Feb 2024
(version 1)

Intersection Control Evaluation (ICE) Guide [DRAFT]

OKLAHOMA DEPARTMENT OF TRANSPORTATION

TRAFFIC ENGINEERING DIVISION

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Preface

This is the first version of Oklahoma Department of Transportation's Intersection Control Evaluation (ICE) Guide, published in February 2024. New developments in research on Intersection Control Evaluation are still being made, and this document will be periodically updated to reflect changes as needed. Please visit our website or contact ODOT Traffic Engineering Division directly to acquire the most recent version.

Please refer to NCHRP Research Report 1087: Guide for Intersection Control Evaluation for additional information or for clarifying details about ICE. Please include additional information, performance metrics, or other details identified in NCHRP 1087 in the ICE process and documentation if applicable or useful. If questions arise regarding differences between ODOT's ICE Guide and NCHRP 1087, please contact Traffic Engineering Division directly for clarification. Feedback received will be considered as revisions to this Guide are drafted.

Introduction

Background

This document serves as a practical guide and framework for the decision process on intersection design. It outlines guidance and necessary procedures used in Intersection Control Evaluation (ICE), a data-driven, performance-based framework and approach used to objectively screen alternatives and identify an optimal geometric and control solution for an intersection. ICE will aid in the State of Oklahoma's goals of implementing highway safety improvement projects to address the safety of road users, including vulnerable road users (VRUs), as outlined in the Highway Safety Improvement Program, and implementing countermeasures and strategies that advance the Toward Zero Deaths highway safety vision, in line with the Safe System Approach, by focusing on the reduction of fatalities and serious injuries on all public roads, as outlined in the Strategic Highway Safety Plan.

Innovative intersection designs have been introduced in other states across the United States but have seen little use in Oklahoma at the time of writing of this document. Experience with these innovative designs suggests greater safety and operational benefits could be realized at a system level with broader implementation. ICE will help expand use of these innovative intersections in Oklahoma and increase awareness of their benefits in service of the State of Oklahoma's commitment to innovation and cost-effective investments.

Purpose

The purpose of the ICE process is to document, justify, and support design decisions made for intersections throughout the course of a project. The ICE process ensures a consistent, objective, and defensible assessment of intersection control alternatives to deliver thorough and transparent reports and recommendations in line with the State of Oklahoma's safety goals. It is a rigorous process that considers existing and future traffic operational and safety needs along with other site-specific issues and constraints. The ICE process is expected to provide more thoroughly vetted intersection control choices resulting in earlier, more confident project decisions. The documentation of this process can also be beneficial in the event of public or legal challenges on project decision-making.

This document has been developed for use by a person with at least a moderately advanced understanding of and experience with traffic engineering methods of analysis to assess performance. The contents of this guide do not excuse the user of the responsibility to exercise sound engineering judgement throughout the process.

The results of an ICE will help inform the extent of the needs of a project and conceptual designs. These conceptual designs will then be used for initial and final design of the project. The ICE process consists of two phases:

- Phase 1: Scoping and Screening
    - During Phase 1 the location is evaluated to determine specific needs to be addressed and control strategies and other modifications are evaluated for feasibility and reasonability for the project location. Preliminary analyses and data are used to identify the preferred alternative(s). Phase 1 may be sufficient for some projects if only a single alternative is deemed feasible at the end of the screening process.
- Phase 2: Alternative Selection
    - During Phase 2 the alternatives deemed feasible in Phase 1 are further analyzed if needed, and additional considerations of each alternative are discussed, such as cost, right-of-way impacts, public impact, etc.

Applicability

An ICE may be considered useful or beneficial as part of a project if the project has one of the following purposes:

- Mitigation of congestion (operational improvement)
- Broader corridor improvements
- Safety improvement
- Enhancements to pedestrian and/or bicycle facilities
- Access modifications or land development
- Pavement rehabilitation or bridge projects

An ICE is required for the following situations on the State Highway System, National Highway System, or for projects that will be funded with state or federal funds:

- New traffic control
- A proposed change in traffic control
- Proposal of new or alternative types of intersections or interchanges
- Major intersection improvements

An ICE is recommended, but *may be required* by a District Engineer depending on the needs of the project, for the following situations:

- Access modifications for driveways and medians
- As part of Traffic Impact Analyses (TIAs) if traffic control improvements or modifications will be recommended in the report

An ICE is not required and is considered optional for the following situations:

- Removal of an inoperable traffic signal and replacement with stop control at the request of a City or Town where no operational or safety concerns are observed (at minimum a cursory operational analysis shall be performed to verify adequate performance of stop control)
- Intersections with no operational or safety concerns
- Minor intersection improvements, such as adding turn lanes or modifying signal phasing—unless movement restrictions or other control types are being considered
- Right-in/right-out driveways
- Addition of new pedestrian signals at mid-block locations

Process Overview & Instructions

Phase 1: Scoping and Screening

Phase 1 consists of a report which documents identified needs at the project location, all intersection control types under consideration, and a recommendation of alternatives at the project location.

Phase 1 Steps

- Project Description & Background Information
    - The purpose of the ICE and preliminary investigation of the intersection and its context shall be discussed. This shall include:
        - Description of the location of the intersection(s), including surrounding land use, nearby major destinations, or other traffic generators, and their impacts on the intersection
        - Relevant details about pedestrian use, bicycle use, retail developments, access management challenges, driveways and driveway density, driver population, community attributes, parking zones, illumination, roadside design features, nearby rail crossings, etc.
        - Existing control types of the intersection(s) and nearby intersection control types
        - Lane configuration of the intersection(s) and approaching roadways
        - Roadway classifications
        - Approach speeds
        - Aerial imagery of intersection(s)
- Traffic Data Collection
    - Turning movement counts shall be collected at the subject location(s) for use in analysis. These counts must be no more than two (2) years old, unless no significant changes to traffic patterns have recently occurred in the area, in which case the counts must be no more than five (5) years old. These counts shall note heavy vehicles and include pedestrian data if applicable. Three (3) days of 24-hour data is recommended to be collected, usually either a Tuesday-Thursday or Thursday-Saturday depending on land use and regional traffic patterns.
    - Future traffic may be projected using historical traffic growth trends. Consult with ODOT Traffic Engineering Division's Design Data Group to confirm an appropriate growth rate.
    - Historical collision data shall be collected from ODOT's collision database. Five full years of collision data must be retrieved but it is recommended that ten years of data be

considered, especially for locations with a history of severe collisions. Collision numbers shall be summarized in a table based on collision type (rows) and the KABCO severity scale (columns) and include totals and percent of total of each collision and severity type.
    - K – Fatality
    - A – Suspected serious injury or incapacitating injury
    - B – Non-incapacitating injury or visible injury that does not fall under K or A
    - C – Possible injury or injury reported that does not fall under K, A, or B
    - O – No injuries, property damage only
  - If a signal exists at the project location, then signal timings and detection details shall be collected for use in analysis.
- Analysis of Existing Intersection Traffic Control
  - Operational analysis of the intersection's existing traffic control shall be performed using HCS7 or Synchro 11 (or other software approved by ODOT) based on peak traffic periods. Peak traffic periods are generally AM or PM but may also include a mid-day or "lunch" peak.
  - Analysis shall be performed for the existing condition and the design year, generally 10 or 20 years in the future. Both design horizons may be analyzed as needed. This analysis may also be presented for existing conditions, opening year, and design year.
  - Results from analysis shall include, at minimum, the Level of Service, Delay (in seconds per vehicles and vehicle-hours), and 95th Percentile Queues by approach, or by movement if necessary or useful.
- Screening of Alternatives
  - Screening is intended to narrow down the design alternatives for further analysis based on safety impacts and capacity. The list of control types at the end of this document shall be screened, but additional control types may be considered as necessary. The following Screening Questions and FHWA's CAP-X tool shall be used to preliminarily screen intersection alternatives. Some alternatives may not be included in the CAP-X tool analysis, and instead may be considered on an individual basis for capacity and included in screening. CAP-X is meant for pass/fail-style preliminary screening only and its results should be verified as needed before eliminating alternatives. Alternatives with very high (greater than 1 in the current year) or very low volume-to-capacity ratios may be considered for elimination. Generally, between two (2) and five (5) alternatives should remain at the end of screening, however more may be analyzed as needed.
    - Question 1: Is the alternative feasible and reasonable given site characteristics and geometric constraints (right-of-way, number of approaches, median, etc.)?
    - Question 2: Does the alternative address the needs of the location determined in data collection and initial analysis (safety, mobility, etc.) and is it the appropriate scale for the problem?
    - Question 3: Does the alternative improve or preserve existing safety performance of the location (for all modes, including bicyclists and pedestrians)?
    - Question 4: Is the alternative feasible and reasonable with respect to all other factors:

        - Initial capital & recurring costs
        - Continuity, uniformity
        - Utility impacts
        - Additional factors
    - Signal warrant analysis shall be performed in this step per the MUTCD to check feasibility and reasonability of signalized alternatives. ODOT considers an intersection to meet signal warrants when at least two (2) are met. Please note Warrant 3: Peak Hour Warrant is only applicable in unique contexts and must be justified if used.
    - Other improvements to the intersection may also be considered in this step, such as lighting improvements, modifications to signal coordination, medians, turn lanes, etc.
    - If a traffic signal is deemed the only feasible and reasonable alternative, variations in signal timings, coordination schemes, etc. shall be analyzed as alternatives. When other alternatives are considered feasible and reasonable, this effort may be reserved for Phase 2 if the traffic signal becomes a recommended alternative.
- Analysis of Proposed Alternatives
    - Operations
        - As with the existing condition, operational analysis of the proposed alternatives shall be performed using HCS7 or Synchro 11 (or other software approved by ODOT) based on peak traffic periods. Peak traffic periods are generally AM or PM but may also include a mid-day or "lunch" peak.
        - Analysis shall be performed for the existing condition and the design year, generally 10 or 20 years in the future. Both design horizons may be analyzed as needed. This analysis may also be presented for existing conditions, opening year, and design year.
        - Results from analysis shall include, at minimum, the Level of Service, Delay, and 95th Percentile Queues by approach, or by movement if necessary or useful. Results for the existing condition and each alternative shall be presented in a table for ease of comparison.
    - Safety
        - Each alternative shall be presented with applicable Crash Modification Factors (CMFs) or Crash Reduction Factors (CRFs) from the Highway Safety Manual (HSM) and projected collision impacts based on said CMFs. If none exist in the HSM for a particular alternative, the Crash Modification Factor Clearinghouse or other research from FHWA, TRB, or other relevant organizations shall be consulted. All reported CMFs shall be documented with either a reference to the location in the HSM or other document or a CMF ID, or both. It is preferred that reported CMFs from the Clearinghouse have minimum ratings of four stars. If reported CMFs have lower ratings, additional justification is needed for use. If no applicable or adequate CMFs can be found, then safety impacts of the alternative shall be discussed in terms of conflict points, crash severity reduction, etc. Highway Safety Software or other relevant safety analysis tools may be used.

        - Speeds and sight of road users shall also be discussed in this section. Minimum sight distances, sight triangles, etc. shall be considered to ensure safety at the proposed intersection.
    - Vulnerable Road Users (VRUs)
        - Pedestrian and bicycle accessibility and impacts shall be discussed for each alternative and may be presented in terms of drawbacks and benefits or "pros and cons."
        - HCM7 Multimodal Analysis may be used.
    - Right-of-Way
        - An approximate footprint of each alternative shall be estimated. Potential increases in footprint may be discussed in relative terms compared to the existing footprint. E.g., a roundabout will have a larger footprint and may require additional right-of-way as opposed to installation of a traffic signal with no lane modifications.
        - Impacts of alternatives on surrounding businesses or property shall be discussed.
    - Cost
        - The initial cost and recurring maintenance costs of each alternative shall be discussed and compared, using a high/moderate/low scale. More detailed information may be included if available.
        - A benefit-cost analysis may be required if requested by ODOT.
    - Environmental
        - If it is clear the project will need any specific environmental evaluation, study, or other consideration, the need shall be mentioned in the ICE documentation.
- Alternative Analysis Summary
    - A summary matrix shall be made to compare the feasible alternatives. Information for major vs. minor may be included where appropriate. Metrics in italics are considered optional. Additional metrics may be required on a case-by-case basis. The summary shall include, but is not limited to, the following metrics:
        - Existing Overall Delay in veh-h
        - Existing Critical Approach LOS/Delay in s/veh (note critical approach)
        - Existing Longest Queue in feet and/or vehicles (note critical approach)
        - Design Year(s) Overall Delay in veh-h
        - Design Year(s) Critical Approach LOS/Delay in s/veh (note critical approach)
        - Design Year(s) Longest Queue in feet and/or vehicles (note critical approach)
        - Expected Total Collision Reduction (%)
        - Expected Injury Collision Reduction (%)
        - *Expected Collision Reduction for Primary Collision Pattern (e.g. Angle Collisions)*
        - Pedestrian and Bicycle Accessibility Impacts
        - Right of Way Needs/Impacts
        - Initial Cost (relative)
        - Recurring Maintenance Cost (relative)
- Alternative Recommendation

    - Based on the results of the Analysis of Proposed Alternatives and the Performance Summary Matrix, a recommendation for which alternative(s) to implement at the intersection shall be presented. Multiple alternatives may be recommended if their analyses resulted in similar outcomes and they are equally feasible and reasonable. Supplemental intersection modifications, such as illumination, may be recommended in addition to the proposed intersection control type(s). If a single alternative is recommended it may be moved forward for design and construction in collaboration with the District. If multiple alternatives are recommended then Phase 2 will begin.
- Preliminary Conceptual Designs
    - 2D conceptual drawings may be required for recommended alternatives that modify the intersection geometry. These shall include approximate striping.

Phase 1 Report Outline

- Executive Summary
- Project description
    - Reason for ICE/Project type
    - Intersection summary/context
- Traffic Data Summary
    - Traffic Counts
    - Collision History
- Alternative Screening
    - Feasible Alternatives
        - If innovative or lesser-known control types are included, briefly describe characteristics, benefits, and possible drawbacks of these
        - Optional: A brief table summarizing the volume-to-capacity ratio results from the CAP-X Tool
- Analysis
    - Existing Operations
    - Proposed Alternatives
        - Alternative 1
            - Operations
            - Safety
            - Vulnerable Road Users
            - Right of Way and Cost
            - Other Sections, as needed
                - Illustrative examples of alternatives may be included, especially for innovative or lesser-known control types
        - Repeat for each feasible alternative
        - Alternative Analysis Summary
    - Repeat for each intersection included in the project
- Summary & Recommendation
- Appendices
    - Turning Movement Data
    - Collision History

- Collected Signal Timings (if applicable)
- Analysis Outputs
- Signal Warrant Analysis (if applicable)
- CAP-X Output

Phase 2: Alternative Selection

Phase 2 consists of additional information to be added to the ICE report documenting differences between alternatives in regards to additional operational and safety analysis results, right-of-way impacts, environmental impacts, project cost, and other negative user impacts. Phase 2 is collaborative with the District and Traffic Engineering Division and may include iterations of meetings for discussion of alternatives with the District and Traffic Engineering Division. At the end of Phase 2, one preferred alternative shall be selected for the project location.

Phase 2 Steps (if requested by the District or Traffic Engineering Division)

- Additional Analysis
  - Operational Analysis
    - If additional useful analysis results are obtainable through other tools, such as Vissim or other in-depth analysis tools, this analysis may be performed in Phase 2 in an effort to acquire additional information to aid in decision making.
    - Variations in signal timings, coordination schemes, etc. may be analyzed for signalized alternatives.
    - If previously studied design horizons were insufficient for comparing breakover points of alternatives' operational performance, other intermediate design horizons may be analyzed.
    - Any reevaluation needed based on new information obtained in Phase 2.
  - Safety Analysis
    - If the CMFs determined in Phase 1 were not adequate for comparison and decision-making, Safety Performance Functions (SPFs) may be used to further analyze alternatives.
- Cost Estimates
  - Cost estimates may be developed in collaboration with the District. These cost estimates may include:
    - Right-of-Way Acquisition
    - Utility Relocation
    - Environmental Mitigations
    - Design Costs
    - Construction Costs
    - Maintenance Costs
- Alternative Recommendation
  - Based on the results of Phase 2, one alternative shall be selected for design and construction at the project location.

Phase 2 Report Outline (to be added to the Phase 1 Report)

- Summary of discussion of Phase 1 with District and Traffic Engineering Division and decision on next steps

- Additional Alternative Analysis (if needed)
- Cost Estimates
- Alternative Analysis Summary
    - This summary table may include metrics from Phase 1, but may also include any other relevant metrics as needed
- Other Considerations (as needed)
- Summary & Recommendation
- Appendices
    - Additional Analysis Reports
    - Other relevant documentation

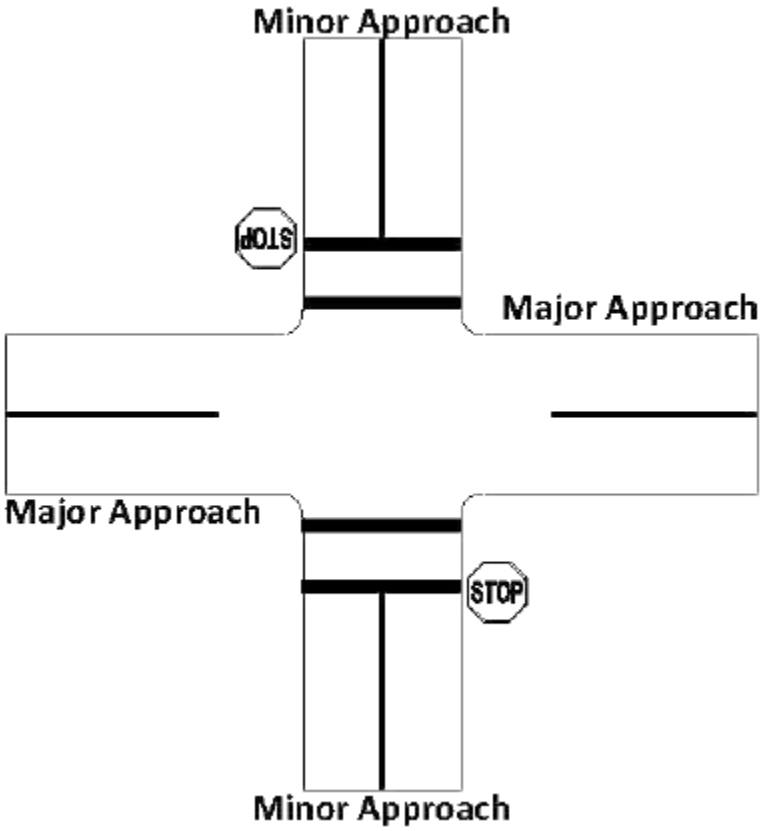
Deviations from this outline are permitted when justified and agreed upon with the District and Traffic Engineering Division.

Report Approval

ICE Reports shall be reviewed by ODOT Traffic Engineering Division and the District. Requested modifications shall be incorporated in the report in a timely manner.

Intersection Control Types

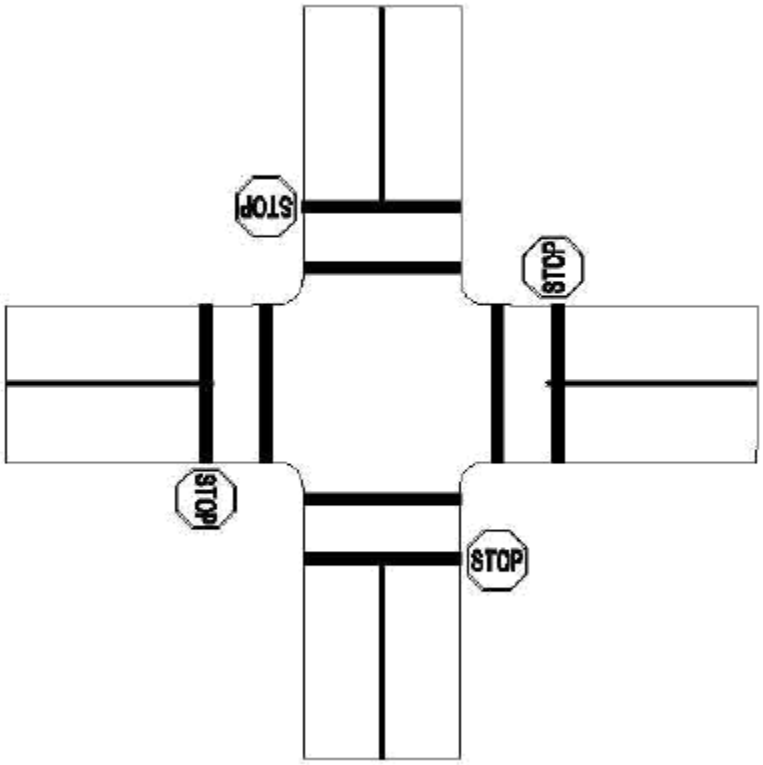
Two-Way Stop Control



1: FDOT Manual on Intersection Control Evaluation

- A conventional intersection control type in which the minor street approaches are stop-controlled and the major street movements do not encounter any traffic control devices; simple and low-cost
- Common applications:
    - Lower volume intersections
    - Single lane approaches
    - Intersections with right-of-way, utility, or environmental constraints on geometry
- Limitations:
    - Higher collision risk than other control types
    - Limited capacity
    - Limited ability to accommodate U-turns

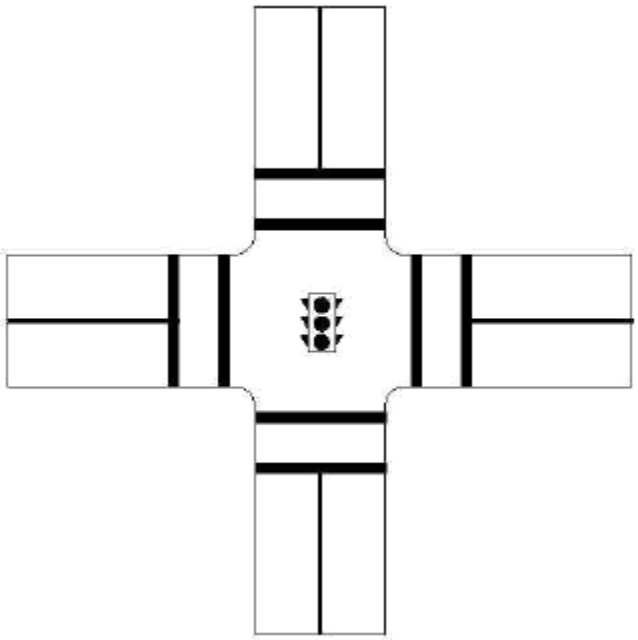
All-Way Stop Control



2: FDOT Manual on Intersection Control Evaluation

- A conventional intersection control type in which every approach is stop-controlled; simple and low-cost
- Common applications:
  - Lower volume intersections
  - Single lane approaches
  - Intersections with a high rate of right-angle collisions
  - Intersections with sight distance issues
  - Intersections with right-of-way, utility, or environmental constraints on geometry
- Limitations:
  - Limited capacity
  - Limited ability to accommodate U-turns

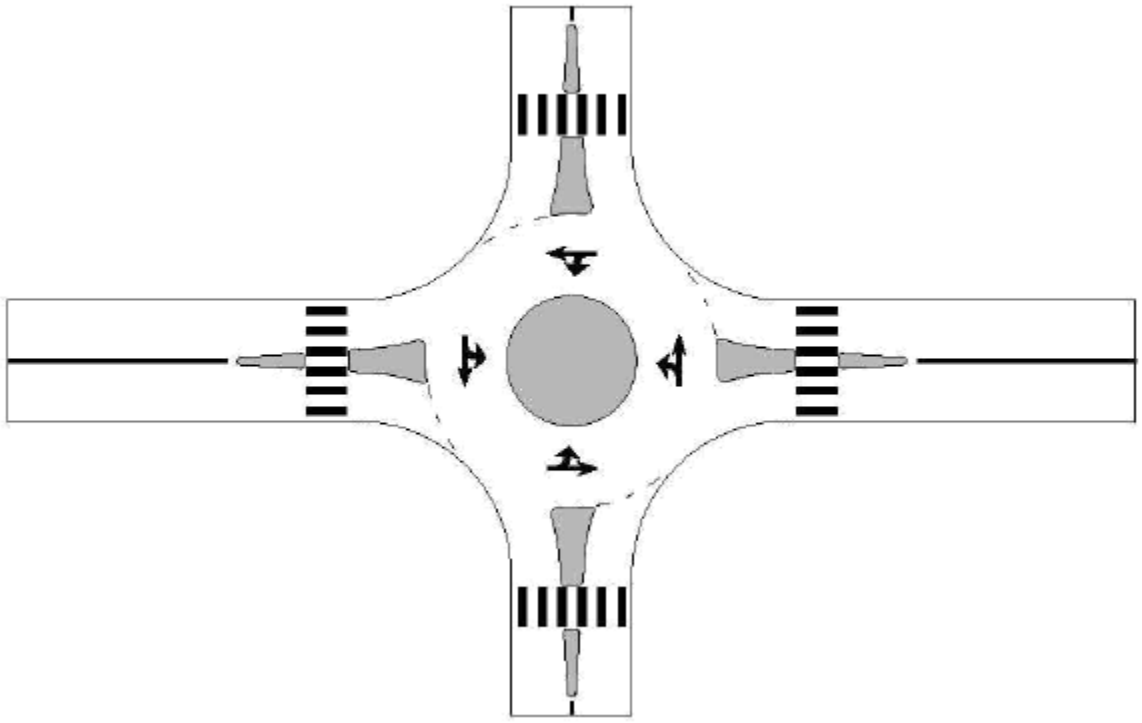
Signalized Control



3: FDOT Manual on Intersection Control Evaluation

- A conventional intersection control type in which each approach is controlled by a traffic signal
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Intersections with sight distance issues
    - Intersections with right-of-way, utility, or environmental constraints on geometry
    - Intersections near coordinated signals
    - Intersections with high pedestrian demand
    - Intersections that need emergency vehicle prioritization (pre-emption devices)
- Limitations:
    - Limited capacity, may increase delay and queues, and may require additional lanes
    - Limited ability to accommodate U-turns
    - Limited ability to serve high left-turn volumes
    - Requires considerable maintenance
    - May increase rear-end collisions

Roundabout

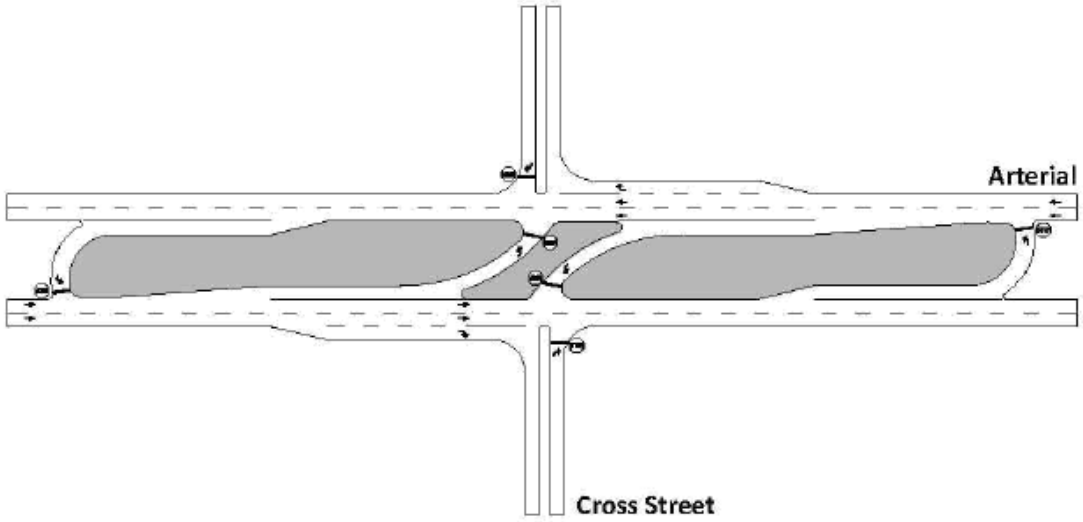


4: FDOT Manual on Intersection Control Evaluation

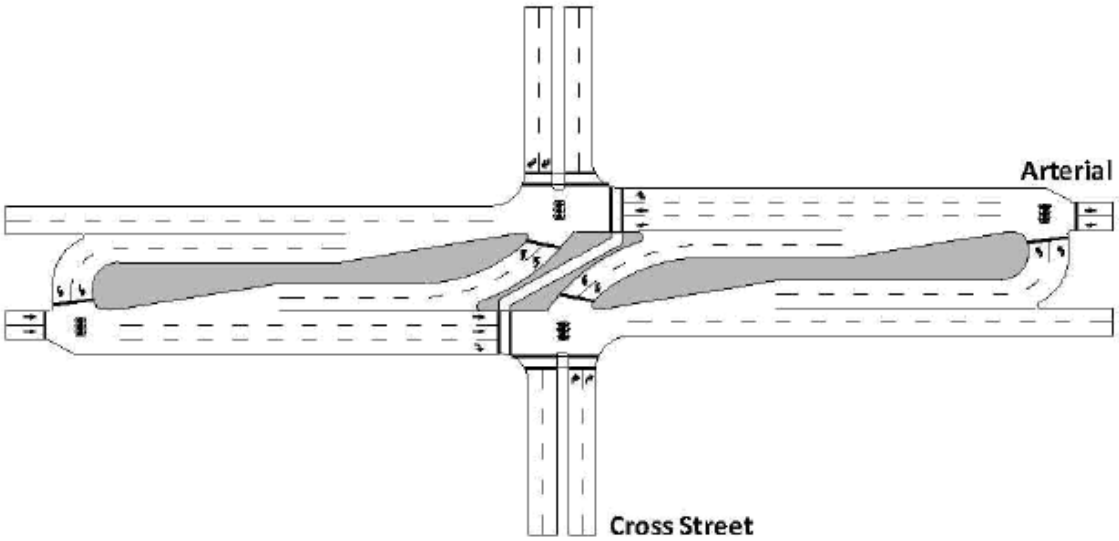
- A circular intersection in which traffic travels counterclockwise around a central island and in which entering traffic must yield to circulating traffic
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions or severe collisions
    - Intersections that would benefit from speed management or traffic calming, such as at transitions between land uses or speed zones
    - Intersections with higher volumes; intersections with up to 25,000 AADT for a one-lane roundabout, or up to 30,000 for a two-lane roundabout; a two-lane roundabout may also adequately serve intersections with AADT up to 45,000 (NCHRP 672)
    - Intersections with high delay
    - Intersections with more than four approaches
    - Skewed intersections
    - Intersections with high U-turn volumes
    - Intersections with heavy left-turn traffic
    - Intersections with similar traffic volumes on each approach
    - Intersections close together in series along a corridor
    - Intersections in access-controlled corridors using right-in/right-out access points
    - Intersections at diamond interchange ramp terminals
- Limitations
    - Right-of-way, utility, or environmental constraints may limit footprint

- Close proximity to other control types may hinder performance at subject or adjacent intersections
- Close proximity to driveways or limited access management options may hinder a roundabout's performance
- Steep vertical curves may cause sight distance issues at a roundabout
- May not handle unbalanced approach volumes well
- Typically requires lighting

Restricted Crossing U-Turn (J-Turn for unsignalized, Superstreet for signalized)



5: FDOT Manual on Intersection Control Evaluation

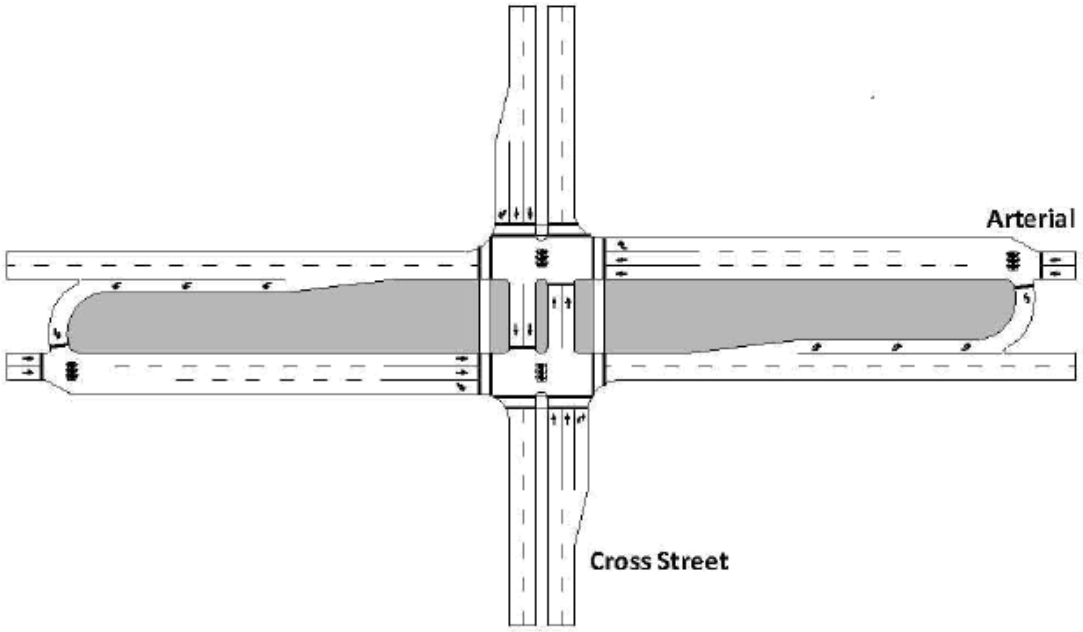


6: FDOT Manual on Intersection Control Evaluation

- An intersection design that restricts left-turn and through movements from side street approaches as permitted in conventional designs
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Intersections with sight distance issues
    - Intersections with high volumes on the major street that make minor left and through movements difficult
    - Signalized intersections with high delay on major approaches (signalized version)

  - Signalized intersections with long coordinated cycle lengths that still cannot adequately convey peak flows on the major street (signalized version)
  - Intersections in access-controlled corridors using right-in/right-out access points
  - Intersections where an interim solution is needed while an interchange is planned
  - Intersections with high pedestrian demand (signalized)
- Limitations:
  - Right-of-way, utility, or environmental constraints may limit loon designs at median crossovers
  - Best implemented where a sufficiently wide median exists
  - Median crossover locations may be limited by geometric constraints or require access modifications or limitations
  - Two-stage pedestrian crossing (signalized version)
  - Limited pedestrian accommodation (unsignalized version)
  - Turning paths of median U-turns may encroach on bike lanes

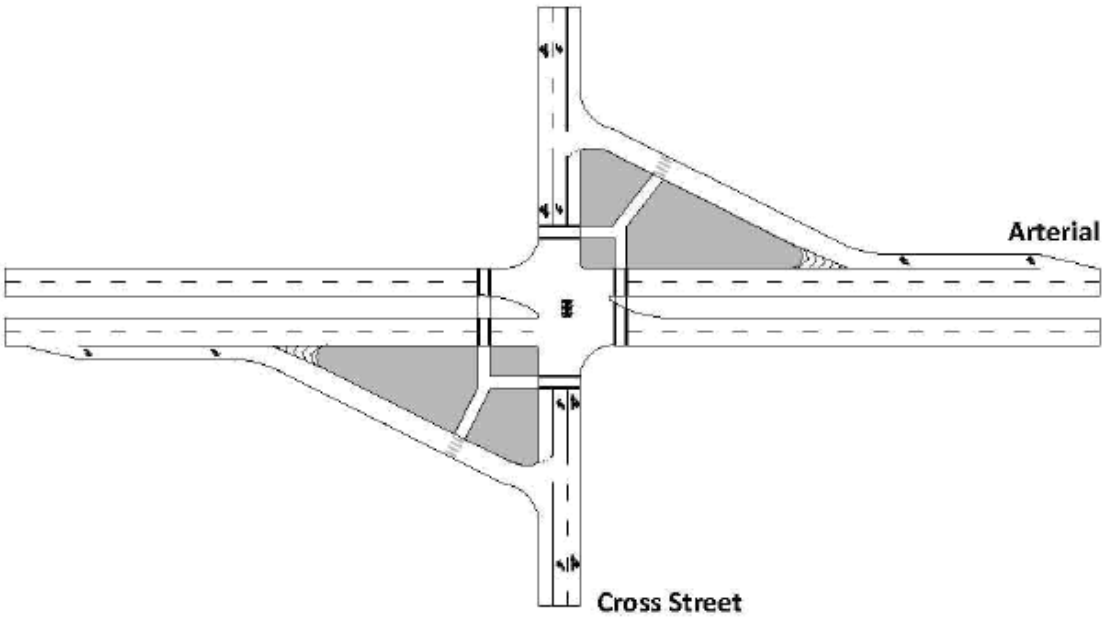
Median U-Turn (or ThrU-Turn)



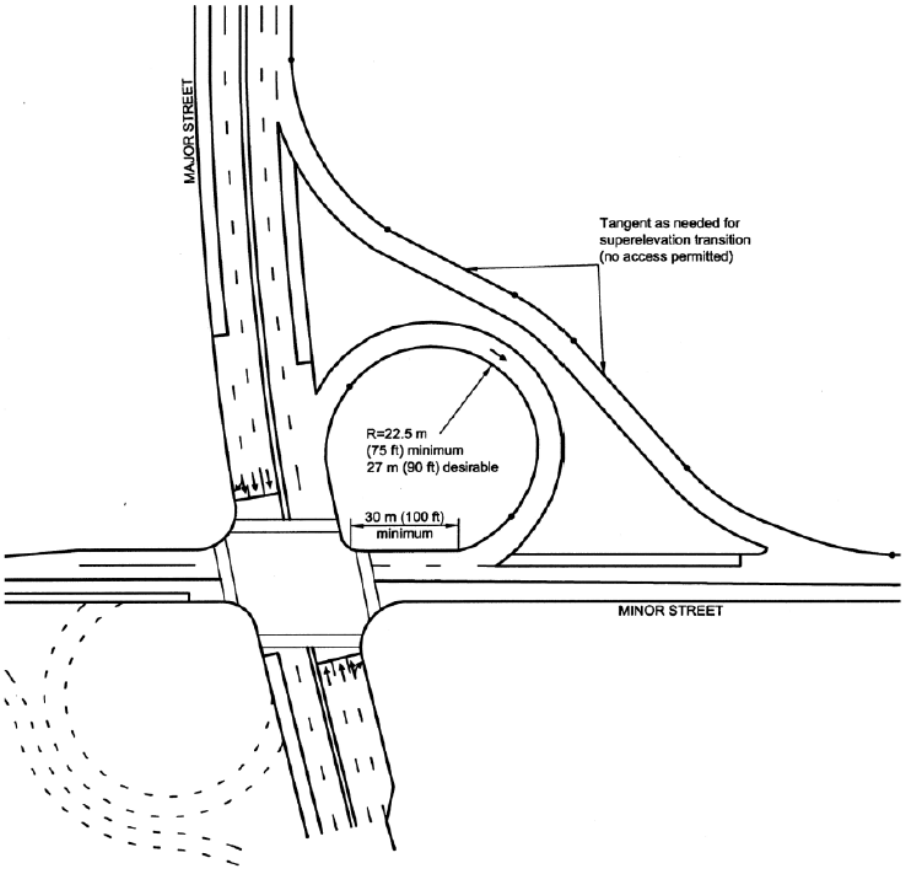
7: FDOT Manual on Intersection Control Evaluation

- An intersection treatment that eliminates direct left-turns at intersections from major and minor approaches and replaces them with U-turns on the major street; primary intersection is usually signalized but crossovers may or may not be depending on signal warrants and guidelines for protected left turns
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Intersections with sight distance issues
    - Intersections with high volumes on the major street that make minor left turn movements difficult
    - Signalized intersections with high delay on major approaches (signalized version)
    - Signalized intersections with long coordinated cycle lengths that still cannot adequately convey peak flows on the major street (signalized version)
    - Intersections with high pedestrian demand
- Limitations:
    - Right-of-way, utility, or environmental constraints may limit loon designs at median crossovers
    - Best implemented where a sufficiently wide median exists
    - Median crossover locations may be limited by geometric constraints or require access modifications or limitations
    - Two-stage pedestrian crossing (signalized version)
    - Limited pedestrian accommodation (unsignalized version)
    - Turning paths of median U-turns may encroach on bike lanes

Jughandle



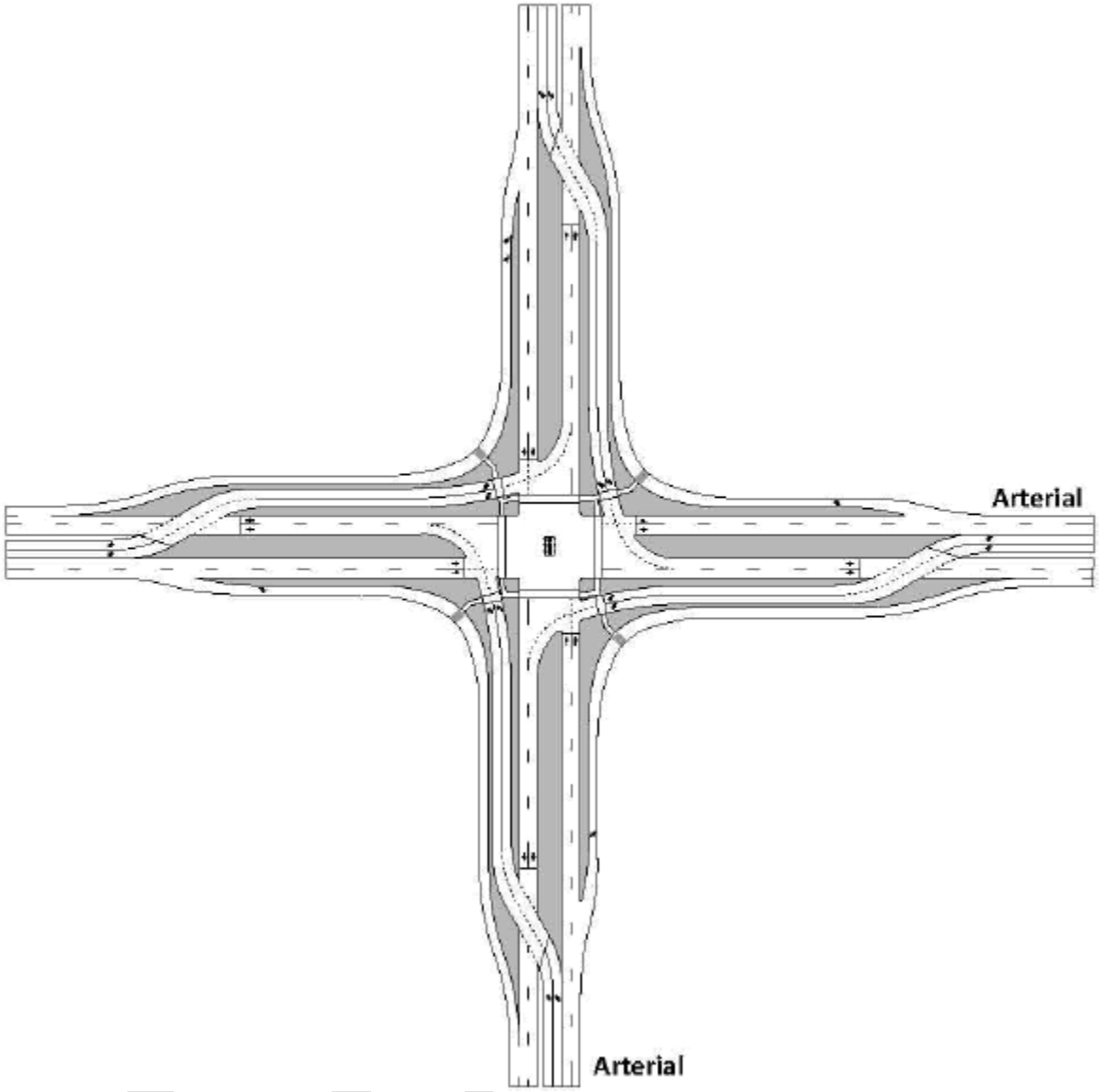
8: FDOT Manual on Intersection Control Evaluation



9: MnDOT Intersection Control Evaluation Manual

- A signalized intersection that uses at-grade ramp connectors between intersecting roadways to facilitate indirect left-turns or U-turns; connectors may be placed upstream (with diagonals) or downstream (with loops) of the cross street
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Intersections with high through volumes with moderate left turn volumes and low to moderate cross street volumes when a conventional signalized intersection is at or near capacity
    - Large, congested intersections in the middle of a coordinated signal system with good progression otherwise
    - Signalized intersections with high delay that may benefit from fewer signal phases
    - Intersections with high pedestrian demand
- Limitations:
    - Right-of-way, utility, or environmental constraints may limit footprint
    - Ramp diverges may create higher speed conflicts between motor vehicles and vulnerable road users

Displaced Left-Turn/Continuous Flow Intersection

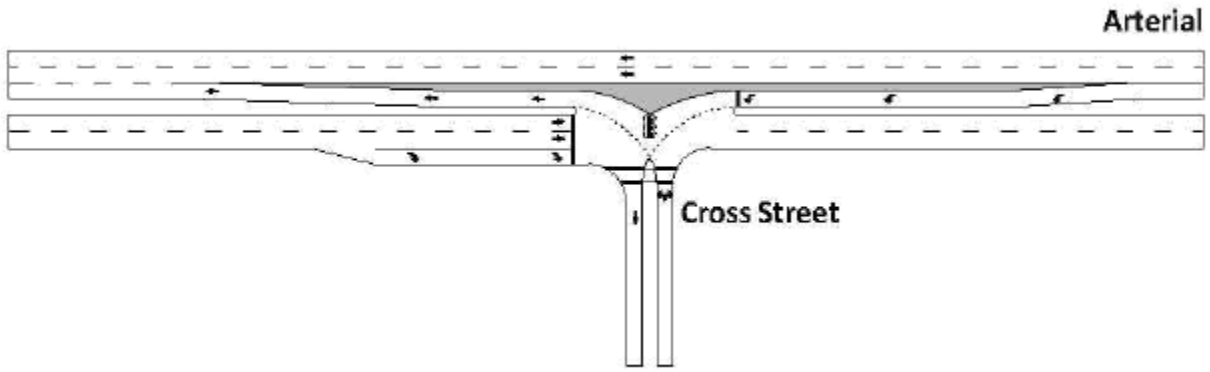


10: FDOT Manual on Intersection Control Evaluation

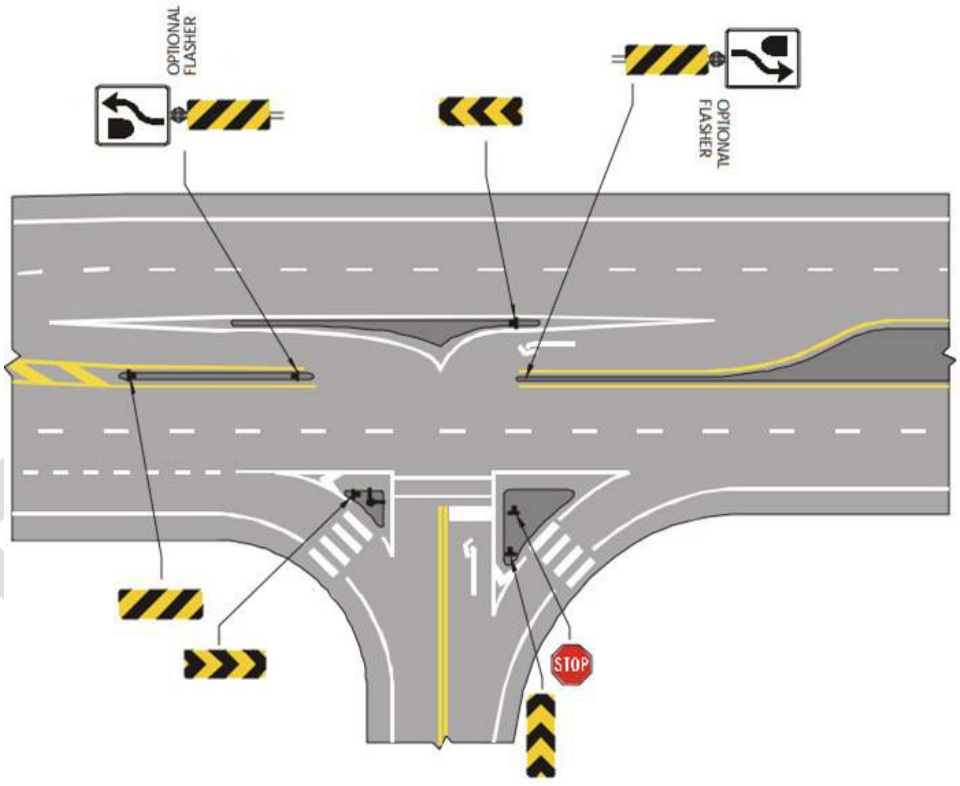
- A signalized intersection where one or more left-turn movements are relocated to the other side of the opposing traffic flow; these movements proceed through the intersection simultaneously with the through movements, which eliminates the left-turn phase on the approach
- Common applications:
    - Intersections with a high rate of collisions, especially left-turn collisions or pedestrian-related collisions
    - Intersections with moderate to high volumes in all directions
    - Intersections with heavy left-turn volumes throughout the day
    - Intersections where left-turn queues spill beyond the left turn storage bays
    - Signalized intersections with high delay with many signal phase failures
    - Intersections where an interchange is desired but available space is limited

- Limitations:
    - Right-of-way, utility, or environmental constraints may limit footprint
    - Proximity to nearby intersections may limit available space for footprint
    - Restricted access to parcels near the primary intersection, may require frontage roads
    - High pedestrian demand can cause long vehicular delays; multiple stage crossing may be needed by providing pedestrian refuges in medians
    - Visually impaired pedestrians may struggle with the layout
    - Limited ability to accommodate U-turns

Continuous Green-T/Turbo-T



11: FDOT Manual on Intersection Control Evaluation

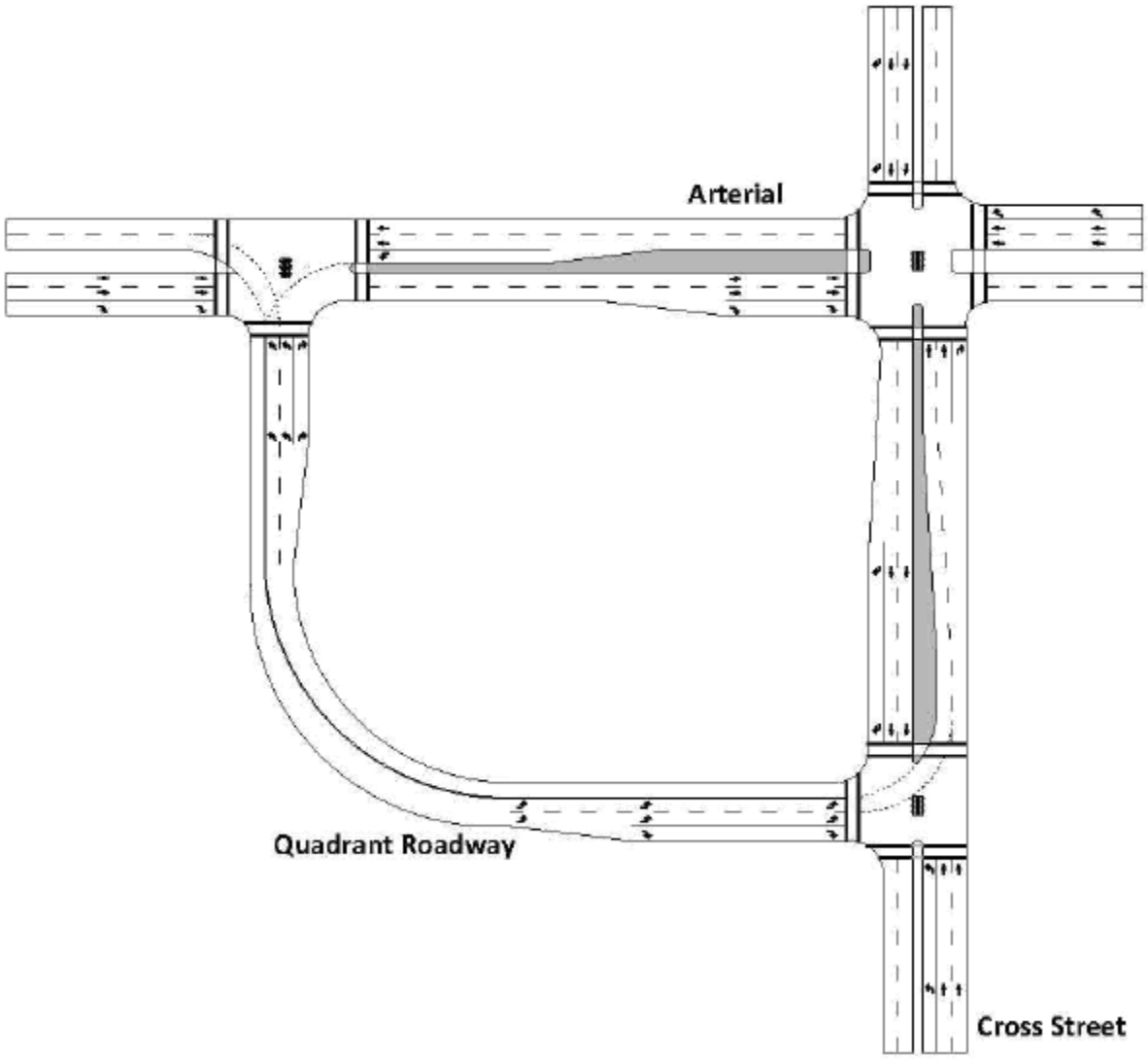


12: British Columbia Ministry of Transportation and Infrastructure

- A signalized or unsignalized 3-leg intersection that features raised channelization that separates the "top" through movement from the other movements of the intersection, enabling the top through movement to operate unsignalized with no conflicting movement
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Intersections where the major movement is the highest volume movement and the minor has a high volume of left-turns

  - Signalized 3-leg intersections that may benefit from fewer signal phases
- Limitations:
  - Only applicable at T-intersections
  - No pedestrian crossing for the major movements

Quadrant Roadway Intersection

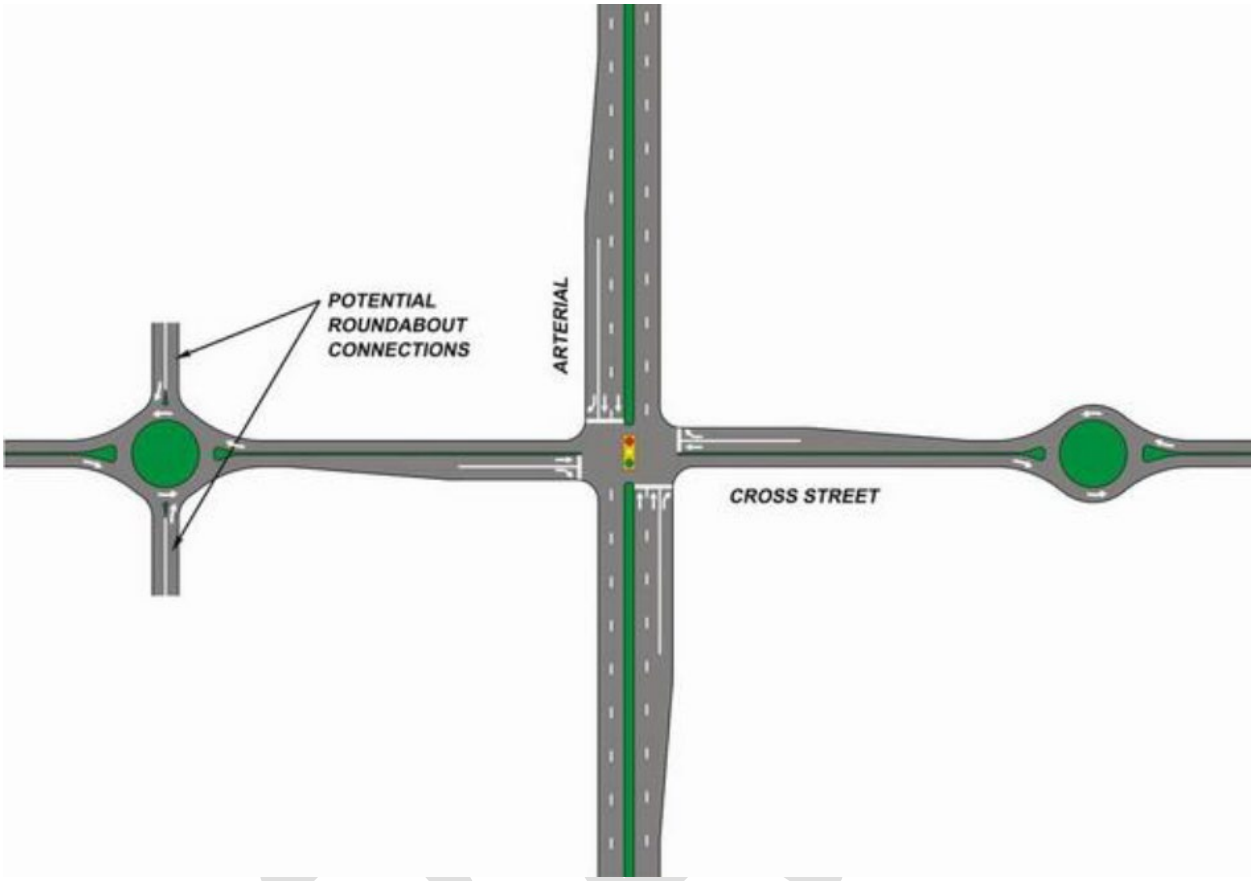


13: FDOT Manual on Intersection Control Evaluation

- An intersection intended to eliminate all direct left-turn movements from the main intersection by re-routing them to turns to and from a connector located in one quadrant
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Skewed intersections where the connecting quadrant roadway can be shorter and eliminate left turns that are not 90 degrees
    - Intersections with high major through volumes and moderate major left-turn volumes, especially signals at or near capacity
    - Large, congested intersections in the middle of a coordinated signal system with good progression otherwise
    - Signalized intersections that may benefit from fewer signal phases
    - Intersections near developing areas with available right-of-way or an existing street system that could serve as a quadrant roadway

  - Intersections where it would be beneficial to decrease pedestrian crossing distances
  - Intersections where an interim solution is needed while an interchange is planned
- Limitations:
  - Right-of-way, utility, or environmental constraints may limit footprint
  - May require access modifications or limitations

Bowtie Intersection



14: MnDOT Intersection Control Evaluation Manual

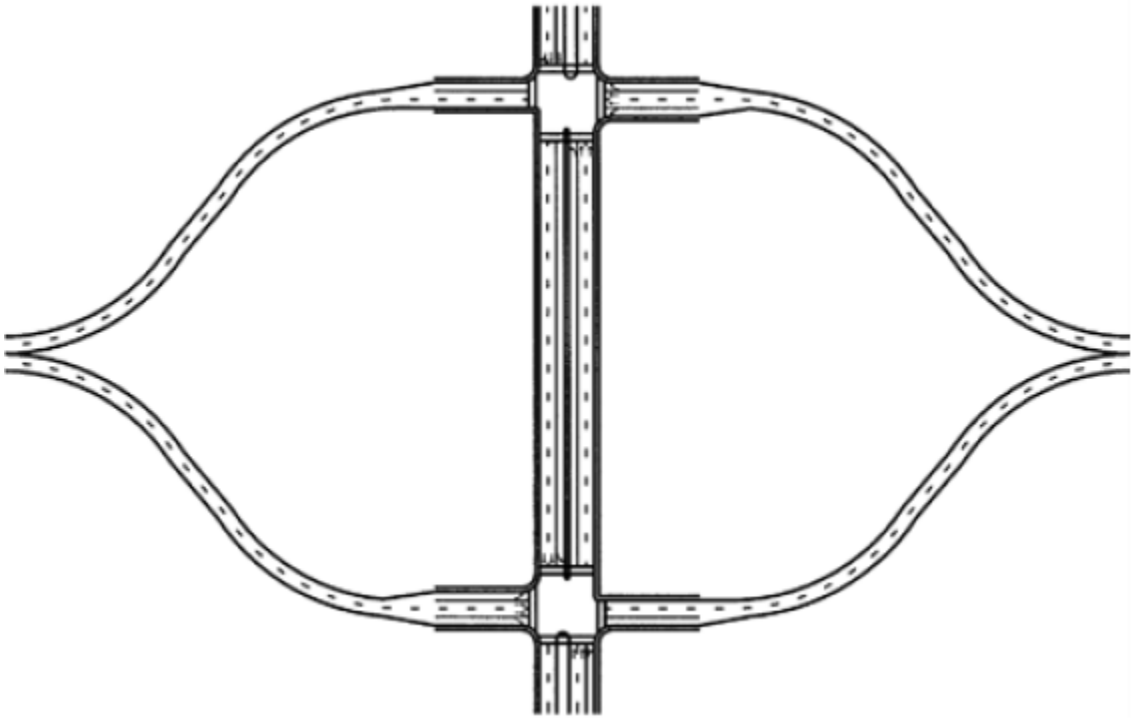
- An intersection that is a variation of the Median U-Turn using roundabouts that may or may not serve as intersections for adjacent roadways; primary intersection is usually signalized
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Intersections that would benefit from speed management or traffic calming
    - Intersections with high volumes on the major street that make minor left turn movements difficult
    - Signalized intersections that may benefit from fewer signal phases
    - Intersections where median size prohibits use of the MUT
- Limitations:
    - Right-of-way, utility, or environmental constraints may limit footprint
    - Roundabout locations may be limited by geometric constraints or require access modifications or limitations

Paired Intersections

15: MnDOT Intersection Control Evaluation Manual

- A combination of intersections alternating prohibited left turn movements from the arterial then the cross street along an arterial corridor; circulation to provide adequate turning movement connection to the cross street requires a system of two-way “backage” roads parallel to the arterial
- Common applications:
    - Intersections or corridors with a high rate of collisions, especially right-angle collisions
    - Intersections or corridors with high delay to through traffic
- Limitations:
    - Right-of-way, utility, or environmental constraints may limit footprint
    - May increase travel times for drivers

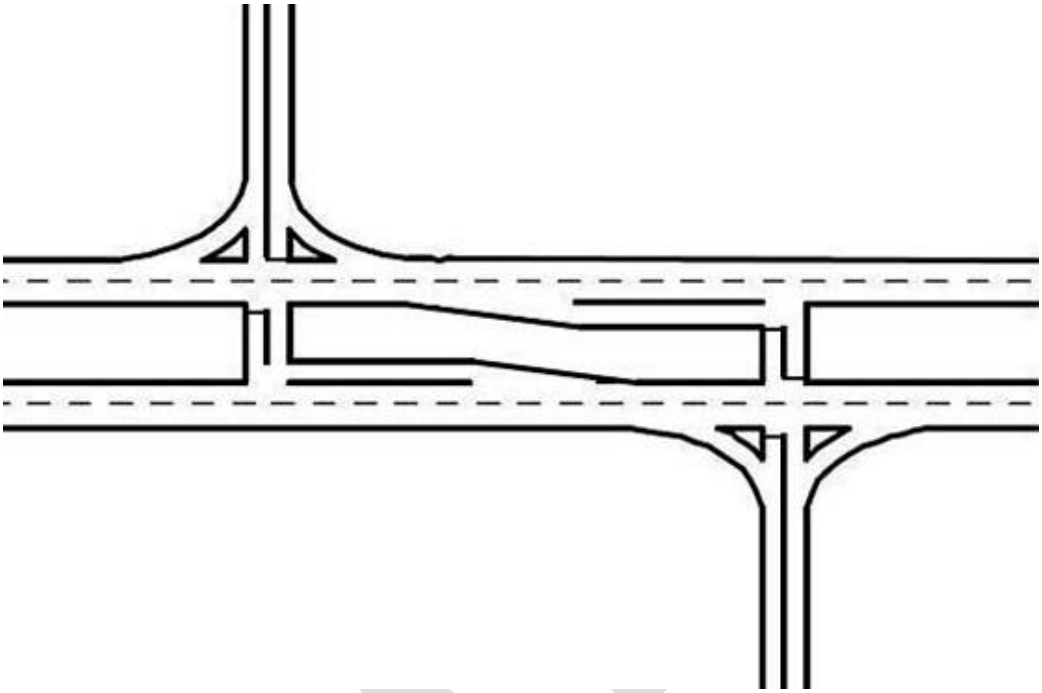
Split Intersection/One-Way Pairs



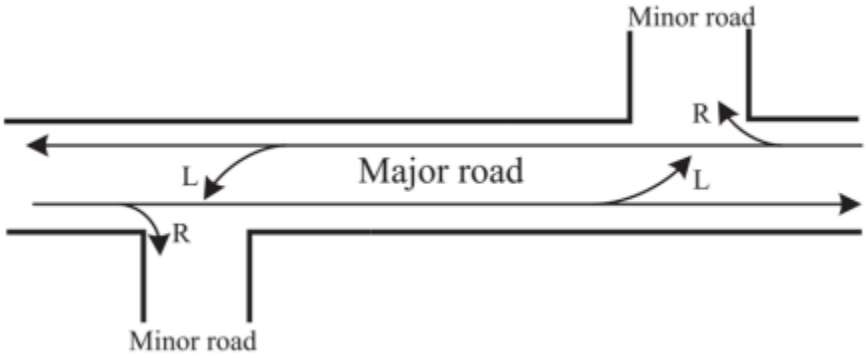
16: MnDOT Intersection Control Evaluation Manual

- A pair of intersections that operates like an at-grade diamond configuration where two intersections operate with three-phase signals instead of one intersection with a four-phase signal; may be used as a "stage" in constructing a diamond or other interchange
- Common applications:
    - Intersections with a high rate of collisions, especially right-angle collisions
    - Intersections where it would be beneficial to decrease pedestrian crossing distances
    - Intersections where an interim solution is needed while an interchange is planned
- Limitations:
    - Right-of-way, utility, or environmental constraints may limit footprint

Offset T Intersection



17: FHWA Typical geometry of an offset T-intersection



18: Offset-T Intersection from NCDOT Project 2019-31: Operational Applications of Signalized Offset T-Intersections

- Converts a conventional intersection into two T intersections offset by some distance along the major street
- Common applications:
  - Intersections with a high collision rate
  - Skewed intersections, especially on multi-lane roads
  - Intersections with low major and minor street volumes, but relatively high volumes of turning movements compared to through movements
- Limitations:
  - Right-of-way, utility, or environmental constraints may limit footprint
  - May increase merging and weaving collision risk
  - Limited capacity

Useful Guides

Document	Link
NCHRP 1087: Guide for Intersection Control Evaluation	https://www.trb.org/Publications/Blurbs/183161.aspx
Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis	https://www.trb.org/main/blurbs/175169.aspx
NCHRP 825: Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual	https://www.trb.org/NCHRP/Blurbs/174958.aspx
Capacity Analysis for Planning of Junctions (CAP-X) Tool	https://www.fhwa.dot.gov/software/research/operations/cap-x/
AASHTO Highway Safety Manual	https://highways.dot.gov/safety/data-analysis-tools/highway-safety-manual https://www.highwaysafetymanual.org
FHWA-SA-13-027: Signalized Intersections	https://safety.fhwa.dot.gov/intersection/signal/fhwasa13027.pdf
NCHRP 1043: Guide for Roundabouts	https://www.trb.org/Publications/Blurbs/182939.aspx
FHWA-SA-14-070: Restricted Crossing U-Turn Intersection Informational Guide	https://safety.fhwa.dot.gov/intersection/rltci/fhwasa14070.pdf
FHWA-SA-14-069: Median U-Turn Intersection Informational Guide	https://safety.fhwa.dot.gov/intersection/rltci/fhwasa14069.pdf
FHWA-HRT-09-055: Displaced Left-Turn Intersection	https://www.fhwa.dot.gov/publications/research/safety/09055/09055.pdf
FHWA-SA-14-068: Displaced Left-Turn Intersection Informational Guide	https://safety.fhwa.dot.gov/intersection/crossover/fhwasa14068.pdf
FHWA-HRT-07-032: Traffic Performance of Three Typical Designs of New Jersey Jughandle Intersections	https://www.fhwa.dot.gov/publications/research/safety/07032/07032.pdf
FHWA-SA-09-016: Continuous Green T-Intersections	https://oklahoma.gov/content/dam/ok/en/odot/meetings/a2020/200921/Green-T_Case_Study.pdf
FHWA-HRT-09-058: Quadrant Roadway Intersection	https://www.fhwa.dot.gov/publications/research/safety/09058/09058.pdf
FHWA-HRT-09-060: Alternative Intersections/Interchanges: Informational Report (AIIR)	https://www.fhwa.dot.gov/publications/research/safety/09060/09060.pdf
NCHRP 948: Guide for Pedestrian and Bicycle Safety at Alternative and Other Intersections and Interchanges	https://www.trb.org/Main/Blurbs/181781.aspx