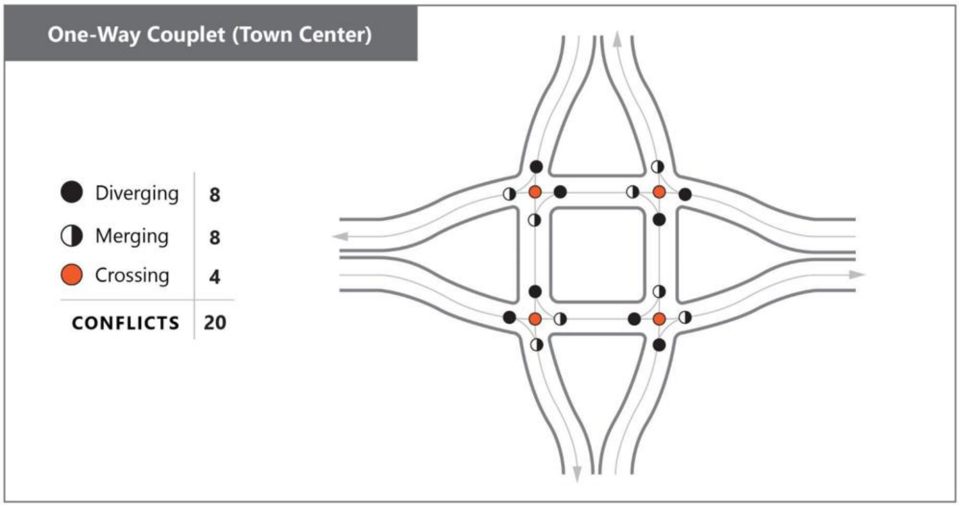
(b)

Figure 2-6 Typical Phasing Scheme at (a) Split Intersection; (b) One-way couplet

2.3.2 Safety Performance



(a)



(b)

Figure 2-7 Number of Conflicts at (a) Split Intersection; (b) One-way couplet

- Safety Performance: Check for CMF, count conflict points
  - A Split intersection has a total of 26 conflict points and couplet has 20, compared to 32 conflict points at a conventional intersection
    - The number of diverging and merging conflicts do not change from the standard intersection.
    - Significantly reduces crossing conflicts from 16 to 10 (split intersection) and 16 to 4 (one-way couplet).
- Sight distance/other safety benefits
  - Reduced severity/exposure of ped conflicts, but two crossings are needed
  - Reduced number of conflicting movements to monitor for turning

2.3.3 Geometric Design and Implementation Considerations

- Unique geometric aspects
  - Reduced ROW needs for one way streets

  - In retrofit, oftentimes a parallel road can be fit to make one-way pairs
  - In retrofit, additional right-of-way can be used for on-street parking or other unique considerations
  - For split intersection, consider design speeds for curves
- Multimodal design
  - Crosswalks and bike lanes similar to one-way street grid
  - In retrofit, additional right-of-way is often available for bicycle lanes
- Access management considerations
  - Reduced directional access removes conflicts
  - Single movement driveways (RIRO/LILO)
  - On-street (public) parking more likely to be considered in lieu of underutilized private parking.

2.3.4 Signal, Signing, Marking and Lighting

- LPIs often used in CBD's with heavier traffic volume conflicts
- Clearly signed turn restrictions a must + wrong way
- Additional guide signs may be needed for split approaches on split intersections and one way couplets similar to diamond interchanges

2.3.5 Construction and Implementation

- Right of way
- Utilities (moving/burying)
- Construction Sequencing (traffic organization during construction phases)
- Maintenance of Traffic
- Maintenance
  - Snow
  - Temporary lane closure impact
  - Lane Marking quality

2.3.6 Multimodal Considerations

- Benefits ped/bike due to slower speeds and reduced conflicts with vehicles
- Multimodal access – bike, ped (crossing types)
- Ped-vehicle control
- Pedestrian phasing is simple with only right and left turn permitted movements that may conflict.
- Transit
- Pedestrian Flags
  - Motor vehicle right turns conflict with crossing pedestrians.
  - Pedestrians may cross yield or uncontrolled vehicle paths, depends on whether ped crosswalks are signal controlled or not.
  - Minor street peds and major street LT peds have extra travel distance to cross the intersection.
  - Possibly multilane crossings if major street has more than 2 lane per direction.
  - Pedestrians may conflict with motor vehicle left turns, if permissive LT signal applies for major street LT traffic.
- Bicycle Flags

  - Bicyclists may cross yield or uncontrolled vehicle paths, depends on if the intersection is signalized or not.
  - Minor street and major street LT bicyclists have extra travel distance to cross the intersection.
  - May have channelized/dedicated RT lanes so motorists may cross bicycle path.

2.3.7 Applicability

- Existing block/parallel roadways with ROW constraints where you can turn two two-way roads into one way pairs.
- Especially beneficial for downtown locations and increases walkability/bikability while improving vehicle capacity
- Can really free up ROW in retrofit situations, making options for transit, on street parking, etc. more feasible.

2.3.8 Other Considerations

- One-way streets can control speeds to slow traffic as they drive in front of businesses and/or access parking (private or public)
- Two one way pairs can create a block/square for park/town feature/architecture
- Both roadway designs can be paired with RCUT where ROW does not allow “blocking” and roads must come together.
  - This is because they still operate as one-way streets with RCUT design.
  - The blocks can be reestablished again downstream where ROW is available and “blocking” is desirable.

2.4 Bowtie / Teardrop

Introduction:

The bowtie is a type of road intersection where secondary intersections can be utilized to reroute one or more of the left turns. The secondary intersections can be full roundabouts or partial ones in the shape of a teardrop.

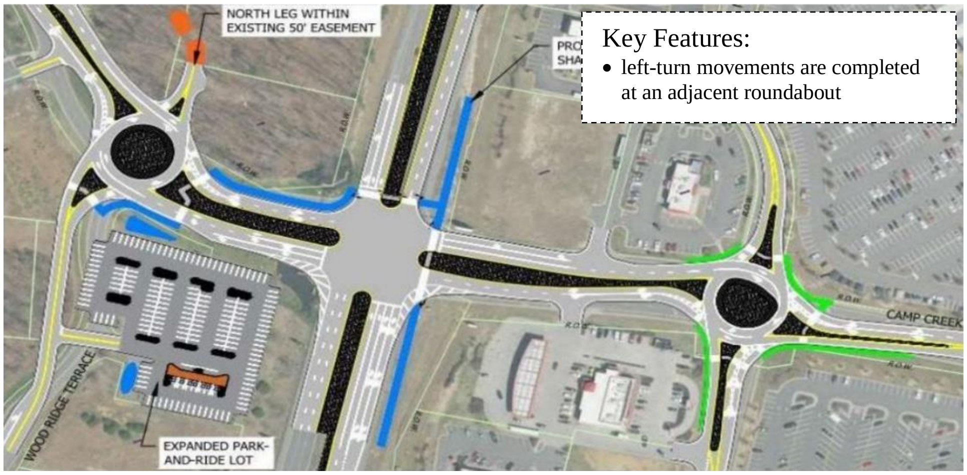
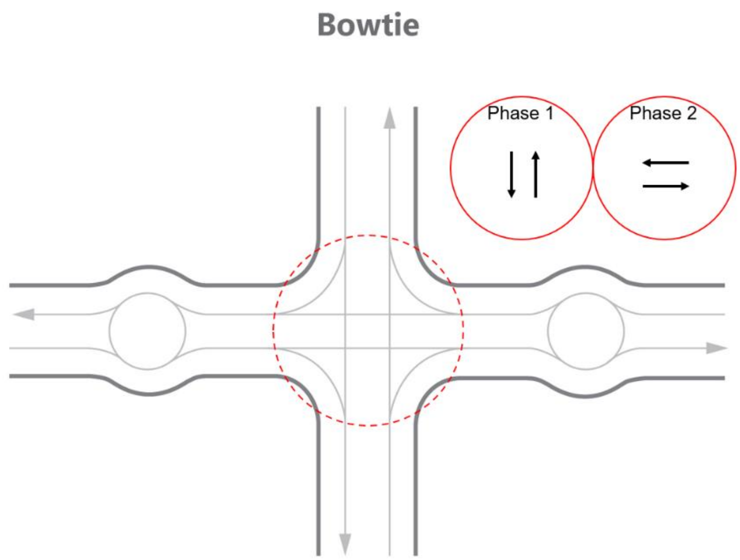


Figure 2-8 Concept drawing of a bowtie intersection

2.4.1 Operational Performance

- Distance Traveled
  - Extra travel distance to left-turning traffic – especially from major
  - If teardrop is utilized, some left turns from side street movements would be out of direction also with increased travel distance.
- Traffic Signalization
  - Estimated number of critical phases
    - 2 critical (likely) with all lefts restricted, 3 critical movements (less likely) if minor lefts allowed
  - Cycle length
    - shorter cycle lengths than a counterpart 4-leg intersection
  - Control type (signalized, stop, yield for certain movements)
    - Central zone signalized, bowtie movements on minor street may be yield/RBT or (unlikely) signalized
- Progression
  - Good one-way progression especially with all lefts restricted
  - Minor progression can be interrupted by yield/RBT movements



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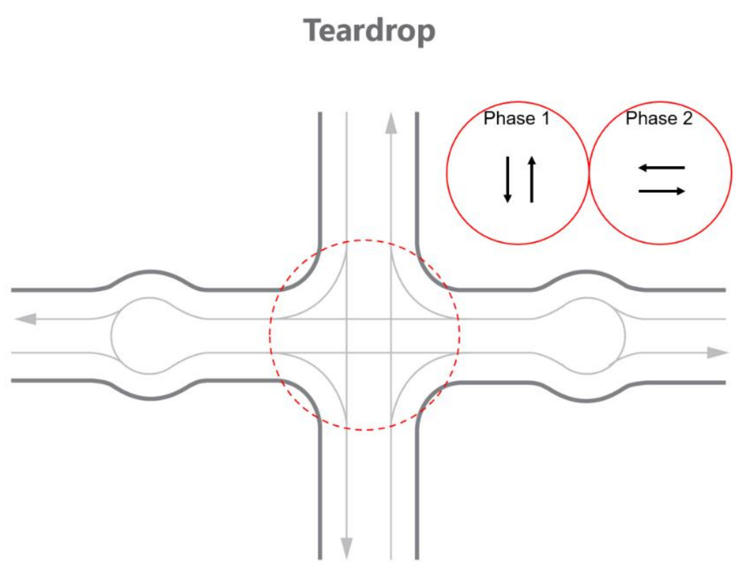
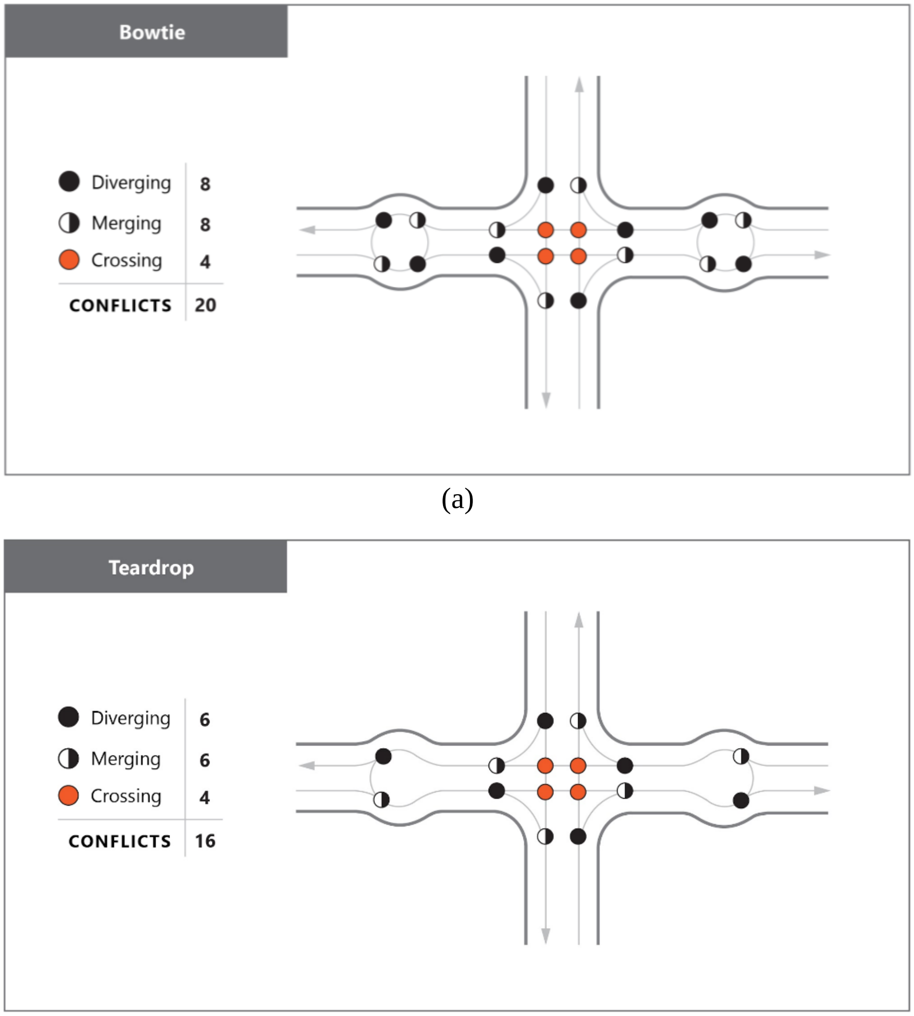


(b)

Figure 2-9 Typical Phasing Scheme at (a) Bowtie Intersection; (b) Teardrop Intersection

2.4.2 Safety Performance



(a)

(b)

Figure 2-10 Number of Conflicts at (a) Bowtie Intersection; (b) Teardrop Intersection

- Safety Performance: Check for CMF, count conflict points
  - A bowtie intersection has a total of 20 conflict points, compared to 32 conflict points at a conventional intersection
  - Teardrop has 16 CPs
  - The primary reduction is crossing conflicts, which are reduced from 16 to 4.
- Sight distance/other safety benefits
  - Can be used on minor streets with low-volume, high-speed, roads to help reduce speeds into the conflict points while also handling traffic with somewhat limited capacity of roundabouts.

2.4.3 Geometric Design and Implementation Considerations

- Unique geometric aspects
  - The upstream and downstream bowtie intersections can be tied in with side streets
  - Minor bowtie intersections may be full roundabout or closed teardrop (depends on the network)

  - Teardrop could help reduce potential for wrong-way movements by preventing lefts into the circulating roadway.
    - However, a major downside to a teardrop is that if side streets are present on both sides, the direct left turn out on one of the approaches is not possible.
    - For this reason, a teardrop should be considered carefully, such as where a T-intersection is present and on the side where left turn out is not needed OR where no side street movements are present.
- Multimodal design
  - Increased number of crossings if side streets are connected to the roundabouts
- Access Management Considerations
  - Can add full movement RBT on minor for increased access (all movements permitted for driveways)

2.4.4 Signal, Signing, Marking and Lighting

- Turn Restriction signage needed on major (right to go left)
- Clear guide signs for bowtie movements should follow typical roundabout design for States
- If teardrop is used and a minor street u-turn of left turn (in certain cases) is needed, it may not be apparent that a driver would need to go all the way to the 2nd RBT to u-turn.
  - This is why a tear drop should be considered carefully, such as where a T-intersection is present and on the side where left turns are not needed OR where no side street movements are present.

2.4.5 Construction and Implementation

- Right of way
- Utilities (moving/burying)
- Construction Sequencing (traffic organization during construction phases)
- Maintenance of Traffic
- Maintenance
  - Snow
  - Temporary lane closure impact
  - Lane Marking quality

2.4.6 Multimodal Considerations

- Multimodal access
  - Pedestrian crossings are fairly standardized and take place at the entry and exit legs of the roundabout. Two stage crossings are made at the entry and exit legs.
  - If bicycle lanes are present, bicycles join vehicular traffic through the roundabout, exiting back into the bicycle lane.
  - Bicycles at two-lane roundabouts can pose challenges (for entering vehicles and bicyclists) when a dual lane entry crosses a dual lane exiting approach
- Pedestrian Flags
  - Motor vehicle right turns conflict with crossing pedestrians at the main intersection
  - Possibly multilane crossings if major street has more than 2 lane per direction
- Bicycle Flags
  - Bicyclists may have out-of-direction travel due to curvatures.
  - Bicyclists may cross channelized lanes, depends on actual intersection configuration.

    - May have channelized/dedicated RT lanes so motorists may cross bicycle path.
- Ped-vehicle control
    - Deflection on the entry and exit legs is an important consideration for slowing vehicles and making the crossing environment safer for peds – especially the exit leg.
    - On the entry leg, it is almost always yield controlled
    - The exit leg is more challenging with higher volumes of cars. If high volumes are present, a signalization, beacon, or geometric design treatment could be considered. Almost always, the treatment for the exit leg is also added to the entry leg for consistency.
- Pedestrian phasing
    - At the main intersection is simple and (unless left turns are allowed at one or more approaches) only has concurrent through movements with permitted lefts.
    - RTOR will be heavier and should be considered carefully with heavy ped movements. An LPI might be needed to safely get pedestrians into the ROW.
- Transit vehicles
    - Loading and unloading should be done on the entry side of the RBT if possible.
    - If the exit leg is necessary for loading/unloading, the bus should be allowed to pull out of through lanes. This helps prevent queue spillback into the roundabout which would prevent movement from any approach.

2.4.7 Applicability

- For full roundabout design, existing minor intersections can be converted to easily maintain network access for businesses
- Adjacent parcels may have available ROW for minor bowtie and can be used to simplify movements in a congested network (adjacent intersections on major street causing weaving to make lefts like nearby interchange)
- Intersection of major four-lane, six-lane, or eight-lane arterial with a collector or minor arterial street
- Left turn demand should be less than 20% of approach demand[32]
- Suburban or urban
- Signalized
- Four legs
- ROW available for roundabouts

2.4.8 Other Considerations

- Any additional considerations that do not fall under existing headers
- Lighting (location Urban/Sub/Rural?)
- Driver confusion when teardrop close to main intersection (see Figure 11)

[32] Fitzpatrick, K., Wooldridge, M., Blaschke, J. Urban Intersection Design Guide: Volume 1 – Guidelines. Report No. FHWA/TX-05/0-4365-P2 Vol.1, Texas Department of Transportation, Austin, TX, 2005.

Figure 2-11 Conceptual rendering of a Bowtie/Teardrop Intersection with U-turn close to main intersection

2.5 Hamburger

Introduction:

A hamburger intersection is a style of roundabout where the main road passes through the center of the roundabout. The name came about because from an aerial view, the roundabout looks like the bread, and the main road represents the "meat". As all the roads are at grade, the intersections are nearly always signal controlled.

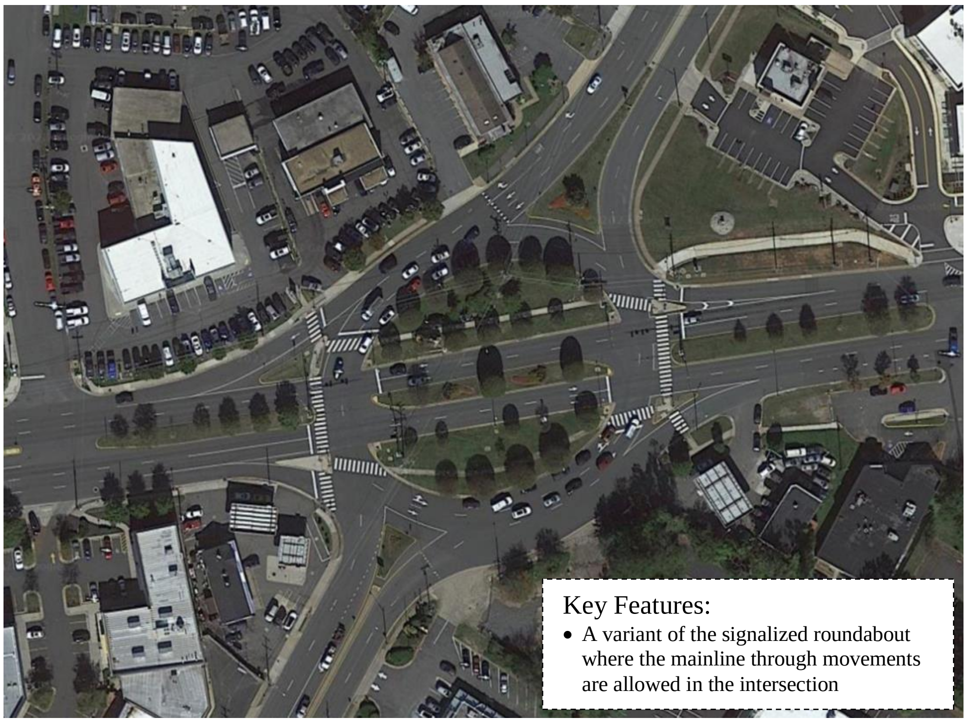


Figure 2-12 Fairfax Circle, Fairfax, VA

2.5.1 Operational Performance

- Distance Traveled
  - Turning movements utilize rotary roadway
  - Like all roundabouts, the left turn incurs the most significant out-of-direction travel; however, the travel times are likely better in low to moderate traffic volumes.
  - Possible direct turn lane into major can reduce extra distance.
- Traffic Signalization
  - Estimated number of critical phases
    - 2 critical movements
  - Cycle length/progression
    - Shorter cycle lengths than a counterpart 4-leg intersection
  - Control type (signalized, stop, yield for certain movements)
    - Low storage for minor lefts (bypass left option if enough storage in center roadway), 1.5 cycles to complete U-turn

- Progression
  - One way progression is possible on major and minor
  - Progression is possible due to signalization, whereas a normal roundabout is harder to use with nearby signals – especially with moderate to high volumes due to queue spillback potential into the circulating traffic.

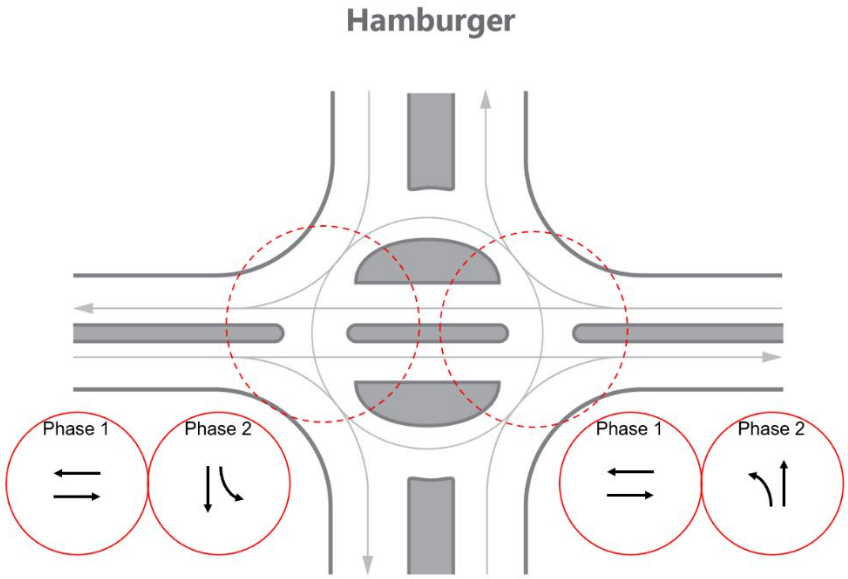


Figure 2-13 Typical Phasing Scheme at Hamburger Intersection

2.5.2 Safety Performance

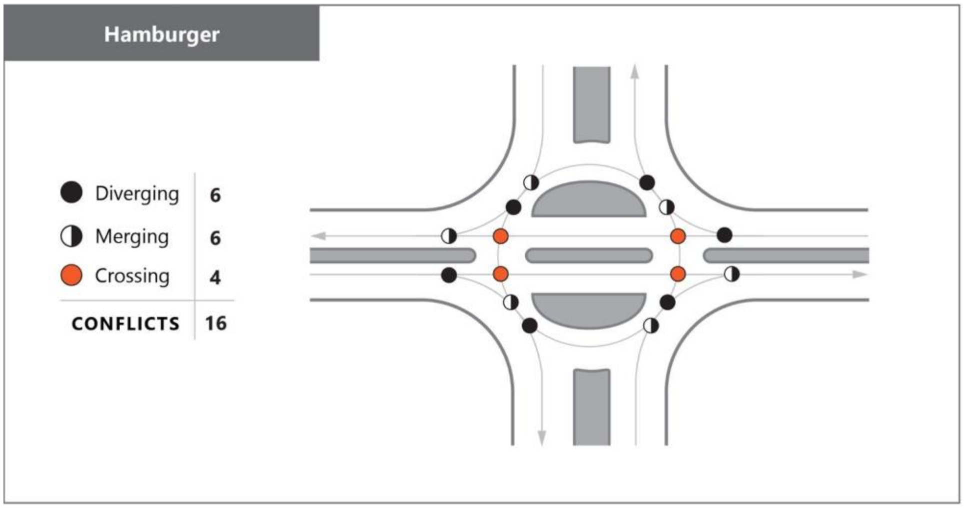


Figure 2-14 Number of Conflicts at Hamburger Intersection

- Safety Performance: Check for CMF, count conflict points

  - A hamburger intersection has a total of 16 conflict points, compared to 32 conflict points at a conventional intersection, and can potentially reduce angle collisions.
  - Adding bypass lefts increases to 22 total conflict points with two additional crossing, two additional merge, and two additional diverge
- Sight distance/other safety benefits
  - Particularly at rural/suburban low-volume minor crossings

2.5.3 Geometric Design and Implementation Considerations

- Unique geometric aspects
  - Very large intersection footprint
  - Minor street approaches may be flared to direct drivers into correct direction of traffic circle
- Multimodal design
  - Crossings at edge of traffic circle reduce the number of crossing locations but will need an additional signal phase for traffic circle exit and increase total crossing distances
- Access Management Considerations
  - Driveways cannot be directly adjacent to the traffic circle especially for exit approaches

2.5.4 Signal, Signing, Marking and Lighting

- Wrong way and guide signs needed, especially for minor street movements
- Arrow markings in traffic circle to indicate movements (especially if there is a left/u-turn bypass)

2.5.5 Construction and Implementation

- Right of way
- Utilities (moving/burying) heavily impacted for retrofit
- Construction Sequencing (traffic organization during construction phases)
- Maintenance of Traffic during retrofit- early installation of rotary allows for quicker return to service, more resiliency
- Maintenance
  - Snow- lots of complex movements to plow
  - Temporary lane closure impact- additional detour options available through rotary and u-turn lanes
  - Lane Marking quality

2.5.6 Multimodal Considerations

- Multimodal access – bike, ped (crossing types)
- Pedestrian Flags
  - Motor vehicle right turns may conflict with crossing pedestrians if channelized lanes exist.
  - May have nonintuitive motor vehicle movements, as a roundabout, drivers may expect one-way circling flow, so two-direction traffic may seem nonintuitive.
  - Pedestrians may cross yield or uncontrolled vehicle paths if uncontrolled channelized RT lanes exist.
  - Pedestrians may have out-of-direction travel due to curvatures.
  - Typically need multiples lanes to warrant a Hamburger intersection.

    - Pedestrians may conflict with motor vehicle left turns, if permissive LT signal applies for major street LT traffic.
- Bicycle Flags
    - Bicyclists may cross yield or uncontrolled vehicle paths if uncontrolled channelized RT lanes exist.
    - Bicyclists may have out-of-direction travel due to curvatures.
    - A Hamburger intersection usually has a large radius and serves heavy traffic flow, so typically needs channelized RT lanes.
    - May have channelized/dedicated RT lanes so motorists may cross bicycle path.
- Ped-vehicle control
- Pedestrian phasing
- Transit

2.5.7 Applicability

- Compared to roundabout, hamburger can be progressed in a signalized corridor. Lower speeds (especially on minor) to complete rotary movements.
- Can sometimes help address spillback and gridlock issues from downstream intersections that could be present at a roundabout as stop bars provide openings for movements.
- Often preferred compared to roundabout with heavy major through traffic needing progression
- Requires lots of right of way which may reduce applications in more urban areas where operational benefits are needed
- Ability to handle multiple minor streets (more than 4 total approaches) and highly skewed approaches connecting to rotary

2.5.8 Other Considerations

- Any additional considerations that do not fall under existing headers
- Lighting (location Urban/Sub/Rural?)

2.6 Synchronized Split-phasing

Introduction:

The synchronized split-phase intersection is the at-grade equivalent of a diverging diamond interchange (DDI), with through traffic on the mainline transitioning to the opposing side of the road between the outer two intersections, providing four efficient 2-phase intersections. Two variations are proposed in the literature – one which allows the through movement on the side street (Figure 2-16a) and one that restricts the side street through movement (Figure 2-16b).

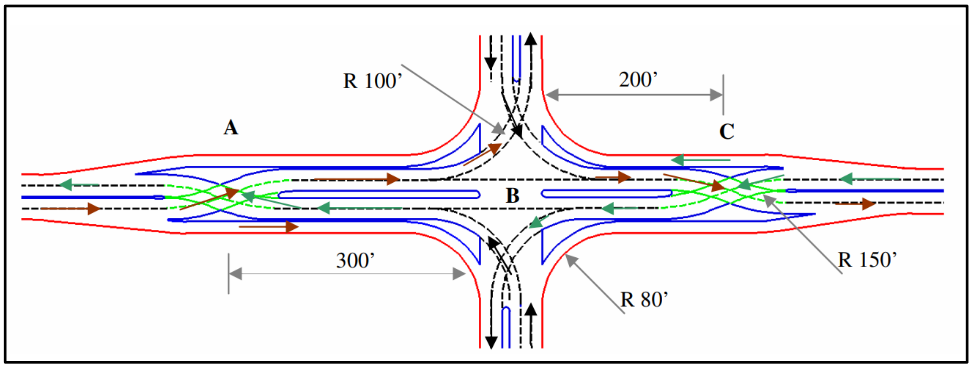
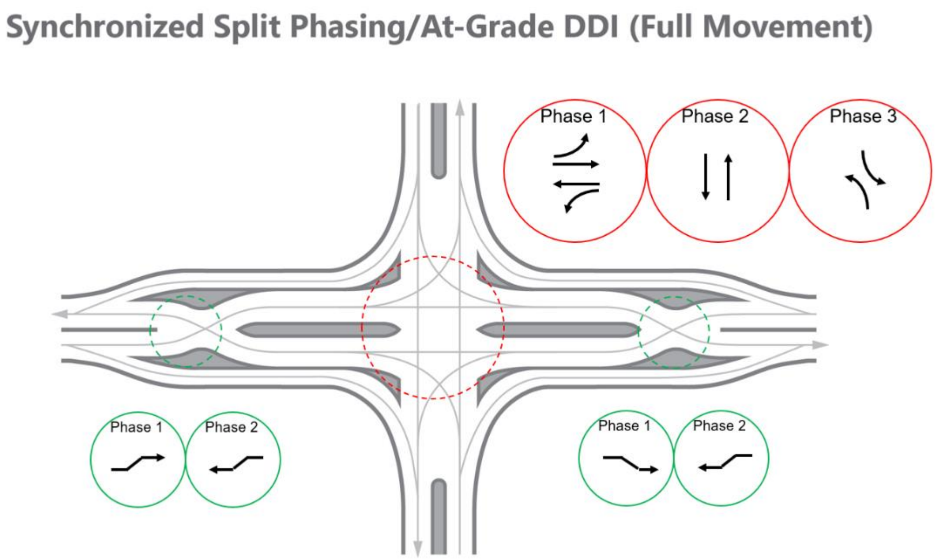


Figure 2-15 Graphical Illustration of Synchronized Split-Phasing Intersection[33]

2.6.1 Operational Performance

- Distance Traveled
  - Minimal extra distance due to alignment change
- Traffic Signalization
  - Estimated number of critical phases
    - Central intersection- 3 critical movements, secondary intersections 2 critical movements
  - Cycle length
    - shorter cycle lengths than a counterpart 4-leg intersection
  - Control type (signalized, stop, yield for certain movements)
    - Three signalized zones including two crossover signals on major
- Progression
  - Coordination on major through 3 signalized zones
  - Only one way progression

[33] https://transportation.ky.gov/Congestion-Toolbox/Documents/FHWA%20DDI%20Performance%20Research.pdf



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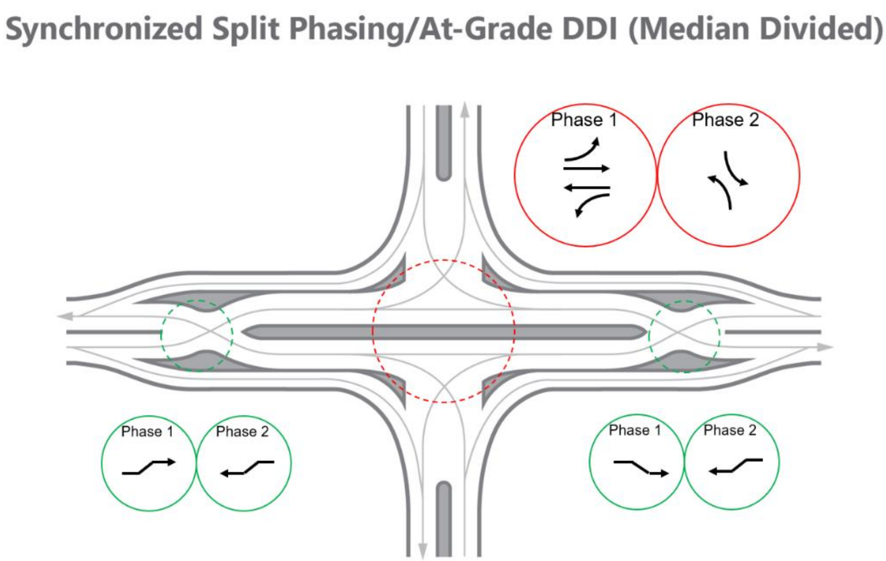
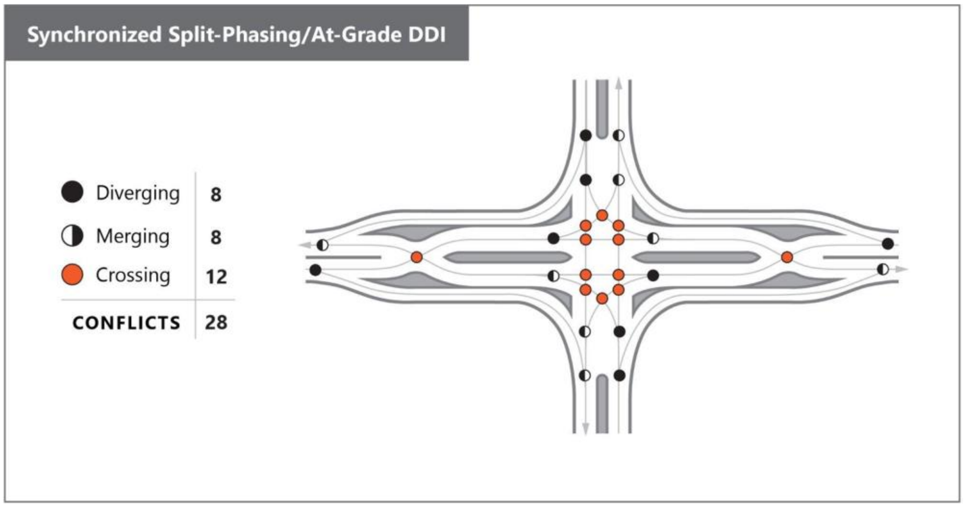


(b)

Figure 2-16 Typical Phasing Scheme at Synchronized Split Phasing Intersection (a) No Median Divided; (b) Median Divided

2.6.2 Safety Performance



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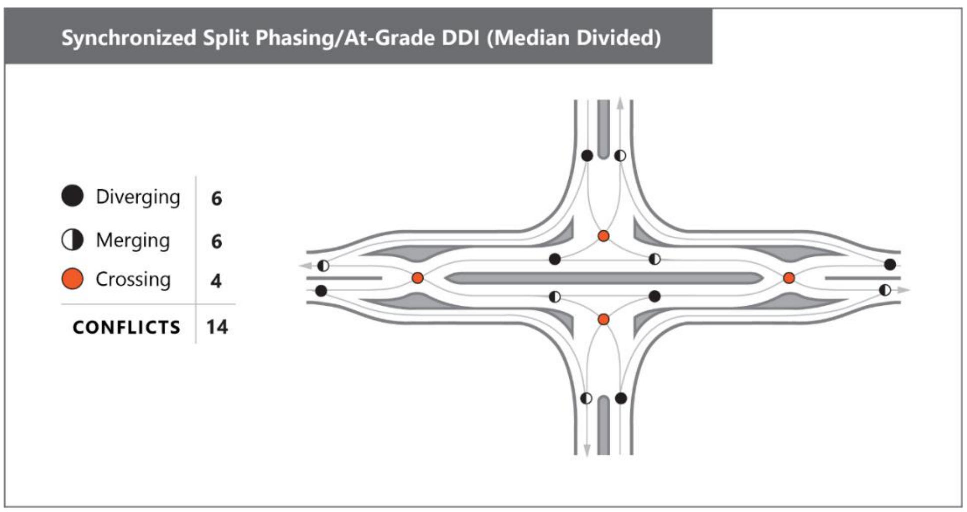


(b)

Figure 2-17 Number of Conflicts at Synchronized Split Phasing Intersection (a) No Median Divided; (b) Median Divided

- Safety Performance: Check for CMF, count conflict points
  - A synchronized split intersection has a total of 28 conflict points for full movement and 20 conflict points for median divided, compared to 32 conflict points at a conventional intersection
  - All conflicts that were removed were crossing conflicts.
- Sight distance/other safety benefits
  - Due to crossover, major lefts do not conflict with opposing through
  - Also has better sight lines and only looking for conflicting traffic at a single approach.

2.6.3 Geometric Design and Implementation Considerations

- Unique geometric aspects
  - Consider the crossover angles (use DDI guide recommendations)
  - Barriers, curbing, striping, and even signal heads can all be used to help with guidance through the crossover intersections
- Multimodal design
  - Marked crossings needed for right turn channelized lanes
- Access Management Considerations
  - Reduced access/parking on major due to crossover and long channelized lanes

2.6.4 Signal, Signing, Marking and Lighting

- Clear guide signs in advance (right channelized lane separates early)
- Crossover skip lines to show main through alignment

2.6.5 Construction and Implementation

- Right of way
- Utilities (moving/burying)
- Construction Sequencing (traffic organization during construction phases)
- Maintenance of Traffic
- Maintenance
  - Snow
  - Temporary lane closure impact
  - Lane Marking quality

2.6.6 Multimodal Considerations

- Multimodal access – bike, ped (crossing types)
- Pedestrian Flags
  - Peds may have passed the channelized RT lane, so RTOG vehicle may or may not conflict with peds.
  - LT vehicles arrive from an unexpected approach direction.
  - Pedestrians may cross yield or uncontrolled vehicle paths if uncontrolled channelized RT lanes exist.
  - Typically need multiple lanes to warrant a Synchronized split phasing intersection.
  - Pedestrians may conflict with motor vehicle left turns if permissive minor LT signal applies.
- Bicycle Flags
  - Bicyclists may cross yield or uncontrolled vehicle paths if uncontrolled channelized RT lanes exist.
  - Bicyclists may cross channelized lanes, depends on actual intersection configuration.
  - Right turn motorists have to cross bicycle path.
- Ped-vehicle control
- Pedestrian phasing
- Transit

2.6.7 Applicability

- Useful for highly directional traffic on major

- May require additional ROW to achieve enough separation for crossover
- Channelized rights also increase ROW need

2.6.8 Other Considerations

- Lighting
  - Location for this intersection would be suburban/urban. Good lighting at the crossovers would ideal, similar to recommendations at the DDI.

2.7 Offset T-intersection

Introduction:

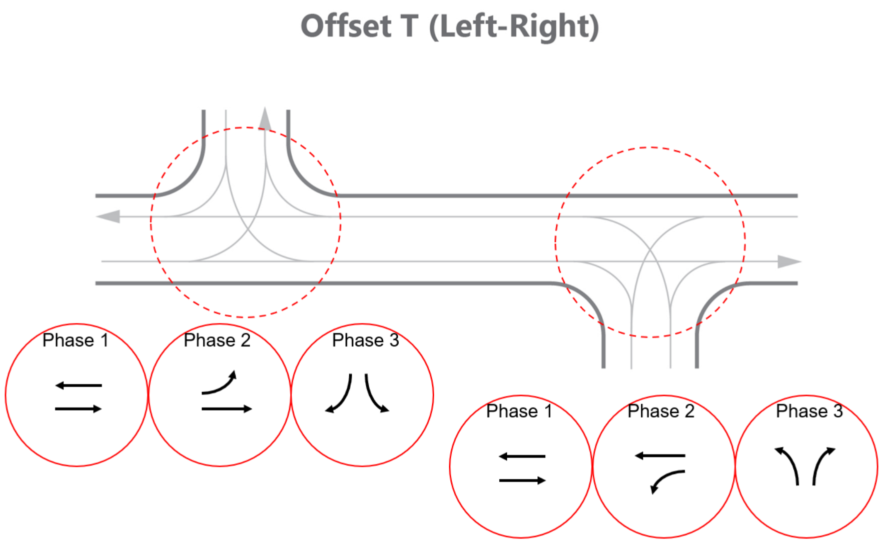
An offset T-intersection is a variation of the conventional intersection, with the minor street approaches offset by a distance (usually 200' to 800'). This lateral separation causes through movements from the minor streets to be diverted to right-turn movements followed by left-turn movements to the other offset minor leg. When considering the side street movements, there are two variations in the Offset-T, a right-left (R-L) and a left-right (L-R). The primary difference is that the R-L design must store left turning queues on the mainline, whereas the L-R design (shown below) does not have left turn storage concerns.

Figure 2-18 Capital Blvd and Highwoods/ Westinghouse Blvd in Raleigh, NC

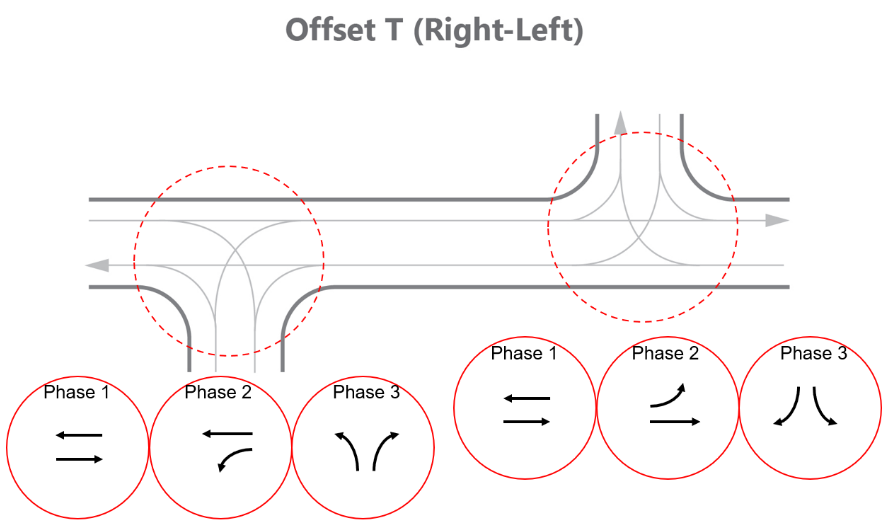
2.7.1 Operational Performance

- Distance Traveled
  - Side street through movements have additional travel distance (and potentially TT)
  - Heavy side street through movements are probably not ideal for this intersection configuration – especially the R-L design.
- Traffic Signalization
  - Estimated number of critical phases
    - No more than 3 critical movements
  - Cycle length
    - shorter cycle lengths than a counterpart 4-leg intersection
  - Control type (signalized, stop, yield for certain movements)
    - Two signalized zones
- Progression
  - Coordination between two T-intersections

        - Queue spillback for left turns on the mainline must be considered if using a R-L design to maximize capacity and progression of vehicles.
    - Good one way progression due to three phase signals
- Vehicle + Multimodal based on simulation/field
    - The L-R offset T-intersection performed better than R-L offset in terms of preventing main-street left turn queue spillback
    - For the LR offset, a longer spacing generally resulted in a lower vehicle delay
    - In general, 4-leg standard intersections resulted in a lower pedestrian delay in comparison with offset T-intersections.



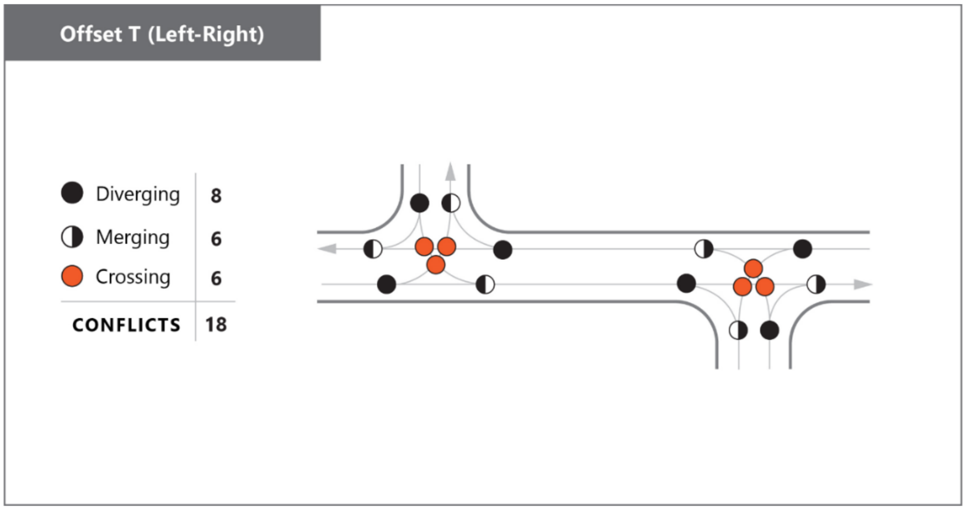
(a)



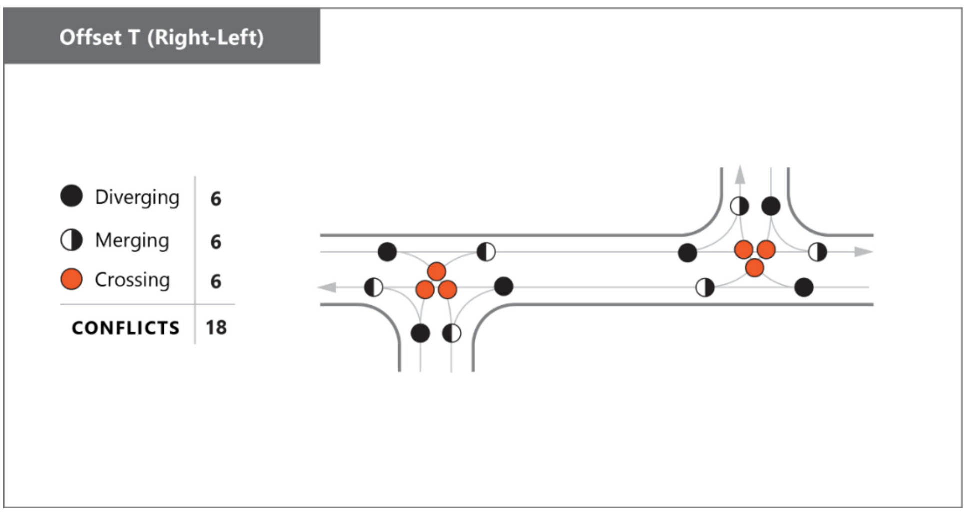
(b)

Figure 2-19 Typical Phasing Scheme at (a) Left-Right Offset; (b) Right-Left Offset

2.7.2 Safety Performance



(a)



(b)

Figure 2-20 Number of Conflicts at Offset T-Intersection (a) Left-Right Offset; (b) Right-Left Offset

- Safety Performance: Check for CMF, count conflict points
  - An offset T-intersection has a total of 18 conflict points, compared to 32 conflict points at a conventional intersection, and can potentially reduce angle collisions.
    - The primary reduction is conflicts is crossing (16 to 6)

Study Name	Summary CMF (range)	Crash Type	CMF	Stars	Applicable Conditions
Persaud et al., 2009	0.662	All		3	Not Specified
		K/A/B/C	0.644	3	Not Specified
		Left Turn All	0.62	3	Not Specified

- Sight distance/other safety benefits
  - Particularly at rural/suburban low-volume high-speed roads
  - Reduced movements per intersection component decreases conflicts

2.7.3 Geometric Design and Implementation Considerations

- Unique geometric aspects
  - Consider if major left storage needs to open prior to upstream intersection as an additional lane
- Multimodal design (offset approaches)
  - Additional ped crossing distance
  - Median crosswalk refuge may be needed
- Access Management Considerations
  - Minimize parking/driveway access internal to the offset pair

2.7.4 Signal, Signing, Marking and Lighting

- Signal phasing for both LR and RL configurations[34]
- Additional guide signs to show minor through movement combination
- Lighting may be needed for median ped refuge

2.7.5 Construction and Implementation

- Right of way
- Utilities (moving/burying)
- Construction Sequencing (traffic organization during construction phases)
- Maintenance of Traffic
- Maintenance
  - Snow
  - Temporary lane closure impact
  - Lane Marking quality

2.7.6 Multimodal Considerations

- Multimodal access – bike, ped (crossing types)
- Pedestrian Flags
  - Motor vehicle right conflict with crossing pedestrians.
  - Pedestrians may cross yield or uncontrolled vehicle paths, depends on whether ped crosswalks are signal controlled or not.
  - Minor street peds and major street LT peds have extra travel distance to cross the intersection.
  - Major street may have more than 2 lane per direction.
  - Pedestrians may conflict with motor vehicle left turns if permissive LT signal applies.
- Bicycle Flags
  - Bicyclists may cross yield or uncontrolled vehicle paths, depends on if the intersection is signalized or not.
  - Minor street and major street LT bicyclists have extra travel distance to cross the intersection.
  - Bicyclists may cross channelized lanes, depends on actual intersection configuration.
  - May have channelized/dedicated RT lanes so motorists may cross bicycle path.
- Ped-vehicle control

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[34] Cunningham et al., Operational Application of Signalized Offset T-Intersections. Report No. FHWA/NC/2019-31, North Carolina Department of Transportation, 2020. https://connect.ncdot.gov/projects/research/RNAProjDocs/2019-31FinalReport.pdf

  - Signalized
  - Peds can cross mainline in single or multistage
  - Minor street crossings single stage
- Transit
  - Transit stops are best suited on the upstream side of the intersection to prevent blocking of movements downstream.
  - If transit stops must be located on the downstream portions of the mainline intersections, a pull-out would ideally be located outside of the travel lanes.

2.7.7 Applicability

- This kind of intersection is particularly useful in situations where both the major and minor road through volumes are low
- Another situation where the offset-T intersection can be appropriate is a retrofit of a skewed intersection with heavy turn volumes and limited through volumes on the minor.
- New neighborhoods do not have to have the minor approaches across from each other. For instance, if a new neighborhood is being designed across from another existing neighborhood, the new intersection leg is often put directly across from the existing side street leg. In time, that can be very inefficient. An offset could be a better alternative.
- Intersection of arterial with collector or minor arterial
- Rural, suburban, or urban
- Signalized or unsignalized
- Four legs
- Low pedestrian demand is ideal – especially if wanting to cross the mainline.
- ROW available to provide large-enough offset
  - Shorter distances, esp. for R-L, can be problematic b/c of need for storage
  - Longer distances are more challenging to coordinate b/c of platoon dispersion.

2.7.8 Other Considerations

- Any additional considerations that do not fall under existing headers
- Lighting (location Urban/Sub/Rural?)

2.8 Continuous Green T-intersection

Introduction:

The Continuous Green-T can only be used at T-intersections. The design provides free-flow operations in one direction on the arterial 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.

Figure 2-21 Avent Ferry Rd and Village Walk Dr in Holly Springs, NC

2.8.1 Operational Performance

- Progression
  - Two-way progression possible due to one uninterrupted through movement
- Distance Traveled
  - None
- Traffic Signalization
  - Estimated number of critical phases
    - No more than 3 critical movements
  - Cycle length/progression
    - short cycle lengths than a counterpart 4-leg intersection
  - Control type (signalized, stop, yield for certain movements)
    - Signalized with one uninterrupted through movement

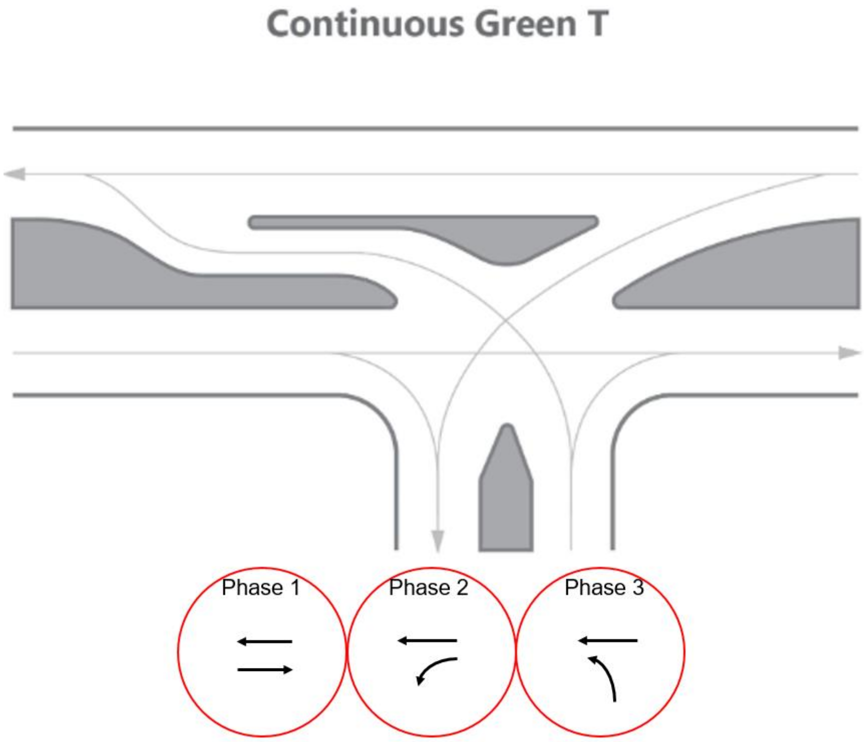


Figure 2-22 Typical Phasing Scheme at Continuous Green-T-Intersection

2.8.2 Safety Performance

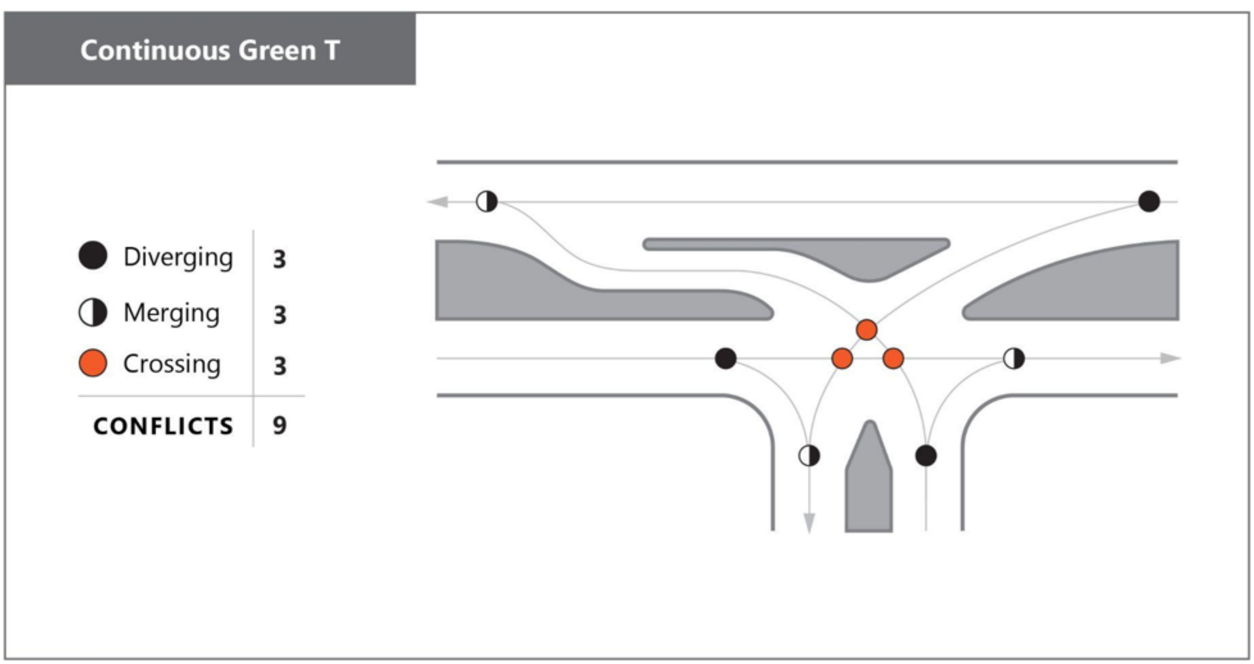


Figure 2-23 Number of Conflicts at Continuous Green-T-Intersection

- Safety Performance: Check for CMF, count conflict points
    - A continuous green T-intersection has a total of 9 conflict points, consistent a conventional three leg intersection

Study Name	Summary CMF (range)	Crash Type	CMF	Stars	Applicable Conditions
Wood and Donnell, 2016	0.958	All		3	Not Specified
		K/A/B/C	0.846	3	Not Specified

- Sight distance/other safety benefits
    - Possible confusion with merge movement
    - Through cannot be uninterrupted and serve peds at grade

2.8.3 Geometric Design and Implementation Considerations

- Unique geometric aspects
    - Limited to single lane for left turn from stem
    - Intersection area extends downstream for merge
- Multimodal design
    - Location of ped crosswalks
- Access Management Considerations
    - Parking and driveway access limited near intersection
    - Median treatment options

2.8.4 Signal, Signing, Marking and Lighting

- Minimal additional signing (maybe speed limit reminder for uninterrupted movement)
- Markings/skip lines- show left turn into merge

2.8.5 Construction and Implementation

- Right of way
- Utilities (moving/burying)
- Construction Sequencing (traffic organization during construction phases)
- Maintenance of Traffic
- Maintenance
    - Snow
    - Temporary lane closure impact
    - Lane Marking quality

2.8.6 Multimodal Considerations

- Multimodal access – bike, ped (crossing types)
- Ped-vehicle control
- Pedestrian phasing
- Transit
- Pedestrian Flags
    - Motor vehicle right turns conflict with crossing pedestrians.
    - Pedestrians may cross yield or uncontrolled vehicle paths if ped crosswalks are unsignalized.
    - May have multilane crossings if major street has more than 2 lane per direction.
    - Pedestrians may conflict with motor vehicle left turns if permissive LT signal applies.

- Bicycle Flags
  - Bicyclists may cross channelized lanes, depends on actual intersection configuration.
  - May have channelized/dedicated RT lanes so motorists may cross bicycle path.

2.8.7 Applicability

- Intersection of arterial with collector or minor arterial
- Minor street demand low enough that only one left turn lane needed
- Great to consider on the outbound leg of a minor street left at a quadrant intersection
- Rural or suburban
- Signalized or unsignalized
- Three legs
- No pedestrian or bicycle demand to cross arterial
- Few nearby businesses to be harmed

2.8.8 Other Considerations

- Any additional considerations that do not fall under existing headers
- Lighting (location Urban/Sub/Rural?)

2.9 Jughandle

Introduction:

A jughandle 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 from the left lane, left-turning traffic uses a ramp on the right side of the road. In a standard forward jughandle or near-side jughandle, the ramp leaves before the intersection, and left-turning traffic turns left off of it rather than the through road; right turns are also made using the jughandle. In a reverse jughandle or far-side jughandle, the ramp leaves after the intersection, and left-turning traffic loops around to the right and merges with the crossroad before the intersection.

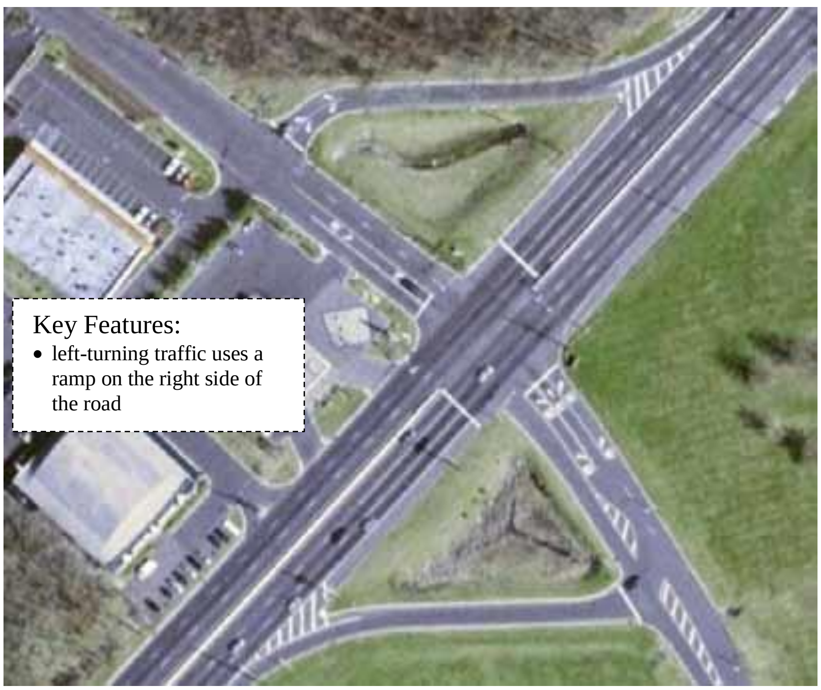


Figure 2-24 A Typical jughandle intersection in New Jersey

2.9.1 Operational Performance

- Distance Traveled
  - Major lefts divert to secondary intersections
- Traffic Signalization
  - Estimated number of critical phases
    - Central intersection- 3 critical movements
  - Cycle length/progression
    - shorter cycle lengths than a counterpart 4-leg intersection
  - Control type (signalized, stop, yield for certain movements)

  - Secondary intersections may be stop controlled under low volumes, signalized with higher turning movements/conflicting volumes
- Progression
  - One way progression
- Vehicle + Multimodal based on simulation/field

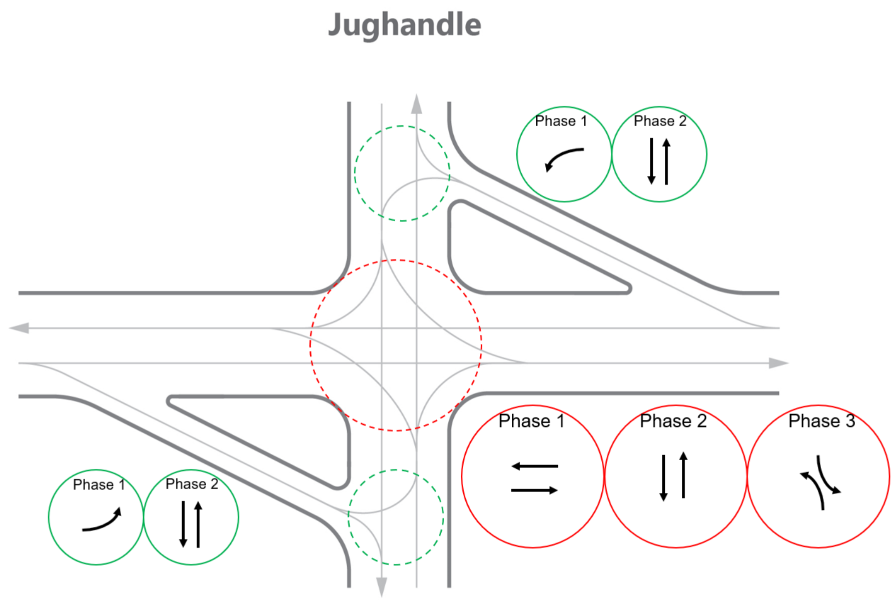


Figure 2-25 Typical Phasing Scheme at Jughandle Intersection

2.9.2 Safety Performance

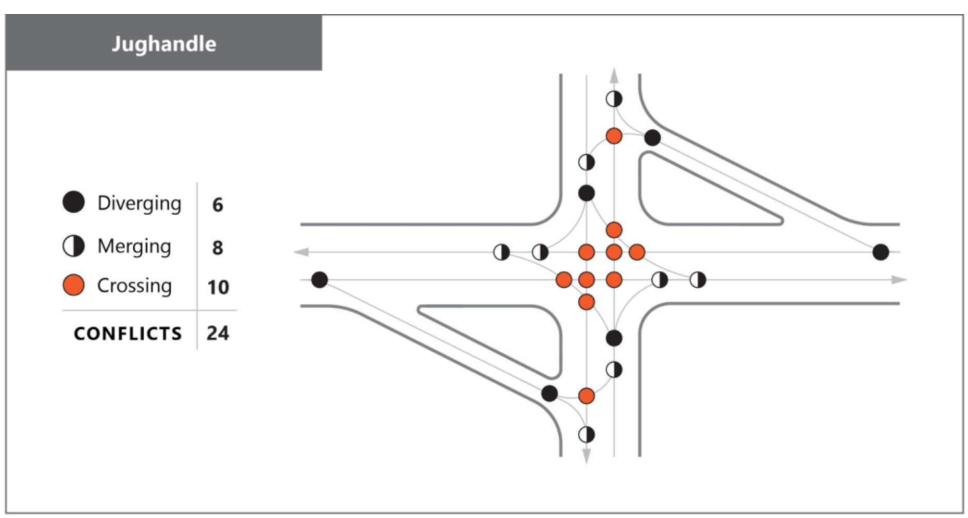


Figure 2-26 Number of Conflicts at Jughandle Intersection

- Safety Performance: Check for CMF, count conflict points

  - A jughandle intersection has a total of 24 conflict points, compared to 32 conflict points at a conventional intersection, and can potentially reduce angle collisions.
- Sight distance/other safety benefits
  - Right to go left needs additional signage

2.9.3 Geometric Design and Implementation Considerations

- Unique geometric aspects
  - Requires jughandle quadrant ROW
  - Possible to use network/adjacent roadways to complete the movements
- Multimodal design (offset approaches)
  - Crosswalks may align with the jughandle channelized lane to avoid crossing the veh diverge point
- Access Management Considerations
  - Jughandle quadrants have limited driveway and parking access

2.9.4 Signal, Signing, Marking and Lighting

- NJDOT has example markings
- Wrong way signage for channelized lanes

2.9.5 Construction and Implementation

- Right of way heavily impacted in jughandle quadrants
- Utilities (moving/burying) may need to be moved for jughandle movements
- MOT is simple for conversion/upgrade

2.9.6 Multimodal Considerations

- Multimodal access – bike, ped (crossing types)
- Ped-vehicle control
- Pedestrian phasing
- Transit
- Pedestrian Flags
  - Motor vehicle right turns conflict with crossing pedestrians.
  - Pedestrians may cross yield or uncontrolled vehicle paths as there may have uncontrolled channelized RT lanes at the main intersection.
  - May have multilane crossings if major street has more than 2 lane per direction.
  - Pedestrians may conflict with motor vehicle left turns if there are LT lanes and permissive LT signals at the main intersection.
- Bicycle Flags
  - Bicyclists may cross yield or uncontrolled vehicle paths if there are uncontrolled channelized RT lanes at the main intersection.
  - Bicyclists may cross channelized lanes, depends on actual intersection configuration.
  - Turning motorists have to cross bicycle paths.

2.9.7 Applicability

- Requires very low volume minor roads to minimize the extra delay added to rerouted turning movements

2.9.8 Other Considerations

- Any additional considerations that do not fall under existing headers
- Lighting (location Urban/Sub/Rural?)

Chapter 3 - Alternative Grade-Separated Intersections

3.1 Overview

- Conceptual Description- two surface streets (arterial or secondary) crossing with grade separation, includes control on both streets (interrupted flow on both roads)
- Goal: Operational efficiency by removing signal phases and safety benefits by reducing conflicts and/or severity
- Important Note: The GSIX shown in this chapter assume the same intersection treatment for the N-S and E-W directions; however, the designer can mix and match many different AIs (for instance, and contraflow can be the N-S direction combined with a MUT on the E-W).
    - o Traffic volumes, ped/bike considerations, available ROW, etc. should all be considered when looking at options.

- Keep it to service interchange and not system interchange
    - o Can categorize 3 and 4 leg again (only a few 3)
    - o Consider urban/rural even

Table 3-1 Comparison of Alternative Grade-separated Intersections with Traditional Designs

AII Design	Operations (Conflicts + Critical Phases)	Progression Quality	Safety (Veh Conflict Points)	Unusual Maneuvers	Wrong Way Potential	Right of Way	Structures	Crossing Pedestrians	Bicycle Accessibility
Center Turn Overpass	****	****	****	*****	*****	***	**	****	****
Echelon	*****	****	****	*****	*****	***	***	***	****
Grade Separated Quadrant	***	***	****	***	*****	**	***	***	***
Grade Separated RCUT (U-turn then Right)	*****	*****	*****	****	*****	***	***	***	**
Grade Separated RCUT (Right then U-turn)	*****	*****	*****	****	*****	***	***	***	**
Grade Separated RCUT (Contra-RCUT)	*****	*****	*****	***	*****	***	***	***	***
Grade Separated Direct Lefts (Diamond)	*****	****	****	****	*****	***	***	***	**
Grade Separated Direct Lefts (Offset)	*****	****	****	****	*****	***	**	**	**
Grade Separated Direct Lefts (Displaced)	*****	*****	****	***	*****	***	**	*	**
Grade Separated Single Point	*****	****	****	*****	*****	***	***	*	**

Notes:

1. Operations indicates the type and number of conflicting critical movements
2. Unusual Maneuvers: Motorized traffic approaching from or leaving to an unexpected direction
3. Crossing Pedestrians and Bicycle Accessibility refer to NCHRP 07-25 (Table 1-3)

General/Common Considerations for Grade Separated Intersections

Operations: One key benefit to separation is the reduced number of conflicting movements and demands which can greatly reduce delays. Many of the GSIs also separate the control of E-W or N-S traffic allowing for two-way progression on these roadways. A common concern for higher demand turning movements is to ensure that ramp traffic does not back up into the main roadways.

Geometrics: Once the decision is made to grade separate, selection between GSIs and interchanges may be heavily influenced by available ROW. GSIs can support lower speed ramps which need less ROW than ramps exiting an uncontrolled roadway at interchanges. For this reason, GSIs are more easily incorporated into urban networks where keeping both arterials controlled is a benefit.

Safety: Each of the GSI designs reduces the total number of vehicle conflict points, with most greatly reducing the number of crossing conflicts. In addition, many of the crossing conflicts removed are those typically with the highest exposure. GSI designs have not received enough before/after safety analysis to develop CMFs, however Chapter 1 notes potential surrogate safety analysis methods which can be used to assist in design selection.

Multimodal: Each GSI design has specific needs on how pedestrian movements can be accommodated, especially when crossing ramps and to/from roadways on different elevations. Consider these movements early in the design process so that all users are safely and efficiently served by the design. In comparison to interchanges, GSIs maintain control on each arterial and can more easily accommodate pedestrian crossings of the roadway and ramps. Design-specific considerations for multimodal safety are included in their respective sections.

Construction and Maintenance of Traffic: Construction planning must account for maintenance of traffic during the conversion from at-grade to grade separation. This may involve temporary structures or use of the existing roadway network at nearby intersections. Most designs also provide potential for accommodating rerouted traffic through the early addition of ramps and or U-Turns to help minimize traffic flow disruptions.

Access Management: The low speed of arterial ramps at GSIs may allow for more direct driveway access with minimal disruption. Portions of the GSI may also include U-turn components which can accommodate direct lefts for more direct and controlled access.

Because the information available for grade separated intersections is limited at this time, one page summaries are provided.

3.2 Center Turn Overpass

Key Features

A Center-Turn Overpass is an intersection that elevates all left-turn movements from the main intersection using ramps in the median; left-turn vehicles use an acceleration lane to merge with through traffic.

Applicability

- May be useful for heavy left turn movements, especially if these are direction and do not oppose each other in elevated intersection.
- Due to ROW needs, more applicable in suburban/rural locations with two heavy arterials

Operational Performance

- Minimal (vertical) extra distance traveled but additional merges needed
- Traffic Signalization: 2 independent signalized zones with 2 critical movements each
- Much shorter cycle lengths than a counterpart 4-leg intersection
- Good one-way progression

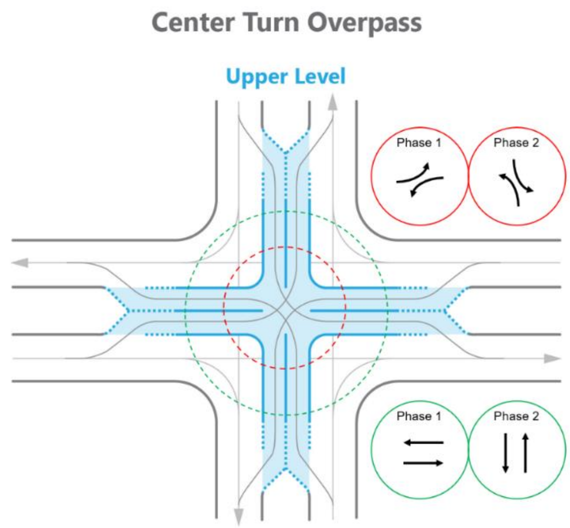
Safety Performance

- 24 total conflict points, can potentially reduce angle collisions with only protected crossing conflicts
- Sight Distance/Other Safety Benefits
  - ✓ Reduced complexity at approaches with the tradeoff of additional merging zones

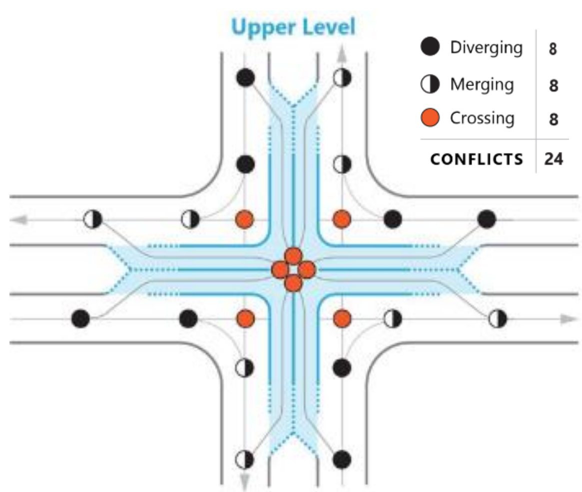
Geometric Design and Implementation Considerations

- Unique structure is required for elevated lefts
- Crosswalks located in traditional location at grade
- Access Management:
  - ✓ Access is limited to RIRO after lefts diverge
  - ✓ Avoid driveways near left downstream merge

Conceptual rendering of a Center Turn Overpass



Typical Phasing Scheme at a Center Turn Overpass



Number of Conflict Points at a Center Turn Overpass

3.3 Echelon

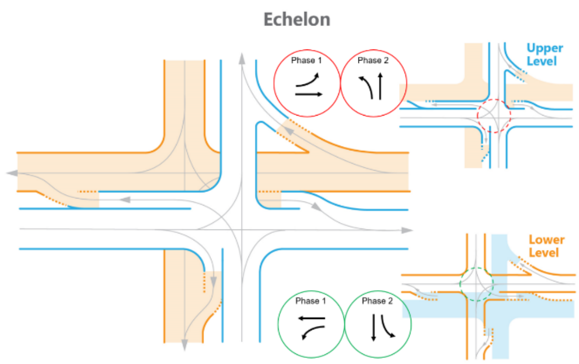
Key Features

An Echelon intersection is a grade-separated intersection where one approach on both roadways is elevated to create a pair of intersections.

Conceptual rendering of an Echelon intersection

Applicability

- With heavy traffic where main and side street traffic volumes are similar
- Where an at-grade conventional intersection is not sufficient for the traffic
- Where there is limited right of way to expand
- A related patent has been submitted, legal review may be necessary to determine if it is active and enforced.



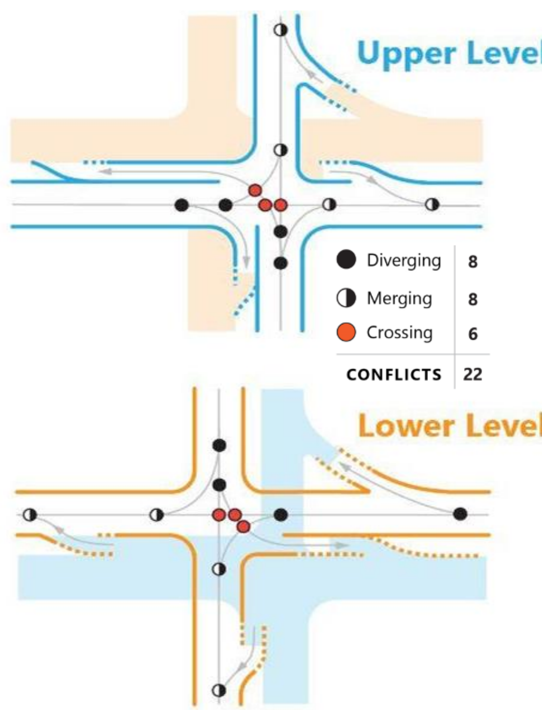
Typical Phasing Scheme at an Echelon intersection

Operational Performance

- Minimal (vertical) extra distance traveled but additional merges needed
- Traffic Signalization: Two zones with 2 critical movements each
- Shorter cycle lengths than a counterpart 4-leg intersection
- Two-way progression possible with independent signalized zones

Safety Performance

- 22 conflict points total, can potentially reduce angle collisions due to only 6 crossing conflicts.
- Sight Distance/Other Safety Benefits
  - ✓ Reduced complexity/conflicts- drivers only need to monitor one approach



Number of Conflict Points at an Echelon intersection

Geometric Design and Implementation Considerations

- Two adjacent approaches are elevated with a unique structure
- Consider impacts for ped crossing multiple elevations or ramps
- Access Management: Only RIRO after directional separation

3.4 Grade Separated Quadrant

Key Features

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

Applicability

- At intersections with low to medium left-turn traffic
- To connect a high-speed street with heavy traffic volumes to another high-speed street
- To connect existing grade-separated streets

Operational Performance

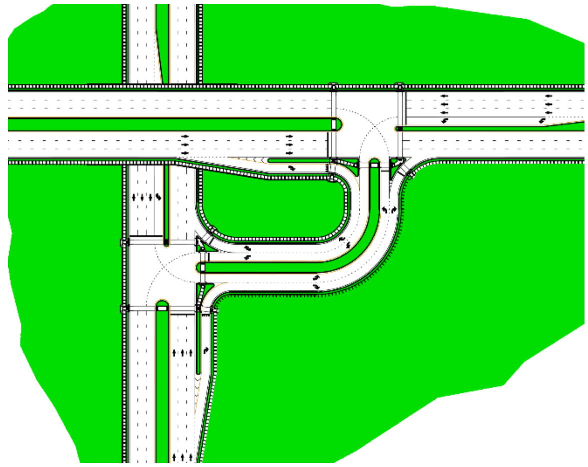
- Some extra distance traveled for diverted turning movements
- Traffic Signalization: Two signalized zones with 3 critical movements each
- Shorter cycle lengths than a counterpart 4-leg intersection
- Progression:
  - ✓ Good one-way progression on each roadway
  - ✓ Ramp to ramp progression possible

Safety Performance

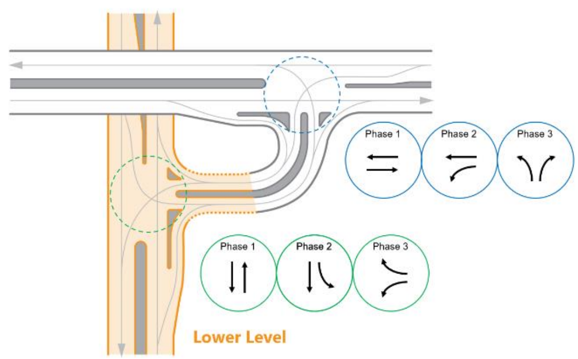
- 18 conflict points total, can potentially reduce angle collisions with only 6 crossing conflicts.
- Rights from ramp may be stop/signalized or merge, consider impact on pedestrians

Geometric Design and Implementation Considerations

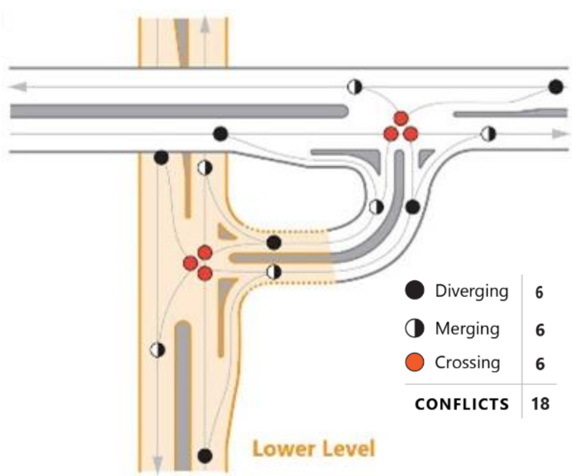
- Requires ROW or network connections for quadrant connector
- Consider right turns- signalized, channelized, merge, yield
- Opposite quadrant movements have large out of distance travel for pedestrians
- Access limited for grade separation but otherwise only impacted on connecting quadrant frontages
- For larger connectors- access may be possible on the connector itself



Conceptual rendering of a Grade Separated Quadrant



Typical Phasing Scheme at an Echelon intersection



Number of Conflict Points at an Echelon intersection

3.5 RCUT (U-turn then Right-turn)

Key Features

The left turn is separated downstream of the signal on the major road; left-turn traffic conflicting with opposing U-turn and opposing thru at U-turn point on the major road.

Applicability

- At intersections with heavy through and / or left-turn traffic volumes on both streets
- Where an at-grade conventional intersection is not sufficient for the traffic
- To connect existing grade-separated streets
- Where there is limited right of way to expand

Operational Performance

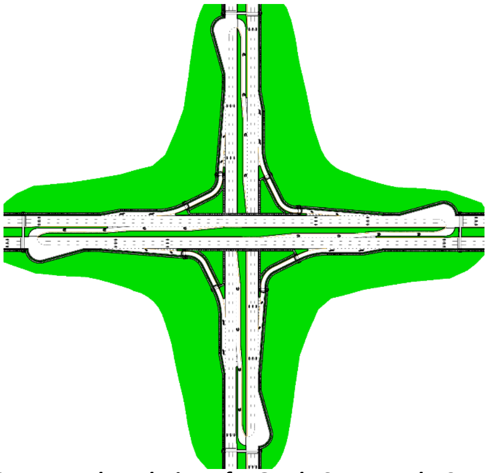
- Moderate extra distance traveled for all left turns
- Traffic Signalization: All signalized zones have 2 critical movements
- Very short cycles possible
- Consider merge vs stop vs signalized for right turn ramp merges
- Good two way progression due to independent operation of the throughs
- One signalized zone for each approach if ramp rights are merges

Safety Performance

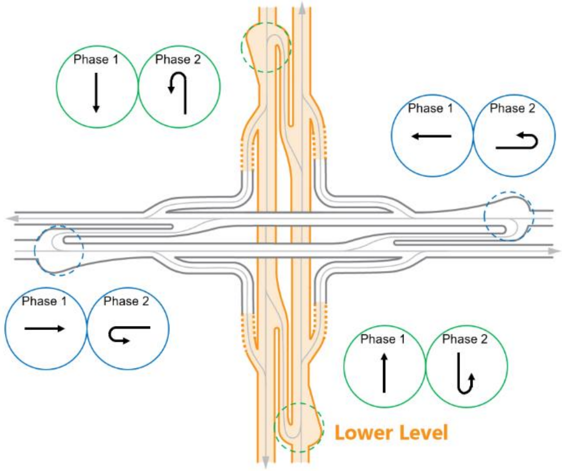
- 16 conflict points total, with large benefits to angle collisions due to no crossing conflicts
- With only merge/diverge the conflicts are simpler due to fewer movements for the driver to monitor

Geometric Design and Implementation Considerations

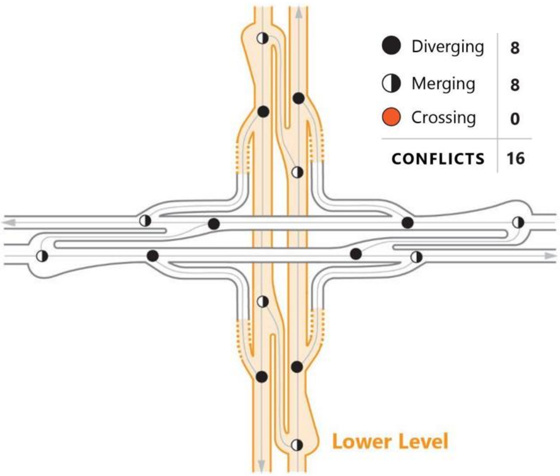
- Extended intersection area compared to more compact designs
- Offset + median crossing or additional pedestrian signal needed to cross the U-turn sections
- Left-over possible at U-turns for additional access



Conceptual rendering of a Grade Separated RCUT (U-turn then Right-turn)



Typical Phasing Scheme at a Grade Separated RCUT (U-turn then Right-turn)



Number of Conflict Points at a Grade Separated RCUT (U-turn then Right-turn)

3.6 RCUT (Right-turn then U-turn)

Key Features

Left turn traffic 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 thru at U-turn point on the minor road.

Applicability

- At intersections with heavy through and / or left-turn traffic volumes on both streets
- Where an at-grade conventional intersection is not sufficient for the traffic
- To connect existing grade-separated streets
- Where there is limited right of way to expand

Operational Performance

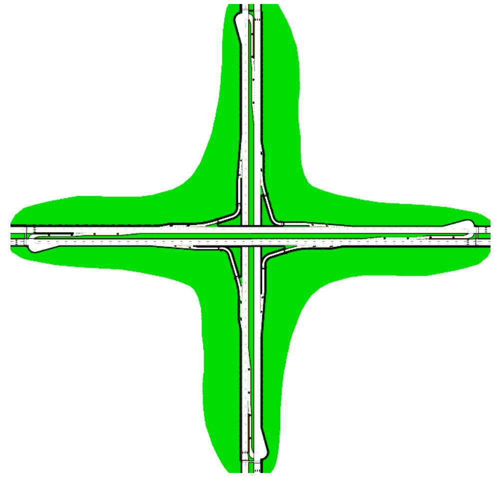
- Extra distance traveled for all left turns
- Traffic Signalization: All signalized zones have 2 critical movements
- Very short cycles possible
- Consider merge vs stop vs signalized for right turn ramp merges
- Good two way progression due to independent operation of the throughs
- One signalized zone for each approach if ramp rights are merges

Safety Performance

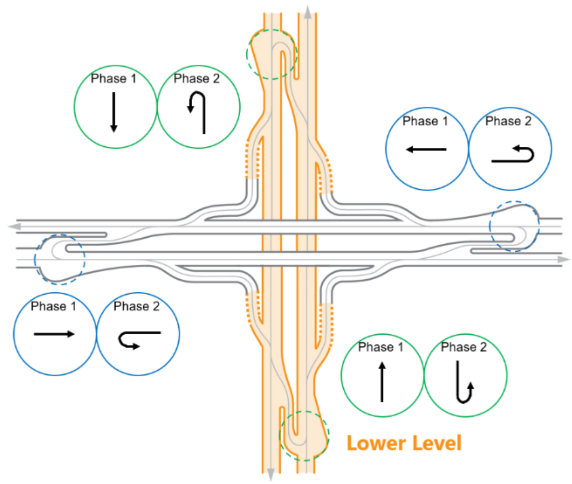
- 16 conflict points total with large benefits to angle collisions due to no crossing conflicts
- With only merge/diverge the conflicts are simpler due to fewer movements for the driver to monitor

Geometric Design and Implementation Considerations

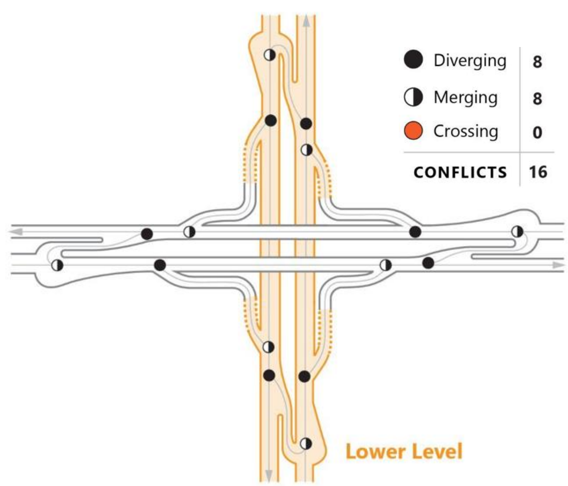
- Extended intersection area compared to more compact designs
- Offset + median crossing or additional pedestrian signal needed to cross the U-turn sections
- Left-over possible at U-turns for additional access



Conceptual rendering of a Grade Separated RCUT (Right-turn then U-turn)



Typical Phasing Scheme at a Grade Separated RCUT (Right-turn then U-turn)



Number of Conflict Points at a Grade Separated RCUT (Right-turn then U-turn)

3.7 Contra RCUT

Key Features

The left turn is separated upstream of the signal on the major road; left-turn traffic conflicting with opposing thru at U-turn point on the major road.

Applicability

- At intersections with heavy through and left-turn traffic volumes on both streets
- Where an at-grade conventional intersection is not sufficient for the traffic
- To connect existing grade-separated streets
- Where there is limited right of way to expand

Operational Performance

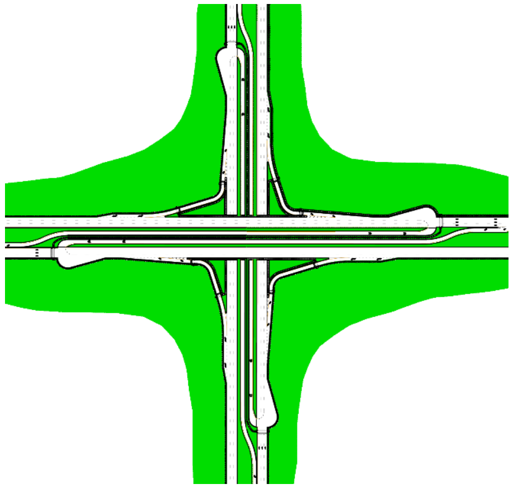
- Minimal extra distance traveled for all left turns
- Traffic Signalization: All signalized zones have two critical movements
- Very short cycles possible
- Consider merge vs stop vs signalized for right turn ramp merges
- Good two way progression due to independent operation of the throughs
- One signalized zone for each approach if ramp rights are merge controlled

Safety Performance

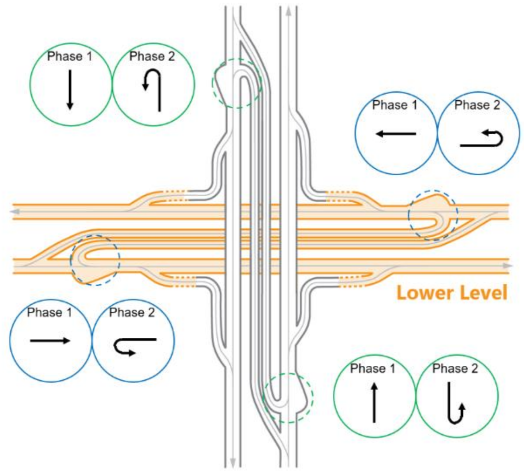
- 16 conflict points total with large benefits to angle collisions with no crossing conflicts
- With only merge/diverge the conflicts are simpler due to fewer movements for the driver to monitor
- Opposing Lefts do not conflict with each other due to contraflow lanes

Geometric Design and Implementation Considerations

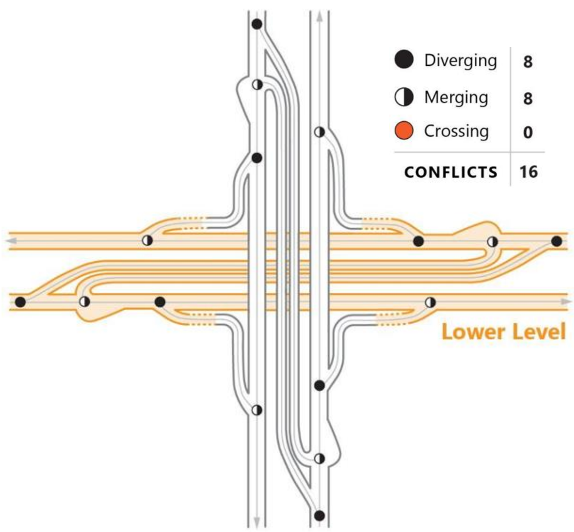
- Contraflow lanes need more right of way between U-turns compared to other RCUT GSIs
- Location of ped crosswalks can be difficult if not additional signalized crossings at U-turns
- Access Management: Left-over possible at U-turns



Conceptual rendering of a Grade Separated RCUT (Contra RCUT)



Typical Phasing Scheme at a Grade Separated RCUT (Contra RCUT)

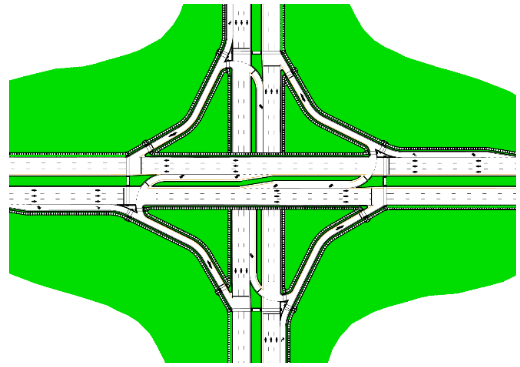


Number of Conflict Points at a Grade Separated RCUT (Contra RCUT)

3.8 Direct Left (Downstream Diamond)

Key Features

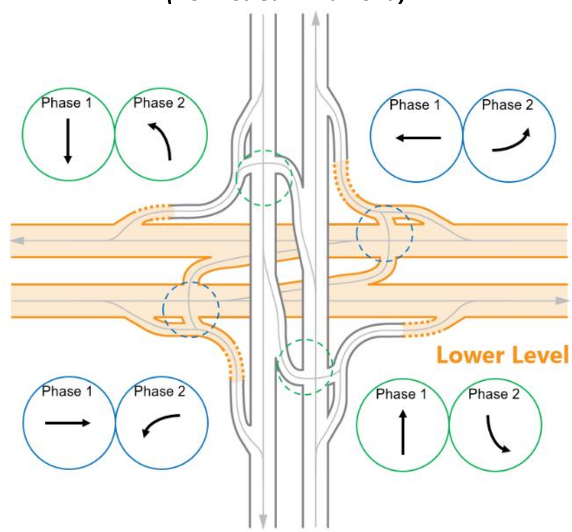
The left turn is separated downstream of the signal on the major road; left-turn traffic conflicting with opposing thru at U-turn point on the major road.



Conceptual rendering of a Grade Separated Direct Left (Downstream Diamond)

Applicability

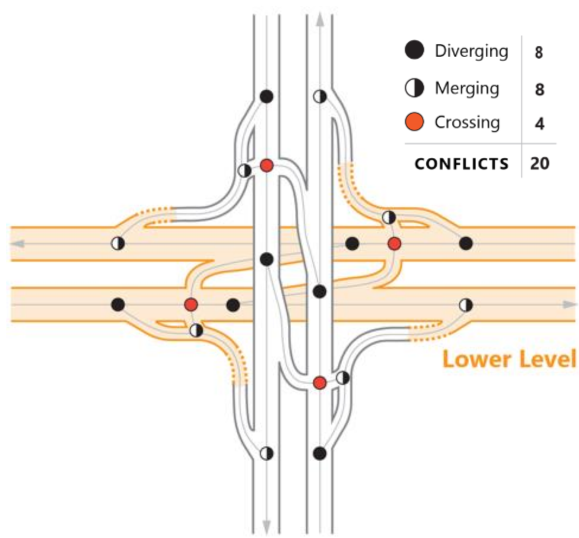
- At intersections with heavy through and left-turn traffic volumes on both streets
- Where an at-grade conventional intersection is not sufficient for the traffic
- To connect existing grade-separated streets
- Where there is limited right of way to expand



Typical Phasing Scheme at a Grade Separated Direct Left (Downstream Diamond)

Operational Performance

- Minimal extra distance traveled on ramps
- Traffic Signalization: All signalized zones have 2 critical movements
- Shorter cycle lengths than a counterpart 4-leg intersection
- Consider merge vs stop vs signalized for right turn ramp merges
- Progression: Both roadways can have good two-way progression due to independent operation of the throughs



Number of Conflict Points at a Grade Separated Direct Left (Downstream Diamond)

Safety Performance

- 20 conflict points total and only four crossing can reduce angle collisions compared to traditional at grade intersection
- Reduced complexity- Design is very similar to diamond interchange and easily understood

Geometric Design and Implementation Considerations

- Traditional Diamond-style configuration, with tighter ramps possible due to lower speed arterial traffic
- Location of ped crosswalks similar to Diamond
  - ✓ Access Management opportunities also like Diamond Interchange

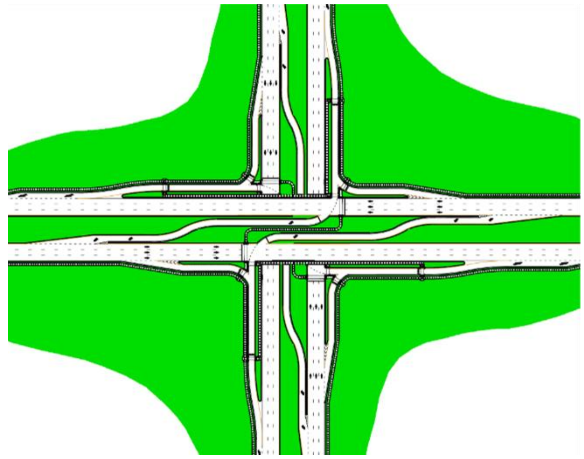
3.9 Direct Left (Downstream Offset)

Key Features

The left turn is separated downstream of the signal on the major road; left-turn traffic conflicting with opposing thru at U-turn point on the major road.

Applicability

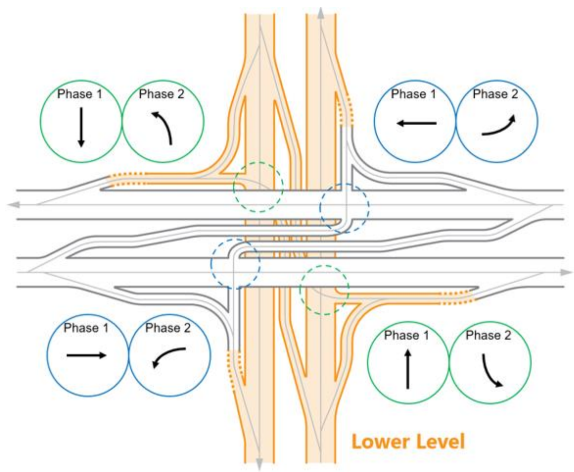
- At intersections with heavy through and left-turn traffic volumes on both streets
- Where an at-grade conventional intersection is not sufficient for the traffic
- To connect existing grade-separated streets
- Where there is limited right of way to expand



Conceptual rendering of a Grade Separated Direct Left (Downstream Offset)

Operational Performance

- Minimal extra distance traveled on ramps
- Traffic Signalization: All signalized zones have two critical movements
- Shorter cycle lengths than a counterpart 4-leg intersection
- Consider merge vs stop vs signalized for right turn ramp merges
- Progression: Both roadways can have good two-way progression due to independent operation of the throughs



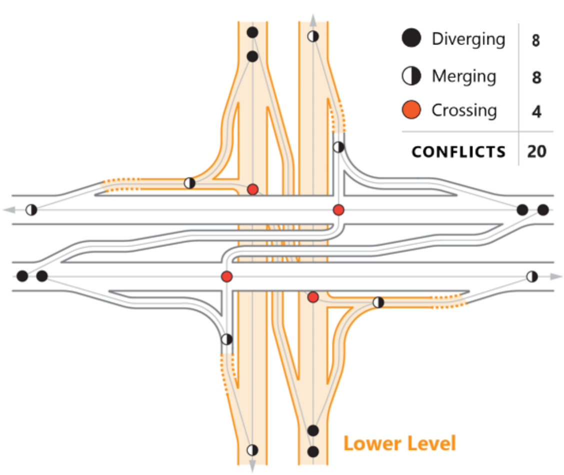
Typical Phasing Scheme at a Grade Separated Direct Left (Downstream Offset)

Safety Performance

- 20 conflict points total and only four crossing can reduce angle collisions compared to traditional at grade intersection
- Reduced complexity due to similarity to Diamond
- Opposing left turns do not conflict with each other due to offset/contraflow lane

Geometric Design and Implementation Considerations

- Contraflow lanes will require more ROW over/under the bridge
- Ped crossings can occur similar to downstream direct lefts or using Z crossing between contraflow lanes
- Access Management: Impacts similar to downstream direct lefts



Number of Conflict Points at a Grade Separated Direct Left (Downstream Offset)

3.10 Direct Left (Upstream Crossover)

Key Features

The left turn is separated upstream of the signal on the major road; left-turn traffic conflicting with opposing thru at U-turn point on the major road.

Applicability

- At intersections with heavy through and left-turn traffic volumes on both streets
- Where an at-grade conventional intersection is not sufficient for the traffic
- To connect existing grade-separated streets
- Where there is limited right of way to expand

Operational Performance

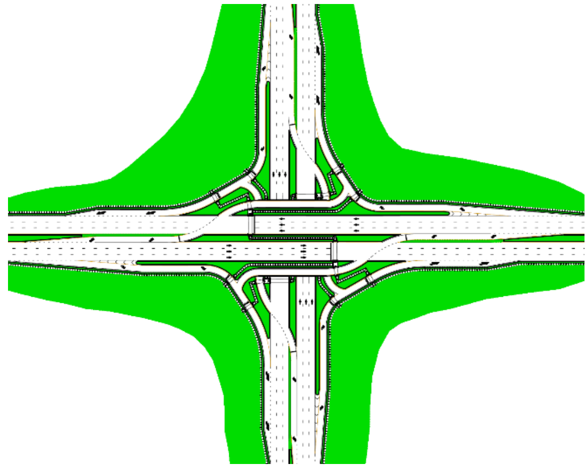
- Minimal extra distance traveled on ramps and crossover
- Traffic Signalization: All signalized zones have two critical movements
- Shorter cycle lengths than a counterpart 4-leg intersection
- Consider merge vs stop vs signalized for right turn ramp merges
- Progression: Both roadways can have good two-way progression due to independent operation of the throughs

Safety Performance

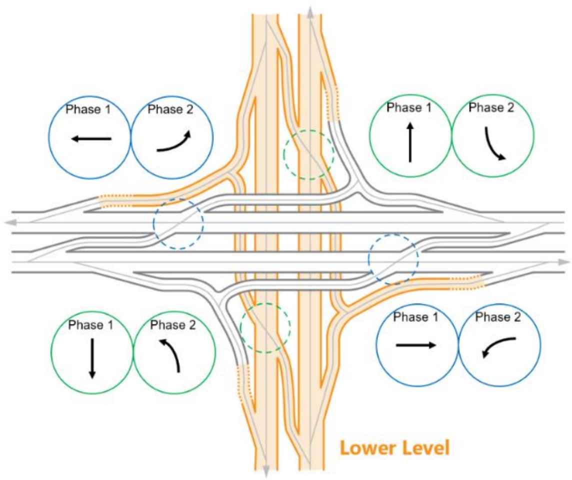
- 20 conflict points total and only four crossing can reduce angle collisions compared to traditional at grade intersection
- While there are a reduced number of movements at each signalized zone, drivers may be unfamiliar with crossover lefts
- Opposing left turns do not conflict with each other

Geometric Design and Implementation Considerations

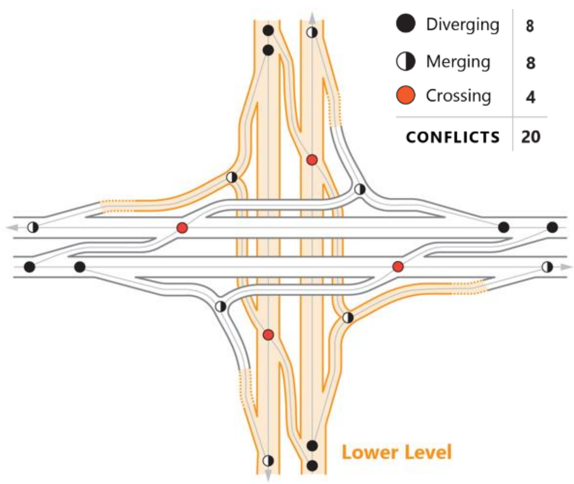
- Moves the signalized zone downstream on each roadway
- Locate of ped crosswalks at crossovers compared to downstream direct left
- Access Management: impacts are larger at the downstream sections and lesser at the upstream when compared to downstream direct lefts



Conceptual rendering of a Grade Separated Direct Left (Upstream Crossover)



Typical Phasing Scheme at a Grade Separated Direct Left (Upstream Crossover)



Number of Conflict Points at a Grade Separated Direct Left (Upstream Crossover)

3.11 Direct Left (Single Point Left)

Key Features

The left turn is separated at the signal on the major road; left-turn traffic conflicting with the opposing through on the major road.

Applicability

- At intersections with heavy through and left-turn traffic volumes on both streets
- Where an at-grade conventional intersection is not sufficient for the traffic
- To connect existing grade-separated streets
- Where there is limited right of way to expand
- A related patent has been submitted, legal review may be necessary to determine if it is active and enforced.

Operational Performance

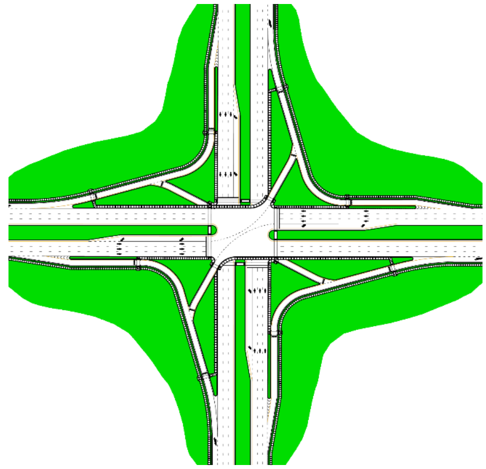
- Minimal extra distance traveled on ramps
- Traffic Signalization: Single signalized zone with 2 critical movements
- Shorter cycle lengths than a counterpart 4-leg intersection
- Consider merge vs stop vs signalized for right turn ramp merges
- Progression: Good one way progression with single two phase signal

Safety Performance

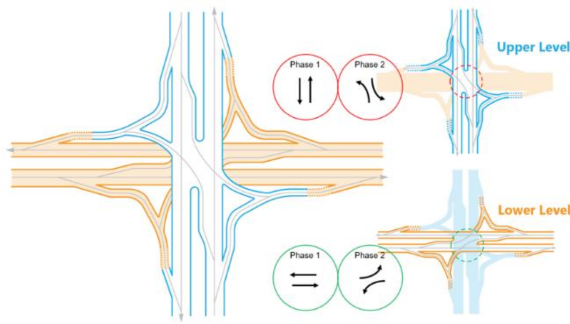
- 20 conflict points total and only four crossing can reduce angle collisions compared to traditional at grade intersection
- Reduced complexity and single signalized zone is easier to navigate

Geometric Design and Implementation Considerations

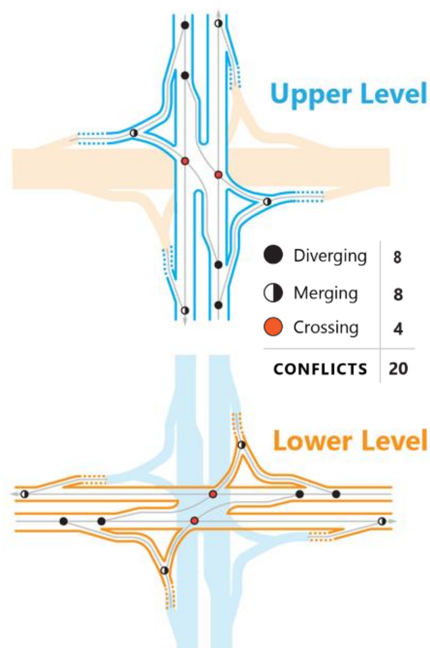
- Single point design needs a large connected structure for turning movements
- Consider multistage or combined crosswalk configurations
- Access Management: Minimal impact to access because movements are condensed to over/under the bridge



Conceptual rendering of a Grade Separated Direct Left (Single Point Left)



Typical Phasing Scheme at a Grade Separated Direct Left (Single Point Left)



Number of Conflict Points at a Grade Separated Direct Left (Single Point Left)

Chapter 4 - Alternative Service Interchanges

4.1 Overview

- Conceptual Description- uninterrupted facility (freeway/highway) crossing a surface street (arterial or secondary) with grade separation
- Goal: Operational efficiency by removing signal phases and safety benefits by reducing conflicts and/or severity
- Possible Design Types you could consider (including AII with standalone guidebooks)

DDI CMF

Study Name	Summary CMF (range)	Crash Type	CMF	Stars	Applicable Conditions
Walls, et al., 2018	0.42	All	--	3	
Zlatkovic, 2015	0.755	All	--	3	
Abdelrahman et al., 2021	0.858	K/A/B/C	0.558	4	Urban and Suburban
		PDO	0.92	4	
		Rear	0.887	4	
		Angle/Left	0.448	4	
		Single Veh	0.845	4	
		Sideswipe	1.241	3	
		Headon	0.643	3	
Hummer et al., 2016	0.67	K/A/B/C	0.59	3	Suburban
Claros et al., 2017	0.625	K/A/B/C	0.45	3	Urban and Suburban
		PDO	0.686	3	
NYE ET AL., 2019	0.633	Angle	0.441	3	
		Rear End	0.549	3	
		Sideswipe	1.139	3	
		K/A/B/C	0.461	3	
		O	0.695	3	

Table 4-1 Comparison of Alternative Service Interchanges with Traditional Designs

AII Design	Operations (Conflicts + Critical Phases)	Progression Quality	Safety (Veh Conflict Points)	Unusual Maneuvers	Wrong Way Potential	Right of Way	Structures	Crossing Pedestrians	Bicycle Accessibility
Diamond Interchange	*	*	****	*****	****	****	***	**	**
Tight Urban Diamond	*	*	****	*****	****	*****	***	***	****
Parclo	****	****	*****	*****	*****	**	***	**	***
SPUI	***	***	****	*****	****	****	**	**	****
DDI	***	***	****	***	***	***	***	*	**
Contraflow Interchange	***	***	***	***	***	***	***	**	***
DLT Interchange	***	***	***	***	***	***	**	*	***
Single Roundabout Interchange	N/A	N/A	*****	***	****	***	**	***	**
Double Roundabout Interchange/Raindrop	N/A	N/A	*****	**	****	***	***	***	**
MUT	***	***	***	***	****	***	***	****	****
Michigan U-turn (Frontage + U-turn)	**	***	****	***	****	**	***	****	****

General/Common Considerations for Alternative Interchanges

Operations: One key benefit to separation is the reduced number of conflicting movements and demands which can greatly reduce delays. Some of the interchanges also separate the control of E-W or N-S traffic allowing for two-way progression on these roadways. A common concern for higher demand turning movements is to ensure that ramp traffic does not back up into the main roadways, especially the uncontrolled roadway. Closely spaced intersections should also be considered to ensure that the interchange design works well on the arterial corridor.

Geometrics: Once the decision is made to grade separate, selection of an interchange requires adjustment of one arterial into an uncontrolled facility. Ramps at interchanges also require additional ROW compared to GSIs as the speeds are higher entering and exiting the uncontrolled facility. For this reason, suburban and rural area types may be more accommodating to the ROW needs.

Safety: Considering a diamond as the "default" design option, many of the interchange designs reduce the total number of vehicle-to-vehicle conflict points, while those with more conflict points still reduce the number of crossing conflicts. In addition, many of the crossing conflicts removed are those typically with the highest exposure. Minimal CMFs are available for alternative interchange designs, and these also typically consider a conversion from Diamond Interchanges. Chapter 1 notes potential surrogate safety analysis methods which can be used to assist in design selection.

Multimodal: The primary concern for accommodating pedestrian movements is when crossing ramps and to/from roadways on different elevations. Consider these movements early in the design process so that all users are safely and efficiently served by the design. Design-specific considerations for multimodal safety are included in their respective sections.

Construction and Maintenance of Traffic: Construction planning must account for maintenance of traffic during the conversion from at-grade to grade separation. This may involve temporary or parallel structures or use of the existing roadway network at nearby intersections.

Access Management: Conversion of one arterial to uncontrolled facility typically negatively impacts access opportunities, and higher speed ramps may limit directly adjacent driveway access. Right in right out access may be utilized in the vicinity of the interchange to avoid adding more median openings or signals close to the interchange and ramps. In high demand locations, a direct access from ramp or dedicated turning lane may be provided to accommodate and separate the traffic without negatively impacting the arterial.

Because the information available for alternative service interchanges is limited at this time, one page summaries are provided.

4.1.1. Diverging Diamond Interchange

Key Features

- Arterial traffic crosses to the other side of the roadway between the freeway ramps
- Vehicles can turn left onto and off freeway ramps without stopping or crossing opposing lanes of traffic

Applicability

- With heavy left-turn traffic volumes onto and off the freeway ramps
- Without adjacent traffic signals or nearby driveways
- Limited roadway width for left-turn lanes between ramp intersections and limited right-of-way to expand

Operational Performance

- Distance Traveled: Minimal extra distance due to ramps
- Traffic Signalization
  - ✓ All signalized zones have 2 critical movements
  - ✓ Overlap phases may be needed to progress traffic across the intersection
  - ✓ Increased arterial left storage reduces spillback opportunities
- Progression
  - ✓ Good one way progression due to coordinated operation of the throughs

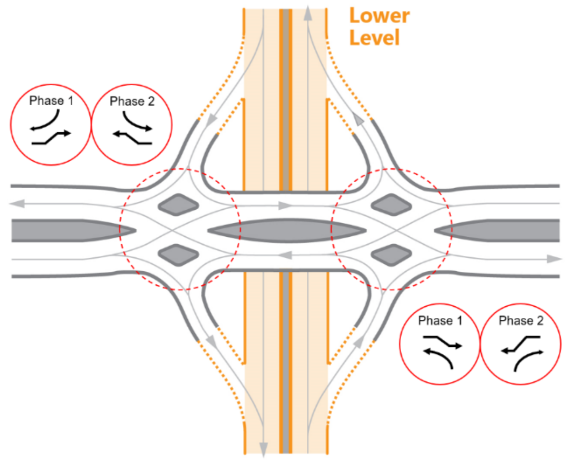
Safety Performance

- Number of Conflict Points
  - ✓ A total of 18 conflict points, compared to 22 conflict points at a diamond interchange
- Overall CMF between 0.42 and 0.86
- Sight Distance/Other Safety Benefits
  - ✓ Offset lefts improve sight distances
  - ✓ Opposing left turns do not conflict with each other

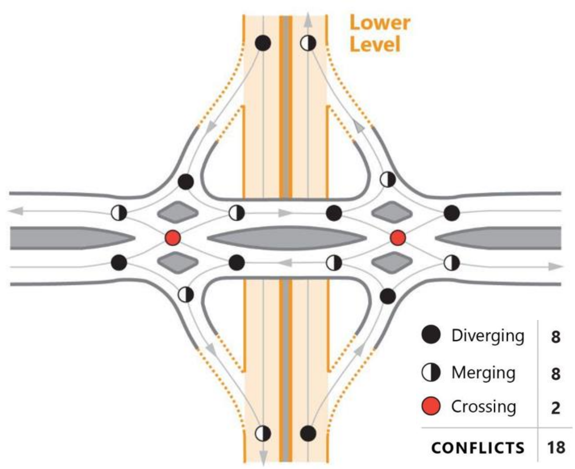
Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ Design allows traffic to enter and exit the freeway without crossing opposing lanes of traffic
  - ✓ Adequate queue storage at the adjacent intersection should be provided to prevent queue spillback into the DDI
- Location of ped crosswalks similar to diamond

I-44 and Kansas Expressway DDI in Springfield, MO



Typical Phasing Scheme at a DDI



Number of Conflict Points at a DDI

4.2 Contraflow Interchange

Key Features

A contraflow left interchange (CFL) is a modified Tight Urban Diamond Interchange, where left-turn traffic on the arterial crosses opposing left-turn traffic via channelized lanes.

Applicability

- Limited right of way to add opposing left-turn lanes
- Heavy left-turn traffic onto the freeway ramps
- Limited roadway width for left-turn lanes between the ramp intersections and limited right of way to expand or to construct loops

Operational Performance

- Distance Traveled: Minimal extra distance due to ramps
- Traffic Signalization
  - ✓ All signalized zones have 2 critical movements
  - ✓ Overlap phases may be needed to progress traffic across the intersection
  - ✓ Most signalized, ramp terminal rights can merge or 90 degree at signal
  - ✓ Increased arterial left storage reduces spillback opportunities
- Progression
  - ✓ Good one way progression due to coordinated operation of the throughs

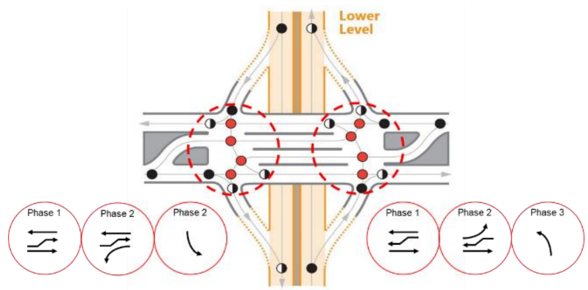
Safety Performance

- Number of Conflict Points
  - ✓ A total of 24 conflict points, compared to 22 conflict points at a diamond interchange
- Sight Distance/Other Safety Benefits
  - ✓ Offset lefts improve sight distances
  - ✓ Opposing left turns do not conflict with each other due to offset/contraflow lane

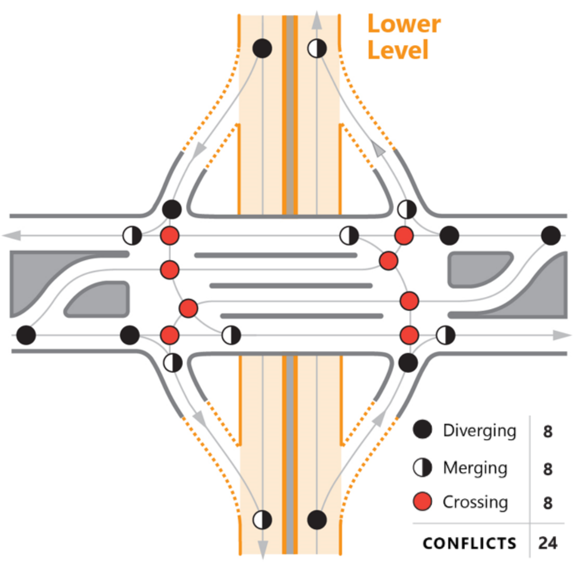
Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ Intersection design must consider contraflow lanes to prevent possible alignments into wrong way movements
- Location of ped crosswalks similar to diamond interchange
- Median openings restricted by contraflow left

Lyons Road underneath Florida State Road 869



Typical Phasing Scheme at a Contraflow Interchange



Number of Conflict Points at a Contraflow

4.3 Displaced Left (DLT) Interchange

Key Features

- Left-turn vehicles cross to the other side of the opposing through traffic prior to the freeway ramps
- Protected left turns and opposing through movements occur simultaneously at the two ramp intersections

Applicability

- Heavy through traffic in both directions of the arterial
- Moderate to heavy onramp left-turn traffic; low to moderate offramp left-turn traffic
- Limited bridge width, but with right of way available approaching the bridge

Operational Performance

- Distance Traveled: Extra distance for ramp movements
- Traffic Signalization
  - ✓ No more than 3 critical movements and shorter cycle lengths possible
  - ✓ Setback crossovers for more left turn storage
  - ✓ Consider merge vs stop vs signalized for right turn ramp merges
- Progression
  - ✓ One way progression on signalized arterial
  - ✓ If median is opened for through ramp traffic, internal progression of left turns can only be done for one direction

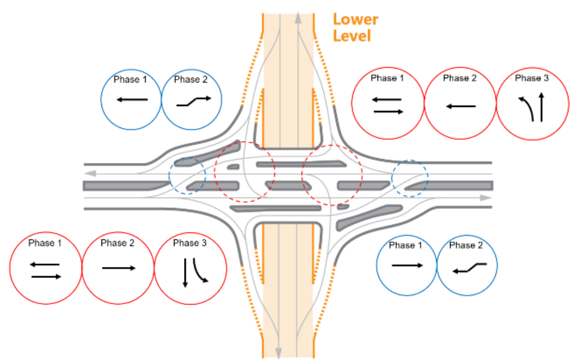
Safety Performance

- Number of Conflict Points
  - ✓ A total of 22 conflict points
  - ✓ Crossing conflicts are more dispersed in the interchange
- Sight Distance/Other Safety Benefits
  - ✓ Left turns have reduced opposing movements
  - ✓ Median may need opening/mountable for emergency vehicle access to ramps

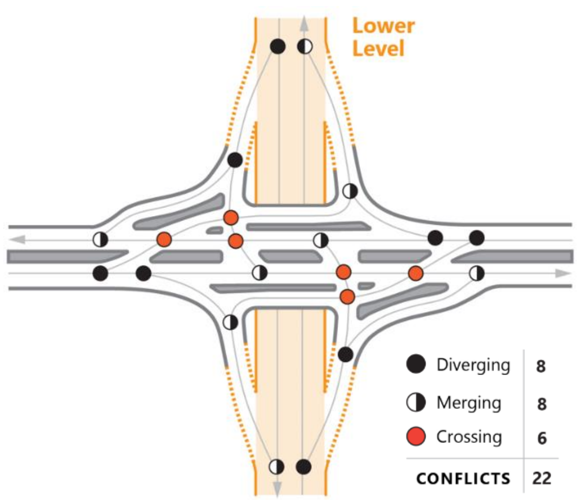
Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ Wide structure is needed to support the displaced/crossover lanes
  - ✓ Multiple raised medians needed with openings to positively direct traffic
- Multimodal design
  - ✓ Location of ped crosswalks
- Access Management Considerations
  - ✓ Driveway access constraints/options
  - ✓ Parking
  - ✓ Median treatment options

I-35 at East Hopkins Street, San Marcos, Texas



Typical Phasing Scheme at a DLT Interchange



Number of Conflict Points at a DLT Interchange

4.4 Michigan U-Turn (MUT) Interchange

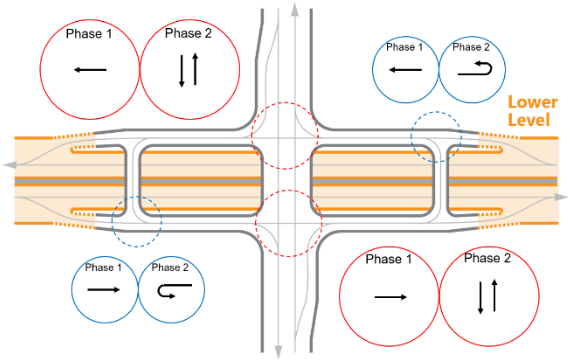
I-696 at Coolidge Highway, Oak Park, Michigan

Key Features

At a MUT Interchange, left-turning motorists make a U-turn at an adjacent crossover to complete the desired movement. The crossovers are parallel to the arterial and are accessed from one-way frontage roads adjacent to the freeway and no left turns are permitted at the main intersection.

Applicability

- Moderate to heavy through traffic volumes and low to moderate left-turn traffic volumes
- With existing frontage roads
- Where access to properties and businesses adjacent to the freeway is important



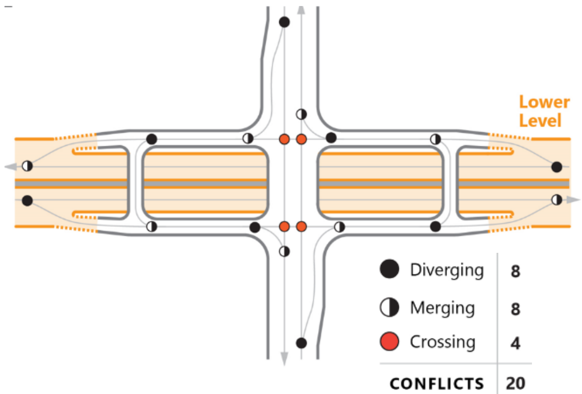
Typical Phasing Scheme at a MUT Interchange

Operational Performance

- Distance Traveled: Extra travel distance to major street left-turn traffic and minor street through traffic
- Traffic Signalization
  - ✓ Two zones with 2 critical movements
  - ✓ Shorter cycle lengths feasible
  - ✓ U-turns on ramps may be stop or signal
- Progression
  - ✓ Good one way progression with two closely spaced signals

Safety Performance

- Number of Conflict Points
  - ✓ A total of 20 conflict points
- Sight Distance/Other Safety Benefits
  - ✓ Intersections have reduced complexity



Number of Conflict Points at a MUT Interchange

Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ MUT interchange requires three separate structures
  - ✓ Fits well with network that has directional access roads
- Multimodal design
  - ✓ Ped crosswalks can all be located on central structure
- Access Management Considerations
  - ✓ Additional RIRO access options available on ramp/frontage roads

4.5 Single-Point Urban Interchange (SPUI) Interchange

Key Features

A single traffic signal at the center of the interchange controls all left turns. Drivers make opposing left-turns at the same time under the protection of this signal.

Applicability

- Limited right of way
- Heavy left-turn traffic onto and off the interstate or primary road ramps
- With space to accommodate wider intersection and structure widths

Operational Performance

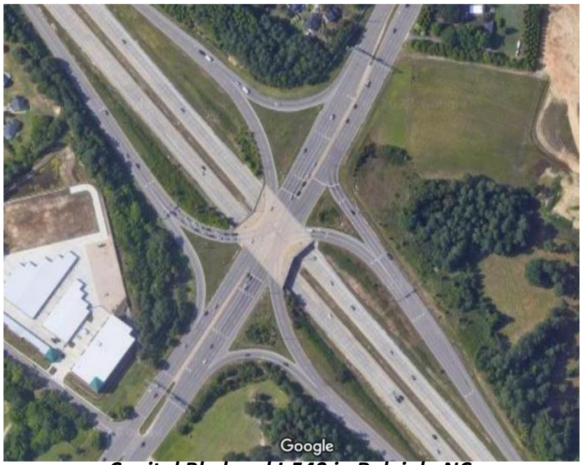
- Distance Traveled: Minimal extra distance traveled
- Traffic Signalization
  - ✓ No more than 3 critical movements
  - ✓ Shorter cycle lengths feasible
  - ✓ Right turns may be signalized, yield or merge
- Progression
  - ✓ Good one way progression with a single signalized zone

Safety Performance

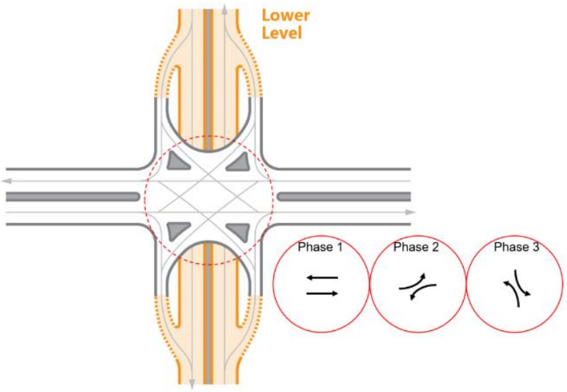
- Number of Conflict Points
  - ✓ A total of 24 conflict points, compared to 22 conflict points at a diamond interchange with two more crossing conflicts
- Sight Distance/Other Safety Benefits
  - ✓ Large intersection footprint so opposing traffic is further away

Geometric Design and Implementation Considerations

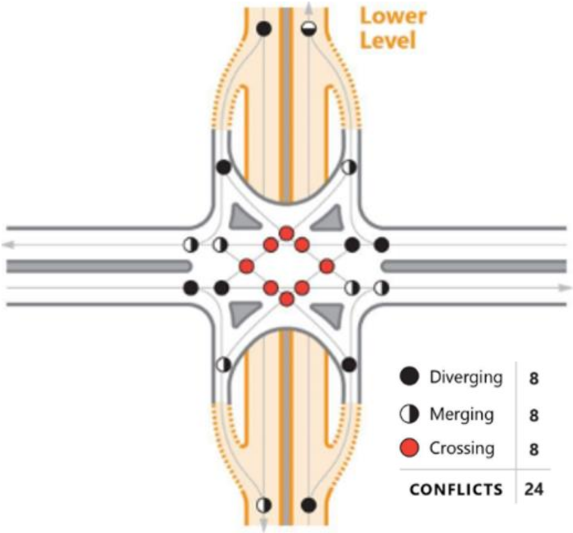
- Unique Geometric Aspects
  - ✓ Very wide structure to accommodate the single point intersection
- Multimodal design
  - ✓ Ped crosswalks can include island refuge in order to allow multistage crossings
- Access Management Considerations
  - ✓ Minimal impacts to access



Capital Blvd and I-540 in Raleigh, NC



Typical Phasing Scheme at a SPUI Interchange



Number of Conflict Points at a SPUI Interchange

4.6 Single Roundabout Interchange

Key Features

At a single roundabout interchange, the slip roads to and from the motorway carriageways converge at a single roundabout, which is grade-separated from the motorway lanes with bridges.

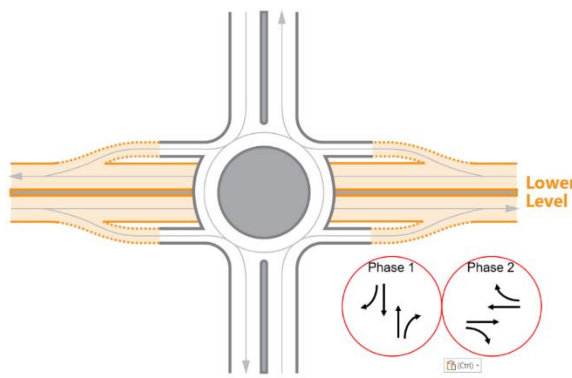
U.S. Route 9 and New York State Route 2, Latham, NY

Applicability

- Heavy turning traffic onto and off of the freeway ramps
- At heavily-used freeway off-ramps where vehicles tend to back up onto the freeway
- Urban areas with moderate traffic
- Where right of way is limited

Operational Performance

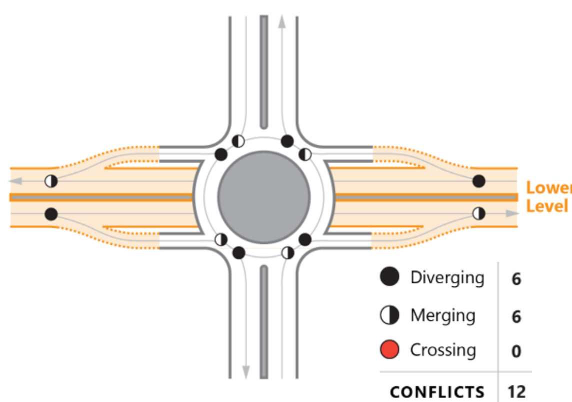
- Distance Traveled: Some extra distance to circulate on roundabout
- Traffic Signalization
  - ✓ Two zones with 2 critical movements
  - ✓ Shorter cycle lengths feasible
  - ✓ Yield or signalized if operating as traffic circle
- Progression
  - ✓ Unsignalized will interrupt arterial progression
  - ✓ Two phase signalized will have good one way progression



Typical Phasing Scheme at a Single Roundabout Interchange

Safety Performance

- Number of Conflict Points
  - ✓ A total of 12 conflict points, and has no crossing conflicts
- Sight Distance/Other Safety Benefits
  - ✓ All conflict points have single approaches to monitor



Number of Conflict Points at a Single Roundabout Interchange

Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ This design requires a large structure or two separate curved structures to support the central roundabout
- Multimodal design
  - ✓ Crosswalks can be located upstream of Roundabout
- Access Management Considerations
  - ✓ Minimal impacts to access

4.7 Double Roundabout Interchange

Key Features

At a double roundabout interchange, all ramps begin or end at one of two roundabouts on the arterial. The roundabouts are circular, unsignalized interchanges where traffic moves in a counterclockwise direction around a central island.

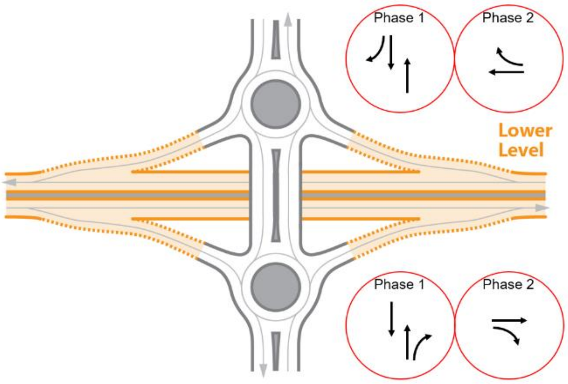
Charles Town Pike at Harry Byrd Highway, Loudoun County, VA

Applicability

- Heavy left-turn volumes onto the freeway ramps
- Limited room between the ramp intersections for vehicles to wait at traffic signals
- At heavily used off-ramp interchanges where vehicles tend to back up on the freeway

Operational Performance

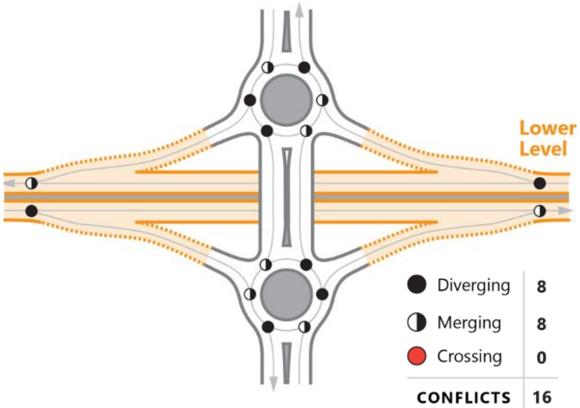
- Distance Traveled: Additional distance for ramp lefts taking roundabout
- Traffic Signalization
  - ✓ No more than 2 critical movements
  - ✓ Can support shorter cycles
  - ✓ Can be stop/yield controlled at low volumes or signalized
- Progression
  - ✓ Coordination between two 2 phase intersections
  - ✓ Moderate one-way progression



Typical Phasing Scheme at a Double Roundabout Interchange

Safety Performance

- Number of Conflict Points
  - ✓ A total of 12 conflict points, and has no crossing conflicts
- Sight Distance/Other Safety Benefits
  - ✓ Particularly at rural/suburban low-volume high-speed roads



Number of Conflict Points at a Double Interchange

Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ Consider closing median adjacent to structure to prevent wrong ways especially in areas where low circulating traffic flows do not positively guide drivers
- Multimodal design
  - ✓ Crossings upstream of RBT
- Access Management Considerations
  - ✓ Some additional ROW needed for RBT compared to Diamond Interchange

4.8 Teardrop Interchange

Key Features

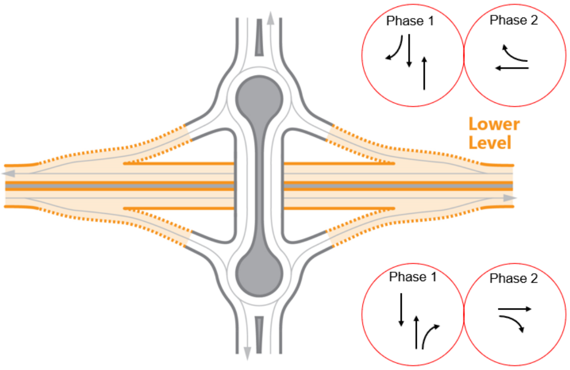
At a teardrop interchange, all ramps begin or end at one of two roundabouts on the arterial. The roundabouts are circular, unsignalized interchanges where traffic moves in a counterclockwise direction around a central island.

Applicability

- Heavy left-turn volumes onto the freeway ramps
- Limited room between the ramp intersections for vehicles to wait at traffic signals
- At heavily used off-ramp interchanges where vehicles tend to back up on the freeway

Operational Performance

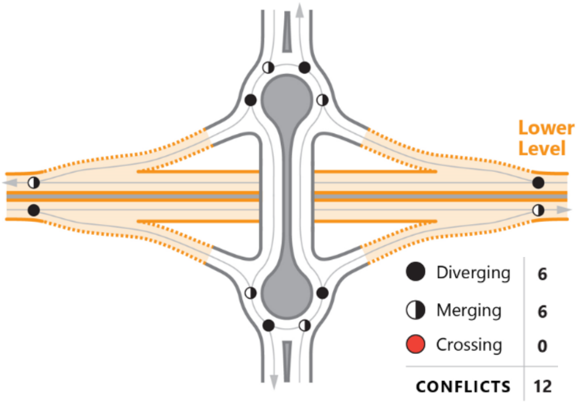
- Distance Traveled: Additional distance for ramp lefts taking roundabout
- Traffic Signalization
  - ✓ No more than 2 critical movements
  - ✓ Can support shorter cycles
  - ✓ Can be stop/yield controlled at low volumes or signalized
- Progression
  - ✓ Coordination between two 2 phase intersections
  - ✓ Moderate one-way progression



Typical Phasing Scheme at a Teardrop Interchange

Safety Performance

- Number of Conflict Points
  - ✓ A total of 12 conflict points, and has no crossing conflicts
- Sight Distance/Other Safety Benefits
  - ✓ Particularly at rural/suburban low-volume high-speed roads



Number of Conflict Points at a Teardrop Interchange

Geometric Design and Implementation Considerations

- Unique Geometric Aspects
  - ✓ Consider closing median adjacent to structure to prevent wrong ways especially in areas where low circulating traffic flows do not positively guide drivers
- Multimodal design
  - ✓ Crossings upstream of RBT
- Access Management Considerations
  - ✓ Some additional ROW needed for teardrop compared to Diamond Interchange

Chapter 5 - Case Studies

- Six case studies, including five individual alternative intersections and an alternative corridor
- Case studies covered various environmental scenarios including Central Business District, Urban, Suburban, and rural areas (shown in Table 5-1)
- For each case, a real-world site was selected with the actual traffic demand and proposed AI design to accommodate this demand scenario
- Case studies following a standardized format as described in Section 5.1, which was pulled from 1st ed. AI Guide.
- The existing AIIR assessment procedure (described in Section 5.2) was employed as the assessment framework

5.1 Case Study Format

Provide generic examples rather than sample plans that can be interpreted as a standard.

Environment: Area Type CBD/Urban/Suburban/Rural

ROW Constraints: Existing Development, Utilities (especially for conversion to grade separation), Existing Access points, cross-section ROW (Divided, median etc.), Specifically grade separation: Structure length changes based on Cross-section and adjacent quadrants

Existing Network: Grid Network, Leftover opportunities, closely spaced intersections, Driveway access, Existing Classifications

Traffic Demand: Directionality, Heavy movement combinations (for peaks),

Multimodal: Demand, Existing Facilities

Table 5-1 Summary of Case Study Scenarios

Area Type	ROW Constraints	Existing Network	Traffic Demand	Multimodal Needs	Options to Consider
CBD Downtown	No new ROW available	Corridor, Existing grid (one-way?)	Bidirectional- both directions on major are heavy at the same time period	Heavy Pedestrian Demand + Bike lane	Split intersection, bowtie teardrop?, rerouting on existing network (Quadrant / Grid network)
Urban	2/4 quadrants w/ development	Corridor, Closely spaced intersections	Heavy through + left one direction	Moderate pedestrian demand	Quadrant, partial CFI, RCUT?, PFI, Jughandle?
Suburban	Existing driveways but some ROW available	Corridor, One parallel road, on signalized corridor	Heavy through commuter pattern	Low peds + bike lane	MUT, RCUT, offset T if alternate connections available, quadrant
Suburban	Large setbacks so GS is possible	Isolated corridor, two major arterials	heavy directional + left turn for both arterials	Low peds	GS Intersection/Interchange
Rural	Some driveways, Gas Station	Isolated signalized corridor	Heavy through major, minor is impacting cycle length for corridor	No bike/ped concerns	RCUT, MUT, partial PFI/CFI

5.2 Assessment Methodology

Will follow the AIIR Alternative Intersection Assessment Methodology (Note: texts Copied from AIIR V1 Manual)

Step 1. Establish Objectives

As the first step, the specific objectives for the site of interest are established by the stakeholders. The objective setting allows greater flexibility with respect to the prioritization and weighting of factors for different projects. This serves as a simplified screening of the alternatives to see if that objective matches a particular strength of an alternative.

For this intersection alternative assessment procedure, the next four steps are to screen alternatives with respect to the following specific factors:

- Pedestrians and conflicts.
- Right-of-way.
- Access.
- Capacity and vehicular throughput.

Step 2. Pedestrian and Conflict Assessment

The second step in the intersection assessment is to examine the alternatives with respect to pedestrians and conflicts. The table to the right summarizes general guidance with respect to viable alternative intersections as a function of the level of importance placed on meeting pedestrian mobility needs at a subject intersection.

Relative Level of Importance for the Need to Provide Crosswalks	Alternative Intersection Design to Consider
Low	MUT
	QR
	DLT
	RCUT
	Roundabout
High	MUT
	QR
	DLT
	Roundabout

Relative Level of Importance for Magnitude of Conflicts Between Pedestrians and Vehicles	Viable Alternative Intersection Design to Consider Further
Low	MUT
	QR
	DLT
	RCUT
	Roundabout
High	MUT
	QR
	DLT
	RCUT

Step 3. Right-of-Way Assessment

The third step in the intersection alternatives assessment methodology is to assess alternatives in terms of the availability of the right-of-way to accommodate the alternative and the cost of additional right-of-way if more is needed. There are greater challenges to implementing these alternative intersection alternatives if the median width is insufficient to accommodate U-turns and if additional and costly right-of-way is needed for the alternative. In some cases, the cost of the additional right-of-way may make many of the alternative intersections cost prohibitive. Table below presents a summary of these points.

Adequacy of Median Widths to Accommodate U-Turns	Affordability of Additional Right-of-Way Required	Viable Alternative Intersection Design to Consider Further
Sufficient	Affordable	MUT
		RCUT
		DLT
		Roundabout
		QR
Sufficient	Very costly	MUT
		RCUT
		DLT
Insufficient	Affordable	MUT
		RCUT
		DLT
		Roundabout
		QR
Insufficient	Very costly	MUT with loons
		RCUT with loons

Step 4. Access Assessment

The next step in the methodology is to assess the need to preserve or provide access to adjacent parcels (e.g., via driveways) from either the major or the minor approaches in the vicinity of the subject intersection. These are often important issues in arterial design. All of the alternative intersections should be included as viable alternatives wherever the primary goal of the major road is to serve through vehicles. Table to the right indicates viable alternative designs as a function of the need to provide access to parcels in four quadrants.

Need to Provide Local Driveways in Close Proximity	Viable Alternative Intersection Design to Consider Further
Low	RCUT
	MUT
	Roudabout
	QR
	DLT
High	RCUT
	MUT
	QR
	Roundabout

Step 5. LOS at Sketch Planning Level

Step 5 includes preliminary analysis of Level of Service (LOS) scoped to a sketch planning level for the remaining alternatives. Tools such as CAP-X or agency-specific ICE applications may be used to estimate the LOS of each design. Agencies may have existing thresholds to exclude designs at this stage or practical thresholds may be established based on the needs of the individual project.

Step 6. Simulation of Viable Alternatives

Step 6 covers simulation at the appropriate level (microscopic, mesoscopic, macroscopic) for the set of viable alternatives. At this point operational performance, safety performance and site-specific considerations can be jointly considered to select the final design.

Case Study 1: One-Way Couplet Town Center Intersections

A Town Center Couplet Intersection is created any time one-way streets are involved. Though one-ways are not new or "innovative," they can achieve high efficiency because there is no need for left-turn arrows, since there is no opposing traffic.

Environment: Urban CBD with heavy vehicular and non-vehicular demands. High control delays at intersections due to 4-phase signals, pedestrian signals, residual vehicle queues

ROW Constraints: No new ROW available at CBD

Existing Network: Existing grid/parallel roadways (either two-way or one-way); closely spaced intersections; relatively low speed limits (usually no more than 30 mph)

Traffic Demand: Heavy bidirectional vehicular traffic demand throughout the day

Multimodal: Heavy pedestrian, bicycle, and transit demands

This conceptional design of Town Center Intersection in Greenville, NC shows how a system of four simple intersections replaces what would have emerged as a single huge intersection. It is especially beneficial for downtown locations and increases walkability/bikability while improving vehicle capacity.

Figure 5-1 Aerial view of the Arlington Blvd at Greenville Blvd in Greenville, North Carolina

At Greenville Blvd and Arlington Blvd, there is a potential of dividing two large Stroads into four walkable one-way streets. As depicted, this would replace one inefficient 4-phase signal with four 2-phase highly efficient signals.

(a) Existing Condition (b) Proposed One-way Couplet Design

Figure 5-2 Arlington Blvd at Greenville Blvd in Greenville, North Carolina

Alternative Intersection Assessment

Step 1: Establish Objectives for Projects and Relative Importance of Factors

- Increase intersection capacity at CBD and reduce pedestrian waiting time by using two-phase signals

Step 2: Assess Level of Expected Pedestrian Activity and Conflicts

- High pedestrian activities and expected conflicts with vehicular traffic

Step 3: Assess Availability of Right-of-Way

- Usually no available ROW

Step 4: Assess Local Site Access Needs

- High needs accessing local businesses

Step 5: Determine Level-of-Service at Sketch Planning Level

- CAPX Existing Condition: V/C = 0.87
- CAPX One-way Couplet - NW Intersection: 0.59
- CAPX One-way Couplet - SW Intersection: 0.7
- CAPX One-way Couplet - SE Intersection: 0.65
- CAPX One-way Couplet - NE Intersection: 0.57

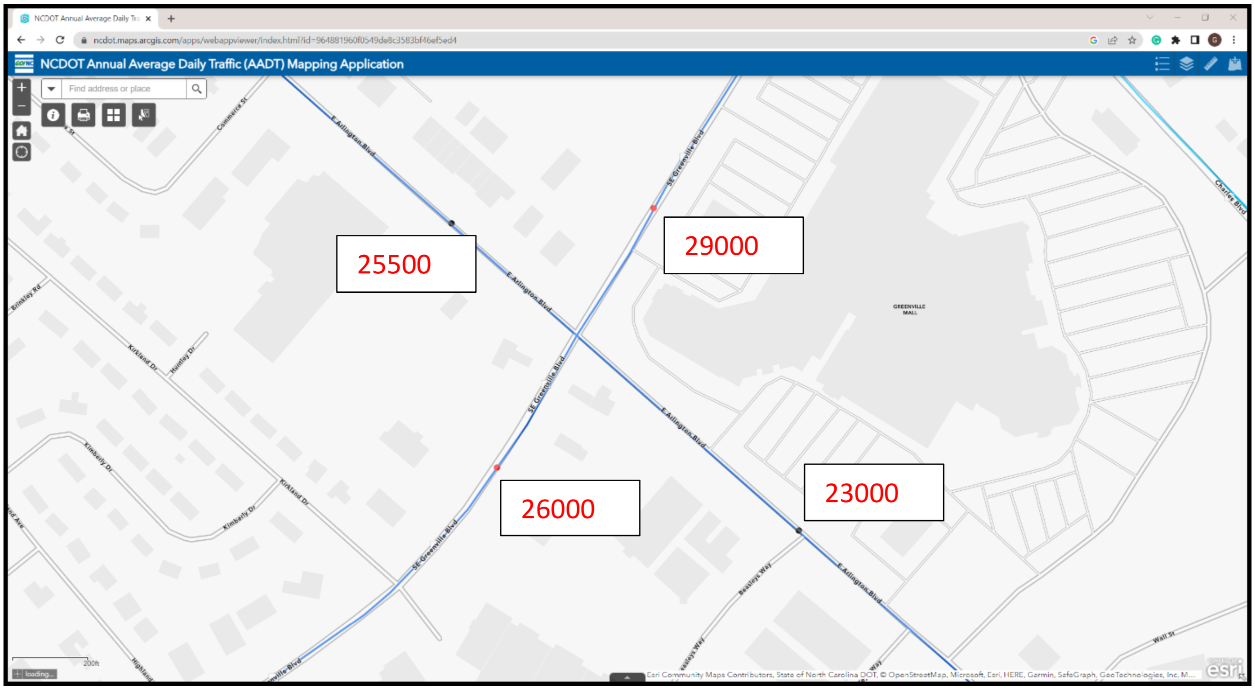


Figure 5-3 AADT of the Arlington Blvd at Greenville Blvd in Greenville, North Carolina

Step 6: Conduct Simulation Analysis of Viable Alternatives

- A one-way couplet intersection design has the potential to reduce system travel time by 40 percent (same demand), or increase capacity by 65 percent (same travel time)

Case Study 2: Quadrant Roadway Intersections

A Quadrant Roadway intersection is a promising design for an intersection of two busy suburban or urban roadways. The intersection works by rerouting all four left–turn movements at a four-legged intersection onto a road that connects the two intersecting roads, so that to increases operational efficiency through a congested intersection by moving the left turns away from the main intersection and allowing a two-phase signal at the main intersection.

Environment: Urban area with heavy vehicular and moderate non-vehicular demands. High control delays at individual intersections due to long cycle length to accommodate 4-phase signals and pedestrian crossings.

ROW Constraints: Two or more quadrants have existing or proposed business developments

Existing Network: Urban arterial with closely spaced intersection that needs signal coordination; may located in the vicinity of freeway interchanges. Multiple Lane roadway with a relatively high speed limit (up to 45 mph); no parallel roadway within 0.5-mile range

Traffic Demand: Heavy bidirectional through vehicular traffic demand; may have heavy left-turn traffic from one direction

Multimodal: Moderate pedestrian, bicycle, and transit demands to access to businesses

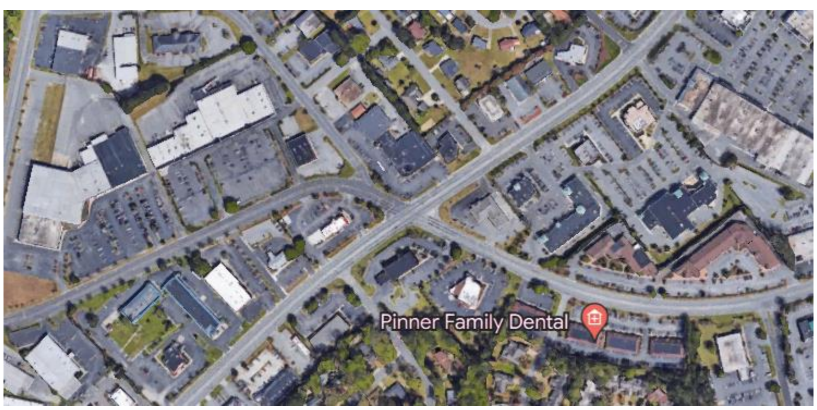


Figure 5-4 Aerial view of the Greenville Blvd at Red Banks Rd in Greenville, North Carolina

(a) Existing Condition (b) Proposed Dual Quadrant Roadway Design

Figure 5-5 Greenville Blvd at Red Banks Rd in Greenville, North Carolina

Alternative Intersection Assessment

Step 1: Establish Objectives for Projects and Relative Importance of Factors

- Increase urban intersection capacity and reduce control delay by using two-phase signals

Step 2: Assess Level of Expected Pedestrian Activity and Conflicts

- High pedestrian activities and expected conflicts with vehicular traffic

Step 3: Assess Availability of Right-of-Way

- Sufficient available ROW particularly when using existing side streets/driveways as connectors

Step 4: Assess Local Site Access Needs

- High needs accessing local businesses

Step 5: Determine Level-of-Service at Sketch Planning Level

- CAPX Existing Condition: V/C = 0.87
- CAPX Quadrant Main Intersection: V/C = 0.53

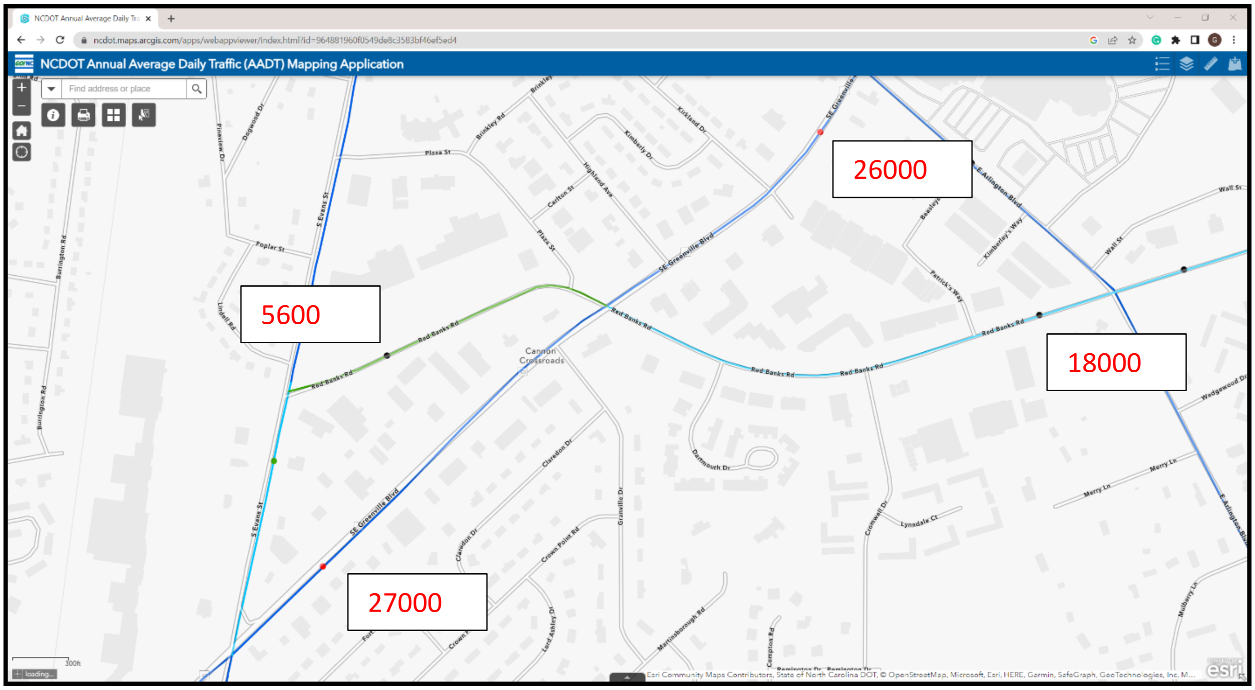


Figure 5-6 AADT of the Greenville Blvd at Red Banks Rd in Greenville, North Carolina

Step 6: Conduct Simulation Analysis of Viable Alternatives

- A single quadrant roadway intersection design has the potential to reduce main intersection delay from 52s to 18s, and reduce system travel time by 24 percent
- A full quadrant roadway intersection design has the potential to reduce system travel time by 18 percent (same demand), or increase capacity by 39 percent (same travel time)

Case Study 3: Median U-Turn Intersections

A full MUT intersection reroutes both major street and minor street left-turning vehicles through one-way median openings located several hundred feet from the main intersection. This eliminates all left turns from the main intersection, reducing conflict points. It also allows two-phase signal controls at the intersection and the signalized U-turn crossovers. The benefits of the MUT intersection include increased capacity and reduced opportunities for crashes compared to conventional designs.

Environment: Suburban area with heavy commuter vehicular demands during peak periods. Rapid urbanization resulted in an increasing growth in traffic demands. High control delays at individual intersections due to long cycle length to accommodate 4-phase signals and heavy demands.

Figure 5-7 Aerial view of the Poplar Tent Rd and Derita Rd Median U-Turn Intersection in Concord, NC

ROW Constraints: Existing driveways with some ROW available for widening the road; may have a wide median

Existing Network: High speed (up to 45 mph) signalized corridor; side streets connect to residential or business areas. Heavy existing commuter vehicular demands during peak periods. A rapidly developing area with an increasing traffic demand. The case study intersection is desired to be a major intersection in the near future because it connects two state routes. Need to consider corridor design consistency to minimize driver confusions.

Traffic Demand: Heavy directional through vehicular traffic demand during peak periods; moderate to low demand from side streets

Multimodal: Low pedestrian and bicycle demands with limited transit access at present; possible needs pedestrian and bicyclist accommodations in the future

(a) Previous conventional intersection configuration

(b) Exiting Medua U-Turn Intersection configuration

Figure 5-8 Poplar Tent Rd and Derita Rd Median U-Turn Intersection in Concord, NC

Alternative Intersection Assessment

Step 1: Establish Objectives for Projects and Relative Importance of Factors

- Increase suburban intersection capacity and reduce control delay by using two-phase signals, eventually reducing corridor travel time

Step 2: Assess Level of Expected Pedestrian Activity and Conflicts

- Low pedestrian activities and expected conflicts with vehicular traffic

Step 3: Assess Availability of Right-of-Way

- Sufficient affordable ROW

Step 4: Assess Local Site Access Needs

- Moderate needs accessing local businesses

Step 5: Determine Level-of-Service at Sketch Planning Level

- CAPX Signalized Conventional Intersection: V/C = 0.82
- CAPX Median U-Turn Intersection: V/C = 0.37

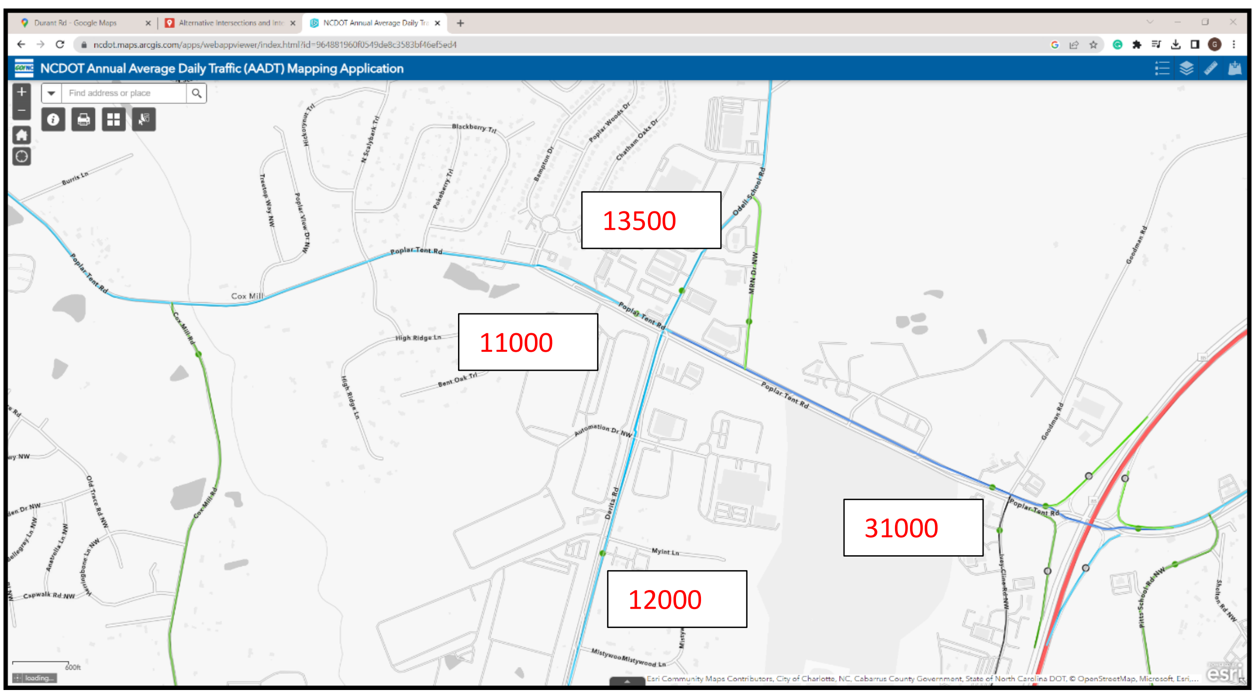


Figure 5-9 AADT of the Poplar Tent Rd and Derita Rd Median U-Turn Intersection in Concord, NC

Step 6: Conduct Simulation Analysis of Viable Alternatives

- *Not included in annotation- optional during full document creation*

Case Study 4: Grade-Separated Intersections

In addition to at-grade QR intersection, there is also a grade-separated form of the QR intersection. Under this design, the secondary intersections operate the same way as described for the at-grade QR intersection but the two intersecting roadways are grade separated to further eliminates intersection conflict points and can provide significant capacity gains compared to the at-grade QR intersection, particularly when one or both roadways have high volumes

Environment: Suburban area with heavy directional through and left-turn vehicular demand from both arterials. High control delays at individual intersections due to long cycle length to accommodate 4-phase signals and heavy demands.

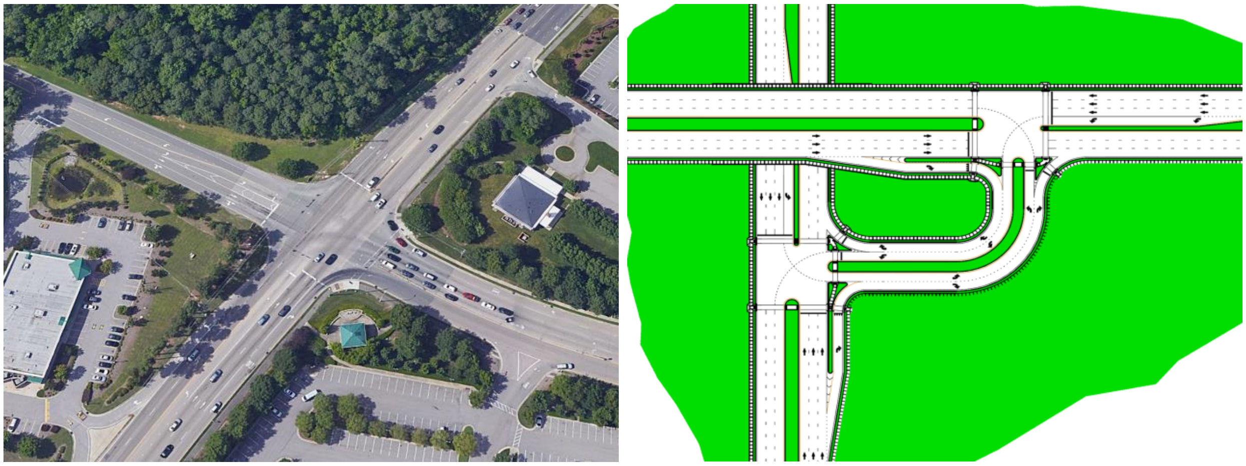
Figure 5-10 Aerial View of the Capital Blvd and Durant Rd Intersection in Raleigh, NC

ROW Constraints: One or more quadrants have large setbacks for construction works

Existing Network: Two isolated signalized corridor with high speeds (up to 45 mph); both corridors are major arterials

Traffic Demand: Heavy directional through and left vehicular traffic demand for both arterials, particularly during peak periods

Multimodal: Low pedestrian and bicycle demands; limited transit access



(a) Existing Condition (b) Proposed Grade-Separated Quadrant Design

Figure 5-11 Capital Blvd and Durant Rd Intersection in Raleigh, NC

Alternative Intersection Assessment

Step 1: Establish Objectives for Projects and Relative Importance of Factors

- Increase suburban intersection capacity via grade separation and consequently reduce control delay for through movements

Step 2: Assess Level of Expected Pedestrian Activity and Conflicts

- Low pedestrian activities and expected conflicts with vehicular traffic

Step 3: Assess Availability of Right-of-Way

- Sufficient affordable ROW

Step 4: Assess Local Site Access Needs

- Low needs accessing local businesses

Step 5: Determine Level-of-Service at Sketch Planning Level

- CAPX Signalized Conventional Intersection: V/C = 1.45
- CAPX Grade-Separated Intersection Echelon: V/C = 0.69
- CAPX Grade-Separated Intersection Center Turn Overpass: V/C = 0.81
- CAPX Grade-Separated Quadrant: 1.1

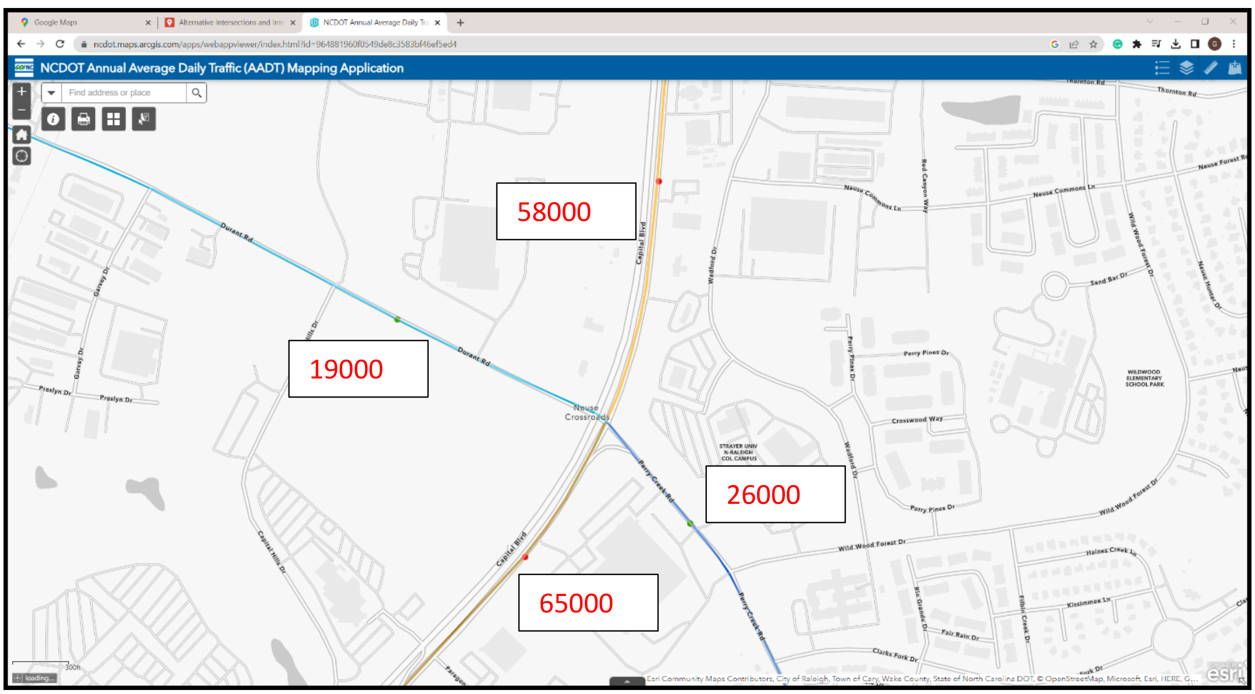


Figure 5-12 AADT of the Capital Blvd and Durant Rd Intersection in Raleigh, NC

Step 6: Conduct Simulation Analysis of Viable Alternatives

- *Not included in annotation- optional during full document creation*

Case Study 5: Restricted Crossing U-Turn Intersections

RCUT intersections reroute minor street left-turn and through movements to a median u-turn crossover located approximately 400 to 1,000 ft downstream of the major road and thereby provide major advantages, including reduced delay and congestion for through traffic on the major road and reduced opportunities for crashes compared to conventional designs.

Environment: Rural corridor with heavy through vehicular demand. No major traffic operational issues but has considerable safety concerns due to high speed so yield or stop control may not be appropriate. Traffic from side streets may impact cycle length for the corridor.

ROW Constraints: Existing driveways with some ROW available for widening the road; may have a wide median

Existing Network: High speed (up to 55 mph) rural highway with isolated signal; low volume side streets connect to driveways and service areas

Traffic Demand: Heavy directional through vehicular traffic demand during peak periods; moderate to low demand from side streets

Multimodal: Very limited pedestrian and bicycle demands

Signalized and Unsignalized RCUTs

Figure 5-13 US 401 and Young St. Signalized Restricted Crossing U-Turn Intersection in Wake Forest, NC

Alternative Intersection Assessment

Step 1: Establish Objectives for Projects and Relative Importance of Factors

- Reduce traffic safety risk at high-speed rural intersections

Step 2: Assess Level of Expected Pedestrian Activity and Conflicts

- Low pedestrian activities and expected conflicts with vehicular traffic

Step 3: Assess Availability of Right-of-Way

- Sufficient affordable ROW

Step 4: Assess Local Site Access Needs

- Low needs accessing local businesses

Step 5: Determine Level-of-Service at Sketch Planning Level

- CAPX Signalized Conventional Intersection: V/C = 0.42
- CAPX Signalized RCUT: V/C = 0.39
- CAPX Unsignalized RCUT: V/C = 0.76
- Additional Insights:
    - Although higher v/c for unsignalized RCUT, but the delay might be lower
    - The final decision for signalized RCUT is considering the fast developing of the area

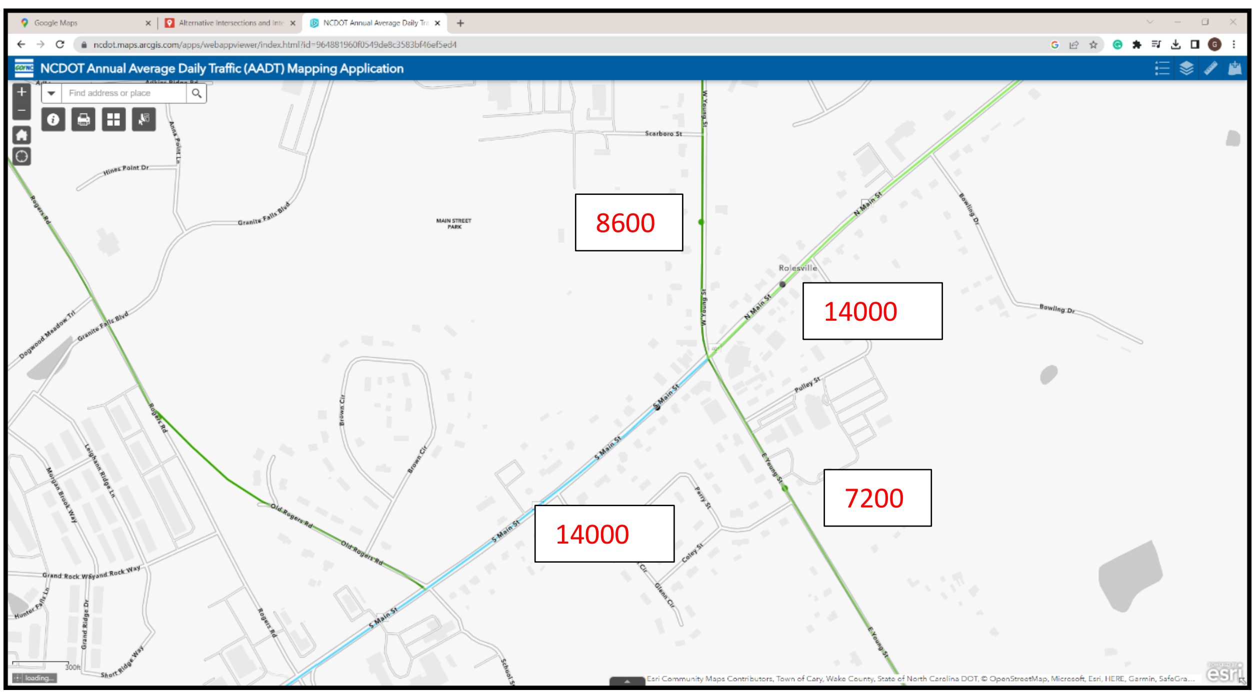


Figure 5-14 AADT of US 401 and Young St. Signalized Restricted Crossing U-Turn Intersection in Wake Forest, NC

Step 6: Conduct Simulation Analysis of Viable Alternatives

- *Not included in annotation- optional during full document creation*

Case Study 6: Alternative Corridor

Environment: Signalized urban corridor with heavy through vehicular demand. High control delays at individual intersections due to long cycle length to accommodate 4-phase signals and pedestrian crossings.

ROW Constraints: Existing driveways with some ROW available for widening the road; may have a wide median

Existing Network: Urban/Suburban corridor with closely spaced intersection that needs signal coordination. Multiple Lane roadway with a speed limit up to 55 mph; no parallel roadway within 0.5-mile range

Traffic Demand: Heavy bidirectional vehicular traffic demand during peak periods; moderate to low demand from side streets

Multimodal: Moderate pedestrian, bicycle, and transit demands to access to businesses

Figure 5-15 Aerial view of the Capital Blvd at Main St Intersection in Wake Forest, NC

Figure 5-16 Capital Blvd in Wake Forest, NC

Alternative Intersection Assessment

Step 1: Establish Objectives for Projects and Relative Importance of Factors

- Increase intersection capacity along urban major arterial and reduce pedestrian waiting time by using two-phase signals; eventually, reduce corridor travel time

Step 2: Assess Level of Expected Pedestrian Activity and Conflicts

- Medium pedestrian activities and expected conflicts with vehicular traffic

Step 3: Assess Availability of Right-of-Way

- Sufficient affordable ROW

Step 4: Assess Local Site Access Needs

- High needs accessing local businesses

Step 5: Determine Level-of-Service at Sketch Planning Level

- *Not included in annotation- optional during full document creation*

Step 6: Conduct Simulation Analysis of Viable Alternatives

- *Not included in annotation- optional during full document creation*

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