OVERVIEW AND DISCUSSION OF OPPORTUNITIES FOR OPERATION AND DESIGN OF SIGNALIZED INTERSECTION APPROACHES WITH TWO POTENTIAL LEFT TURN LANES

AN INFORMATIONAL REPORT FOR THE NORTH CAROLINA DEPARTMENT OF TRANSPORTATION AND MUNICIPAL AND REGIONAL PARTNERS

Prepared by THE REGIONAL TRANSPORTATION ALLIANCE
For the Congestion Management Section

Posted October 18, 2022

October 18, 2022

Summary of opportunities/use cases for intersection approaches with 2 potential left turn lanes

Single, positive offset, permitted-only left turn lane
Lower left turn volumes throughout the day, no or rare cycle failures
Reasonable to excellent sight distance

Single, ideally positive offset, protected-permitted left turn lane
Low/moderate left turn volumes
Reasonable sight distance for one left turn lane
Protected phase can be cycle or time-of-day dependent

Dual, protected-permitted left turn lanes
Significant left turn volumes for at least part of the day
Reasonable sight distance for both left turn lanes for permitted operation with low/moderate volumes
Protected phase can be cycle or time-of-day dependent

Dynamic left turn intersection (DLTi)
Significant left turn volumes for at least part of the day
Sufficient sight distance for one left turn lane for permitted operation under low/moderate volumes
Reduction in complexity of permissive movement compared to permitted phase with two left turn lanes

off-peak:
Single, positive offset, protected-permitted left turn lane; *protected phase can be cycle dependent (positive offset created by the closed adjacent right-most left turn lane)*

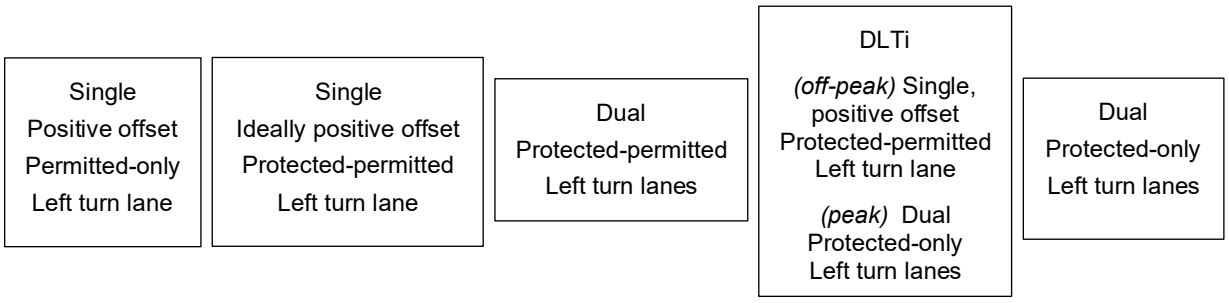
peak:
Dual, protected-only, left turn lanes

Dual, protected-only, left turn lanes
Significant left turn volumes for at least part of the day
Low sight distance for both left turn lanes precludes permitted operation under low/moderate volumes

---

General comparison of left turn opportunities

….. ***Left turn volumes or cross products*** *(low to moderate to high)* …..



….. ***Sight distance*** *(excellent, to reasonable, to reasonable for one left turn lane, to low)* …..

October 18, 2022

OVERVIEW AND DISCUSSION OF OPPORTUNITIES FOR OPERATION AND DESIGN OF SIGNALIZED INTERSECTION APPROACHES WITH TWO POTENTIAL LEFT TURN LANES

Overview of Geometric and Operational Options for Left Turn Lanes

Left turn movements at signalized intersections can be accommodated by single left turn lanes, dual left turn lanes, and occasionally triple left turn lanes. The number of left turn lanes available is typically predicated on current or anticipated turning and opposing through volumes, along with available right of way at the intersection, funding available for construction or modernization, and other site characteristics.

The selection of phasing type – permitted, protected, or protected/permissive – depends on several factors, including number of turning lanes, intersection sight distance, overall geometric conditions, volume distribution of turning and opposing vehicles (i.e., cross product), pedestrians, and safety performance. Phasing type can vary by time of day and often varies from approach to approach.

Single left turn lanes opposed by one or more through travel lanes are usually accompanied by permissive or protected/permissive left turn phasing, particularly when a positive offset geometric configuration is available. However, protected-only operation is not uncommon, particularly during high volume periods and/or when adverse intersection sight distance conditions are present that cannot be readily modified.

Dual left turn approaches that are opposed by one or more through travel lanes are primarily associated with protected-only phasing in North Carolina. However, a small but growing number of dual left locations with effective intersection sight distance employ permitted or protected/permitted phasing, either all day or during those times where favorable volume and travel speed conditions are prevalent.

NCDOT has also initiated a "dynamic left turn" intersection ("DLTi") approach, which provides time-of-day variability between a single, positive offset left turn lane with permitted or protected-permitted phasing during off-peak periods, and a dual left turn lane with protected-only operation during peak hours. NCDOT activated the state's first DLTi approach in early 2020 in Wake County.

NCDOT occasionally employs triple left turns that are opposed by one or more through travel lanes. These always operate under protected-only operation in North Carolina.

This report focuses on signalized intersection approaches with ***two potential*** left turn lanes.

The summary and chart on the preceding page provide an overall comparison of various opportunities.

Left Turn Phasing Types: Safety, Operational, and Capacity Implications

The selection of left turn phasing type for an approach carries with it a number of safety, operational and capacity implications. *It is important to note that phasing is interdependent with the geometric conditions of the intersection, and that the ideal time to consider phasing is while an intersection is designed.*

Protected-only operation reduces motorist uncertainty while greatly lessening the likelihood of conflicts among various vehicle movements and between vehicles and vulnerable users. While the specific safety benefits depend on the intersection and will vary based on conditions, the use of protected-only phasing may serve to mitigate conflicts at locations when completely eliminating them is impractical. Based upon North Carolina Department of Transportation Traffic Safety Unit's Crash Reduction Factors (CRF), left turn accidents can be expected to be reduced by 70% if protected-only left turn phasing is implemented as compared to left turn traffic signal operations with permitted only or permitted/protected left turn signal phasing.

Protected phasing can also create capacity benefits under higher volume conditions, as the protected indication creates an affirmative reservation of intersection time-space for the subject movement, enabling efficient platooning behavior. The addition of a second left turn lane and the activation of protected-only left turn signal phasing may be optimal for at least a portion of the day at various locations.

Protected-only phasing can create suboptimal operational conditions as well. Protected-only phasing necessarily requires the display of the protected phase, even when only one turning vehicle is present for a given approach. Not only do all turning vehicles from the subject approach have to wait for the display of the protected phase, but all conflicting approaches must also wait while the protected phase is served.

A typical left turning phase includes 7-10 seconds of green turning time or more, plus around 4 seconds of yellow and 2 seconds of red – this means that 10-15 seconds or more of a cycle can be devoted to serving a single vehicle. Of course, the delays for an individual turning vehicle may be much longer – from the display of the left red arrow until the subsequent green arrow, which can be two minutes or more.

Permissive left turn operation can substantially reduce delay for those movements, and it can also reduce overall intersection delay, sometimes significantly. The use of a permissive left turn phase allows the redistribution of green time to other movements – by reducing the required green time for the protected left turn phase and/or eliminating the protected left turn phase entirely – during some or all cycles.

In addition, since permitted phases are typically longer than protected turning phases, the use of permitted or protected-permitted phasing substantially increases the proportion of the cycle in which turning is at least theoretically possible for a movement, with the actual usability of a particular permitted phase dependent on the turning and opposing volumes.

Protected-permissive or permissive-protected operation is the sequential display of these two-phase types for a given movement. This provides a combination of the capacity and conflict reduction benefit of the protected phase with the operational efficiency and flexibility of the permissive phase.

The selection of phasing type depends on the intersection, and more specifically the particular movement or intersection approach, as noted above. When protected-only operation is not called for, or only necessary during certain times of day, its overuse may cause drivers to wait unnecessarily for the left turn green arrow and could be deemed a violation of driver expectancy.

Operation and design of signalized intersection approaches with two potential left turn lanes

A primary purpose of this report is to encourage the asking of key questions throughout the design and modernization process for all signalized intersection approaches with two *potential* left turn lanes.

The use of "potential" is intentional – it refers to conditions where space and funding exists to install, activate, or retain a second left turn lane for all or part of the day for a given approach, either now or in the future. The fact that we can install or activate a second left turn lane at a particular location and time does not always mean that we should do so.

While any intersection design and operational review will include a host of mobility and safety elements across various travel modes, the analysis often depends on the interplay of the following two factors:

- Operations: Variability in "cross product" (i.e., product of left turning and opposing through volumes) for the subject movements. As per existing NCDOT practice, left turn traffic signal phasing at intersections should be considered if the product of the peak hour left turn volume multiplied by the peak hour opposing traffic volume exceeds 50,000 along two-lane roadways or exceeds 100,000 along four-lane roadways.
- Safety: Intersection sight distance for the left turning movements (See **NCDOT Roadway Design Manual, Section 8.4 Intersection Sight Distance**, for guidance on sight distance requirements for left turn movements).

A review could commence with a simplified operational analysis to determine whether the potential exists for improved operations, either all day or for part(s) of the day. If that potential does exist, the design analysis should proceed, to determine whether/how to implement or optimize those operational benefits.

Factors such as sight distance limitations, crash histories, pedestrian flows, adjacent land uses near the intersection, traffic progression with adjacent intersections, and/or other factors that may lead the designer to selecting one intersection approach type over another.

Example Left Turn Volume Thresholds for Approaches with Two Potential Left Turn Lanes

Traffic capacity analyses using the Synchro 11 software were conducted at a typical intersection design to determine traffic volumes where a second left turn lane could be considered. Details of the traffic capacity analyses are shown in Appendix A. Based upon independent analyses of the modeled intersection, listed below are some design and operational elements to consider when evaluating an approach with two potential left turn lanes:

1) **If left turn demand is less than around 250 vehicles per hour, a single left turn lane will typically work** – under protected-only, protected-permissive, or permissive-only operation. The designer should examine to see if the less restrictive phasing operation (i.e., permissive only or protected-permissive) can be provided before moving to protected-only.
2) **Left turn demands up to 350 vehicles per hour can generally be accommodated in a single lane with protected-permissive phasing.** The dedicated protected phase provides additional capacity.
3) **Left turn demands above 350 vehicles per hour up to around 500 vehicles per hour can be typically accommodated with either dual left lanes under protected-only operation, a Dynamic Left Turn intersection (DLTi), or a dual left turn with protected-permitted operation.** Each of these options includes dual left turn lanes with a protected phase available during peak periods. The general use case selection among these three choices is as follows:
   a) **A dual left turn with protected-permitted operation** is the least restrictive of the three dual left choices, and is the preferred option if sight distance and intersection complexity conditions allow for successful operation. The permitted phase can be suppressed during part of the day.
   b) **A Dynamic Left Turn intersection (DLTi)** is the next least restrictive of the three dual left choices. The use case here is for situations with adequate sight distance for one left turn lane and/or a desire to reduce complexity for a permissive turning maneuver. This intersection functions as a protected- only dual left during peak periods.
   c) **Dual left turn with protected-only operation** is the most restrictive of the three dual left choices. It incorporates the benefits and tradeoffs of any approach with protected-only phasing. While this is the most prevalent phasing choice in use today for dual left approaches, most existing locations did not consider either dual protected-permitted or DLTi operation upon initial installation.
4) **If left turn demand exceeds 500 vehicles per hour during some periods of the day, dual left turn, protected-permitted movements should be considered** if sufficient sight distance exists or can be created to operate a permissive phase for dual lefts successfully under favorable peak period conditions and there are no other confounding safety factors present. *Note: the permissive phase provides the additional capacity during peak periods above either the all-day protected-only dual left or the DLTi (which operates as protected-only dual left during peak periods).*

Additional notes and observations

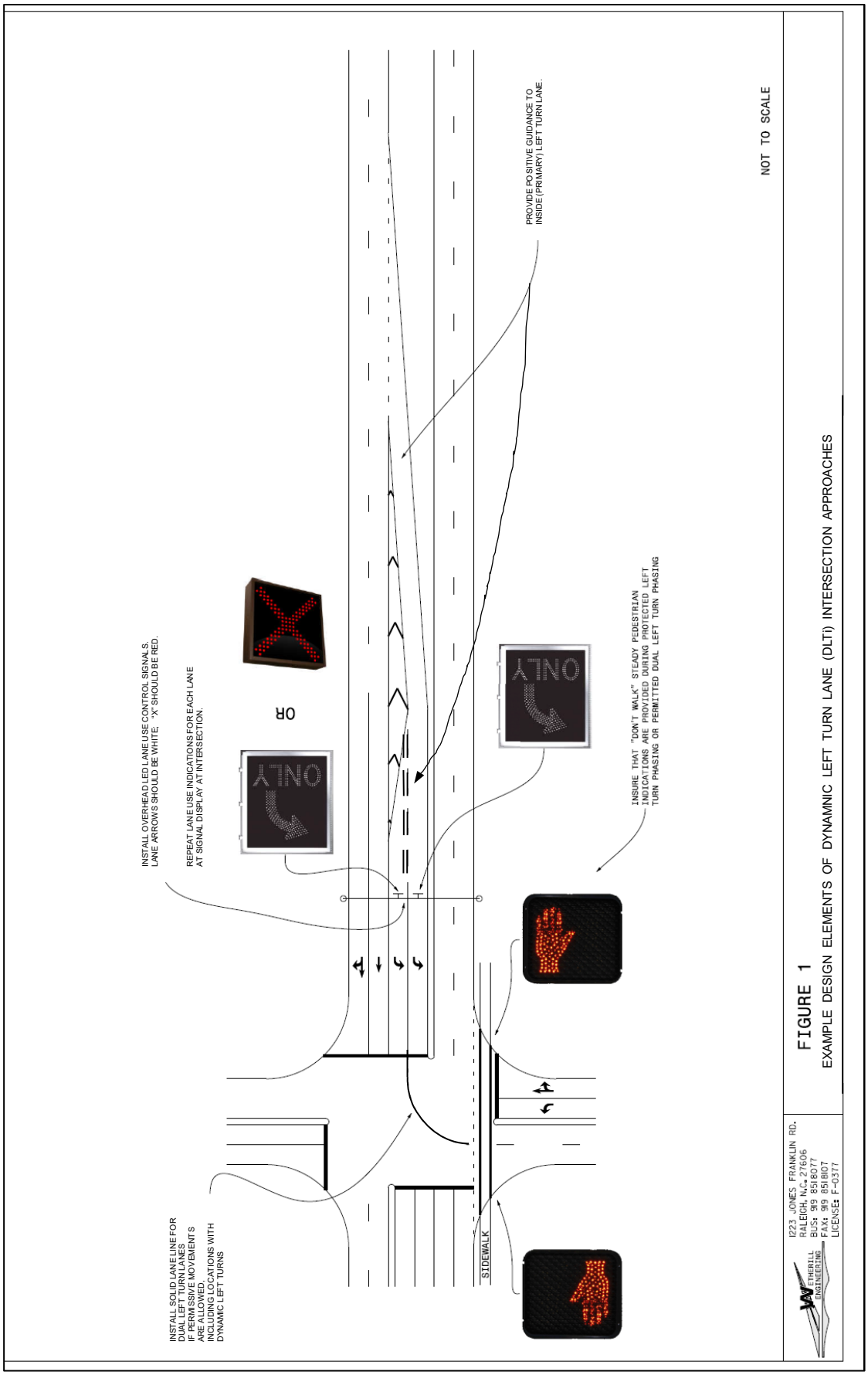
- **The above volume thresholds are based on an analysis of a "typical" intersection and thus should be considered general levels not absolute cutoffs.**
- An engineering study can best ensure that adequate sight distances are available for permissive left turn movements, along with the times of day to apply the two operational configurations for designs with phasing that varies throughout the day.
- When a peak hour analysis would indicate that dual lefts should be considered (e.g., above 350 left turns per hour), the designer should still evaluate how the intersection would operate if single lefts were used or retained – from a capacity, queue length, and delay standpoint, during both peak and off-peak periods.
    - If the peak is expected to be marginally better with two left turn lanes but would be "survivable" with only one left turn lane – perhaps by using a longer left turn phase duration and overall cycle length during the "peak of the peak" and/or a longer storage area – then both dual and single left turn configurations should be examined and summarized so that the tradeoff on both a peak and off-peak basis is clear.
    - As well, the designer is urged to be wary of marginal cases in support of dual left turns during peak periods, particularly when the design volumes involve projections for a future year, as lane balance across multiple left turn lanes cannot be assured during peak periods and single lefts are often far more efficient off-peak.
- Opportunities for improving sight distance through restriping (e.g.) should always be considered.
- Anyone working on the operational analysis of an NCDOT project should follow the "Capacity Analysis Guidelines" assembled by the Congestion Management Section and posted on their website.

Observations on signs, signals, and markings

1. **If protected-only dual left turn phasing is designed**, either a solid white line or "puppy tracks" should be considered to guide the concurrent left turn flows through the intersection.
2. **If protected-permitted or permitted double left turn lanes are considered** in the design, pedestrian actuated signals should be considered as part of the design to discourage conflicts between pedestrians and turning vehicles. A solid DO NOT WALK indication can be displayed during a permissive double left turn movement in the absence of an activation for the conflicting pedestrian movement; conversely, the flashing yellow arrow can be suppressed whenever the WALK and flashing DO NOT WALK indications are displayed as a result of a pedestrian activation.
3. **Any intersection with dual protected-permitted or dual permitted left turns – including DLTi approaches** – should consider a solid white stripe within the intersection to minimize encroachment among turning vehicles and guide the concurrent left turn movements through the intersection.
4. **All dynamic left turn intersection approaches should use two overhead LED lane use control signals** for each left turn lane. Either a white left turn arrow or a red "X" would be displayed for the part-time, peak relief lane depending on the time of day. The primary, typically left-most, left turn lane would remain open at all times and always display a left turn arrow. The LED lane use control signal indications for each lane would be repeated in advance of the intersection and at the intersection itself. A single, four-section head for left turns will be mounted over the lane line separating the two left turn lanes at the intersection.
5. **Dynamic left turn intersection approaches would provide positive guidance to the primary, typically left-most, left turn lane** via striping since this turn lane will be operational at all times. A double dashed white stripe at the entry into the peak relief left turn lane would help guide the motorist to the primary left-turn lane, similar to the double dashed striping used for other restricted or reversible lane situations. See *Figure 1 for Example Design Elements of Dynamic Left Turn intersection (DLTi) approaches.*
6. **Potential redirection of selected U-turns** – U-turns can have significant consequences for both operational efficiency and safety, depending on volumes, location, and geometry. If necessary, the designer could consider redirecting all or some U-turns to an upstream or downstream mid-block location, signalized or unsignalized, whenever feasible. Also, the designer could consider recommending that trucks be prohibited from using certain U-turns if accommodating them at a particular location is impractical and if an alternative U-turn routing were reasonable from both a travel distance and positive guidance standpoint.

A note on funding

If an intersection type that will reduce delay is selected, this improvement may be a viable candidate for North Carolina Department of Transportation (NCDOT) Spot Mobility Funding. *The delay savings achieved via the introduction of permitted phasing can be directly translated into an annual dollar delay benefit that can provide the time frame for the recapture of the investment.*


INSTALL OVERHEAD LED LANE USE CONTROL SIGNALS. LANE ARROWS SHOULD BE WHITE. "X" SHOULD BE RED.
REPEAT LANE USE INDICATIONS FOR EACH LANE AT SIGNAL DISPLAY AT INTERSECTION.
OR
ONLY
ONLY
PROVIDE POSITIVE GUIDANCE TO INSIDE (PRIMARY) LEFT TURN LANE.
INSURE THAT "DON'T WALK" STEADY PEDESTRIAN INDICATIONS ARE PROVIDED DURING PROTECTED LEFT TURN PHASING OR PERMITTED DUAL LEFT TURN PHASING
INSTALL SOLID LANE LINE FOR DUAL LEFT TURN LANES IF PERMISSIVE MOVEMENTS ARE ALLOWED, INCLUDING LOCATIONS WITH DYNAMIC LEFT TURNS
SIDEWALK
NOT TO SCALE
THERRELL ENGINEERING
1223 JONES FRANKLIN RD.
RALEIGH, N.C. 27606
BUS: 919 851 8077
FAX: 919 851 8107
LICENSE: F-0377
FIGURE 1
EXAMPLE DESIGN ELEMENTS OF DYNAMNIC LEFT TURN LANE (DLTi) INTERSECTION APPROACHES

APPENDIX A

TRAFFIC CAPACITY ANALYSES TO DEVELOP TRAFFIC VOLUME CRITERIA FOR INTERSECTION APPROACHES WITH TWO POTENTIAL LEFT TURN LANES

Study Methodology for Design of Intersection Approaches with Two Potential Left Turn Lanes

Synchro 11 traffic simulation software was utilized for a typical intersection design in order to determine general traffic volume criteria to consider for various single or dual left turn lane designs among left turn phasing types (permissive, permissive/protected, and protected-only).

Shown below are the Intersection Assumption Parameters, the Results of Left Turn Lane Design and Traffic Signal Control, and Potential Conclusions of Results.

Intersection Assumption Parameters

1. Major Street – 1 or 2 Left Turn Lane(s) with 300 feet of storage in each lane, 2 Through Lanes, and 1 Right Turn Lane with 150 feet of storage.
2. Minor Street – 1 Left Turn Lane with 200 feet of storage, 1 Through Lane, and 1 Through/Right Lane
3. Peak Hour Factor – 0.90
4. Peak Directional Flow Major – 800 vehicles through movement and 150 right turns
5. Off-Peak Directional Flow Major – 400 vehicles through and 75 right turns
6. Peak Directional Flow Minor – 200 left turns, 400 throughs, and 150 right turns
7. Off-Peak Directional Flow Minor – 100 left turns, 200 throughs, and 75 right turns
8. Eastbound Left Turn is considered the subject left turn movement on major street
9. 120 second cycle length assumed for all scenarios
10. Subject Left Turn was considered at capacity at the LOS D/E threshold or 95th percentile queue was approximately 300 feet based upon Synchro 11 software.
11. Both lead and lag left turn signal phases analyzed.
12. Traffic signal timings optimized.
13. Major Street Speed Limit = 40 MPH, Minor Street Speed Limit = 30 MPH

Results of Left Turn Lane Design and Traffic Signal Control

1. Permitted/Protected Single Left Turn Phasing Traversing with Peak Flows of Traffic = 370 vehicles maximum
2. Permitted/Protected Single Left Turn Phasing Traversing Against Peak Flows of Traffic = 340 vehicles maximum
3. Protected Only Single Left Turn Phasing, concurrent with Peak Flows of Traffic = 270 vehicles maximum
4. Protected Only Single Left Turn Phasing Against Peak Flows of Traffic = 265 vehicles maximum
5. Protected Only Double Left Turn Phasing with Peak Flows of Traffic = 495 vehicles maximum
6. Protected Only Double Left Turn Phasing Against Peak Flows of Traffic = 495 vehicles maximum