TRANSPORTATION CABINET
Frankfort, Kentucky 40622
www.transportation.ky.gov/

Steven L. Beshear
Governor

Joe Prather
Secretary

DESIGN, PERMITS and TRAFFIC JOINT MEMORANDUM

DESIGN MEMORANDUM NO. 03-09
PERMITS MEMORANDUM
TRAFFIC MEMORANDUM

TO: Chief District Engineers
Design Engineers
Permit Engineers
Traffic Engineers
Active Consultants

FROM: Jeff Jasper, P.E.
Director
Division of Highway Design

Nancy Albright, P.E.
Director
Division of Maintenance

Jeff Wolfe, P.E.
Director
Division of Traffic Operations

DATE: July 28, 2009

SUBJECT: Auxiliary Turn Lane Policy

Over the years, the Cabinet has utilized various methods to determine the warrants and design of auxiliary lanes at intersections and access points. The KYTC Highway Design Guidance Manual, Section 900 currently identifies guidelines for the development of auxiliary turn lanes. The current Permits Manual Section 302, also includes separate guidelines for auxiliary lanes. As these methods differ between the Divisions within the cabinet, methods differ between the districts and their respective Design and Permits Sections. This has created a wide range of auxiliary lane requirements and designs for various projects throughout the state.

Recognizing these inconsistencies and the need for a uniform process that could be utilized to develop auxiliary turn lanes both for new projects and along new developments adjacent to existing roadways, the Kentucky Transportation Cabinet in conjunction with the Kentucky Transportation Center set out to develop a consistent set of warrants and design standards that the cabinet could apply to both new and existing facilities.

Attached with this memorandum are the new Auxiliary Turn Lane Warrants and Design Procedures. Also included are guidance for alternative turn lane designs, two-way left-turn lanes and positive offset of left-turn lanes.

An Interactive Excel Spreadsheet is also being developed to coincide with the warrants and design procedures of this new policy. Warrants for left and right turn lanes as well as desirable and minimum Turn Lane Lengths can be obtained thru the use of this spreadsheet. The spreadsheet can be found and downloaded at the following location: http://transportation.ky.gov/design/software/KYTC%20Auxiliary%20Lane%20Policy/Warrant_Calcs_Interactive.xls

These warrants and procedures shall be utilized on all new projects and permits that are started after the date of this memorandum. Existing projects that have not submitted Right of Way Plans or Permits that are in the early stages of review, shall also utilize these new warrants and procedures to develop auxiliary lane designs.

These warrants and procedures should also be applied to any other project that the Project Team decides might benefit by going back and re-examining the proposed auxiliary lane design.

As with any Project Team decision, the use of these warrants and procedures shall be documented in Meeting Minutes or Permit Folders for future reference.

JDJ/NA/JW/RCC

Attachment

LEFT-TURN LANE WARRANTS

The following are guidelines for determining when left-turn lanes should be used at intersections:

Signalized Intersections:

- Left-turn lanes shall be provided on all arterial and collector roadways at signalized intersections.

- Capacity analysis shall be used to determine the need for left-turn lanes at signalized intersections for 1) local roadways, 2) unclassified minor street approaches and 2) public or private access points (driveways).

- Capacity analysis shall be used to determine when multiple left-turn lanes are required.

Unsignalized Intersections:

- Left-turn lanes shall be provided at median openings on divided roadways but shall not be provided at median crossovers on freeways and interstates.

- Left-turn lanes shall be provided on approaches that are not under stop control at unsignalized intersections if the design hour traffic volumes at the intersection meet the thresholds identified in Figures 1 and 2.

- Capacity analysis shall be used to determine the need for left-turn lanes at stop controlled approaches of unsignalized intersections.

- Left-turn lanes should be considered as a safety countermeasure, e.g. where sight distance of advancing traffic is limited.

- Left-turn lanes shall not be required for unsignalized access points serving single family dwellings, multiple family dwellings with 3 or less units and farm/field entrances.

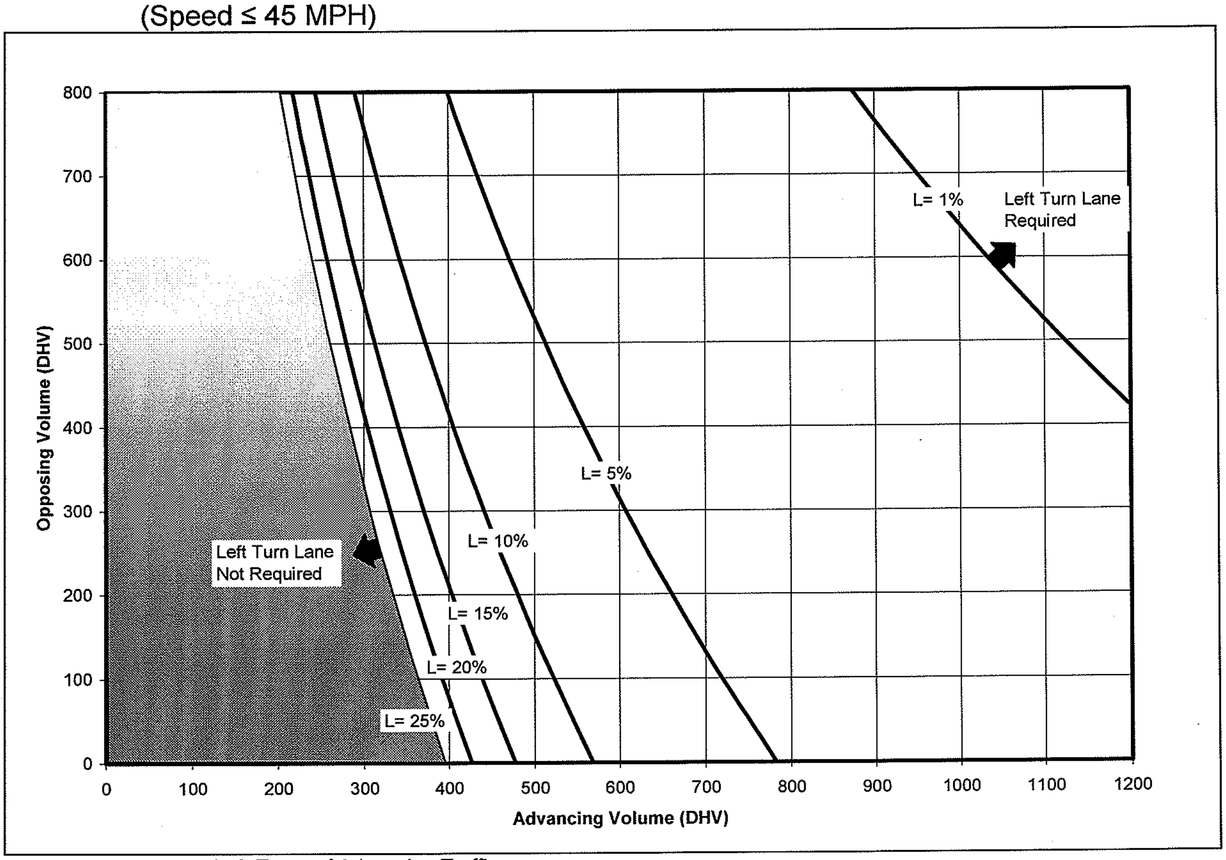
Heavy Vehicle Adjustment Factor

Figures 1 and 2 require the input of the advancing and opposing traffic volumes. At intersections with consistent volumes of heavy vehicles, the advancing volumes should be adjusted based on passenger car equivalencies as summarized in Equation 1 below to account for the diminished capacity of the left-turn movement:

EQ 1. $v_A' = v_A\,[1+P_{HV}(E_{HV})]$

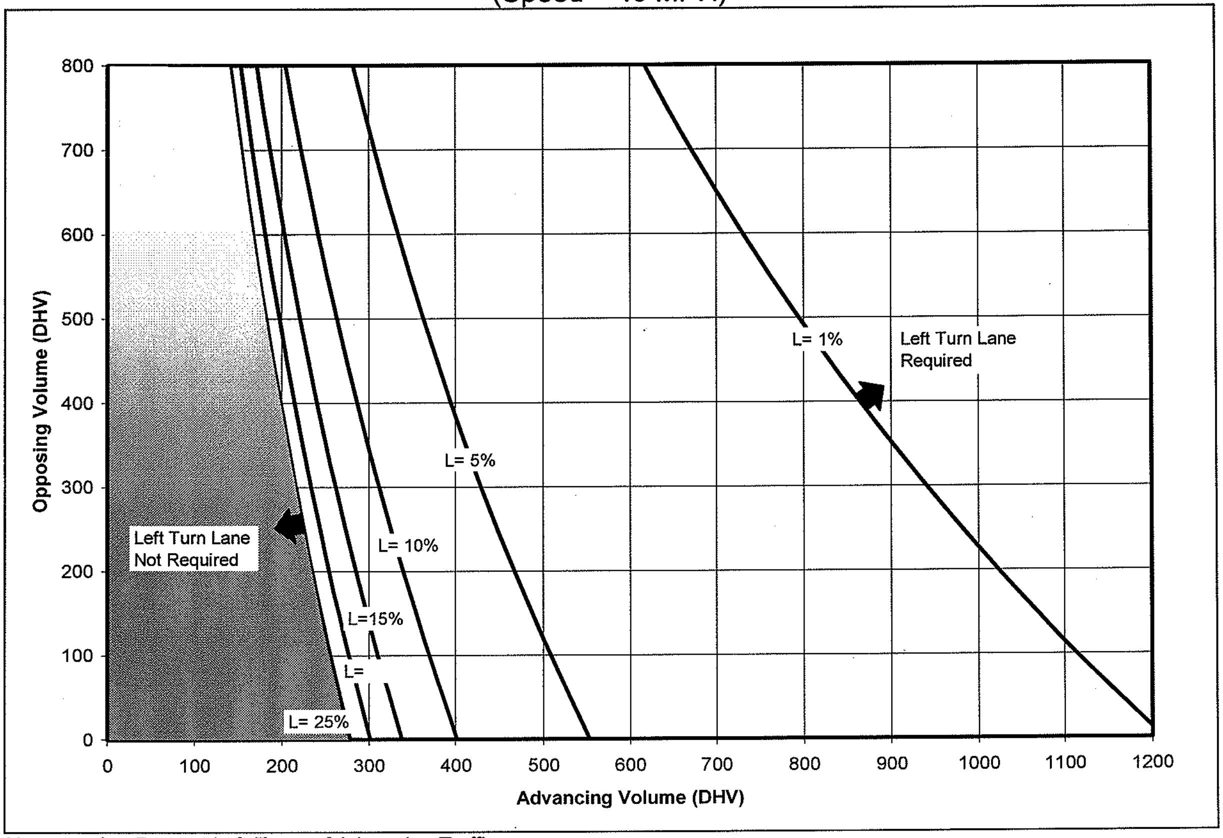
where: v_A' = Adjusted advancing traffic volume
v_A = Unadjusted advancing traffic volume
P_{HV} = Percent heavy vehicles (decimal percent)
E_{HV} = Passenger car equivalency factor
= 0.00035 (v_O) (two-lane facilities)
= 0.0007 (v_O) (four and six-lane facilities)
v_0 = Opposing traffic volume

Figure 1: Uncontrolled Approach; Left-Turn Lane Warrants for Low Speed Roadways (Speed ≤ 45 MPH)



Notes: *L = Percent Left-Turns of Advancing Traffic*
Advancing Volume = Through + Left + Right-Turn Traffic
Opposing Volume = Through + Left + Right-Turn Opposing Traffic

Figure 2: Uncontrolled Approach; Left-Turn Lane Warrants for High Speed Roadways (Speed > 45 MPH)



Notes: *L = Percent Left-Turns of Advancing Traffic*
Advancing Volume = Through + Left + Right-Turn Traffic
Opposing Volume = Through + Left + Right-Turn Opposing Traffic

RIGHT-TURN LANE WARRANTS

The following are guidelines for determining when right-turn lanes should be used at intersections:

Signalized Intersections:

- Right-turn lanes shall be provided on arterial and collector streets at signalized intersections if the design hour traffic volumes on the approach meet the thresholds identified in Figure 3.

- Capacity analysis shall be used to determine the need for right-turn lanes at signalized approaches of local streets.

- Right-turn lanes may also be considered to reduce the frequency of rear end crashes at intersections with a high volume of right-turns.

Unsignalized Intersections:

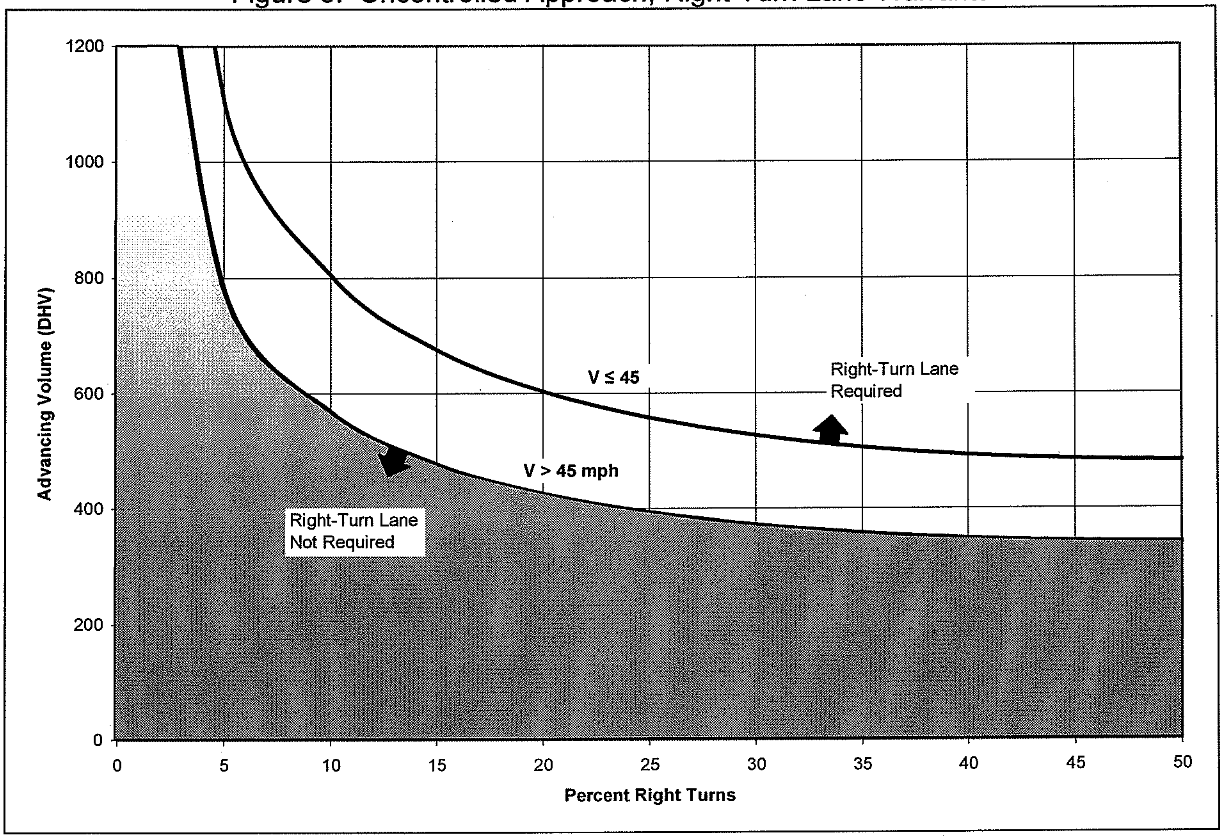
- Right-turn lanes shall be provided on non-stopping approaches at unsignalized intersections if the design hour traffic volumes at the intersection meet the thresholds identified in Figure 3.

- Capacity analysis shall be used to determine the need for right-turn lanes at stop controlled approaches of unsignalized intersections.

- Right-turn lanes should be considered as a safety countermeasure where sight distance of advancing traffic is limited.

- Right-turn lanes shall not be required for access points serving single family dwellings, multiple family dwellings with 3 or less units, and farm/field entrances.

Figure 3: Uncontrolled Approach; Right-Turn Lane Warrants

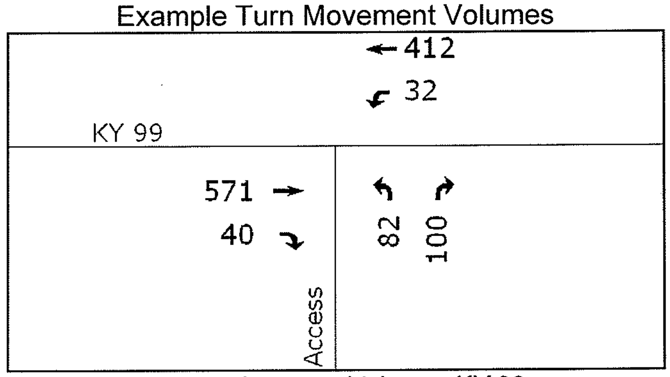


TURN LANE WARRANT EXAMPLE

Example: Problem Statement

A developer proposes a small retail shopping center that will be served by an unsignalized intersection of KY 99. KY 99 is a 4-lane rural arterial with a speed of 45 mph. A traffic impact study was completed and the design hour turning movement volumes were determined as shown in Figure A. **Are right and left turn lanes are warranted on State Route 99?**

Example Turn Movement Volumes



Assume six percent heavy vehicles on KY 99

Example: Heavy Vehicle Adjustment

Figure A indicates that the site is expected have 6 percent heavy vehicles. This requires application of the Heavy Vehicle Adjustment provided in Equation 1, prior to use of the Turn Lane Warrant Graphs.

Based on Figure A the following values are determined:

v_A = Unadjusted advancing traffic volume = 412+ 32 = 444 vph
P_{HV} = Percent Heavy Vehicles = 0.06
v_O = opposing traffic volume = 611 vph
E_{HV} = Passenger Car Equivalency Factor
= 0.0007 (v_0) (four and six-lane facilities)
= 0.0007 (611) = 0.428

Solving Equation 1 for v_A:
$v_A' = v_A\,[1+P_{HV}(E_{HV})]$
$v_A' = 444\,[1+0.06(0.428)]$
v_A' = 455 vph

Example: Left-Turn Lane Warrant

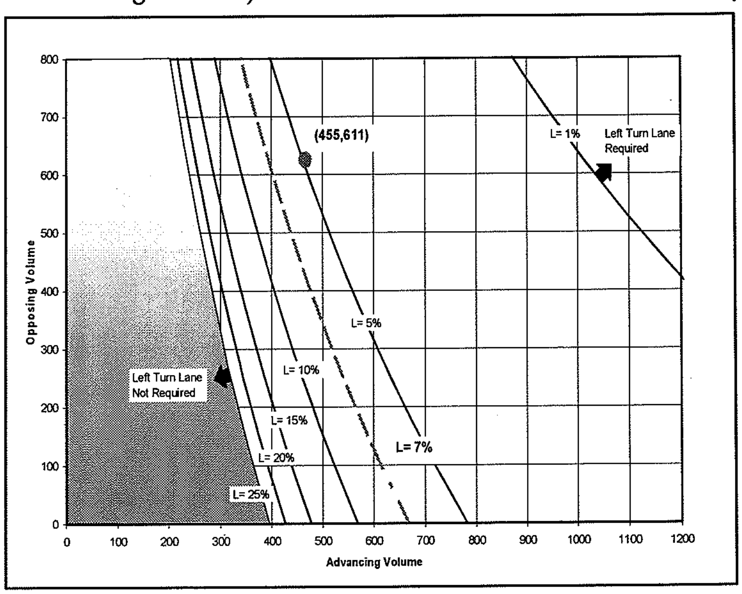
After determining the Heavy Vehicle Adjustment the left turn lane warrant curves provided in Figures 1 and 2 are used. Since KY 99 has a speed of 45 mph, Figure 1 is used (Speed ≤45 mph). The curve requires determination of the advancing volume (v_A), opposing volume (v_O) and left turn percent (L).

Advancing volume was determined under the heavy vehicle adjustment factor calculation above as 455 vph. Opposing Volume is the sum of ALL opposing movements, and is 611 vph. The left turn percent is the left turn volume divided by the advancing volume. *(Note: this calculation is based on the unadjusted advancing volume).*

$L = v_{LT} / (v_A)$
L = 32 / 444
L = 0.072 (7%)

The 7 percent line is interpolated between the 5% and 10% lines and the v_O and v_A values are plotted.

The left-turn lane is warranted.



Example: Right-Turn Lane Warrant

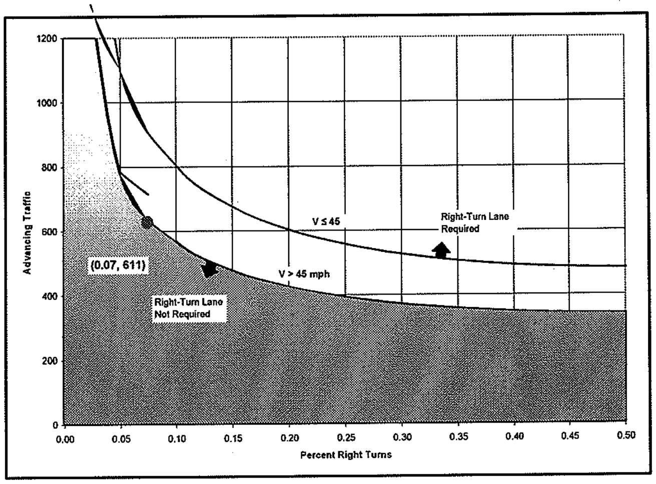
The right-turn lane warrant requires only two values, the total advancing traffic, which includes both through and right turn traffic and the percent of right turns. *(Note: The right turn lane warrant does NOT use a heavy vehicle adjustment factor).*

Advancing volume from the example problem is shown to be 611 vph. The right-turn percent is calculated as the right-turn volume divided by the advancing volume.

$L = v_{RT} / (v_A)$
$L = 40 / 611$
$L = 0.070$

The percent right-turns and advancing traffic are then plotted.

The right-turn lane is not warranted.

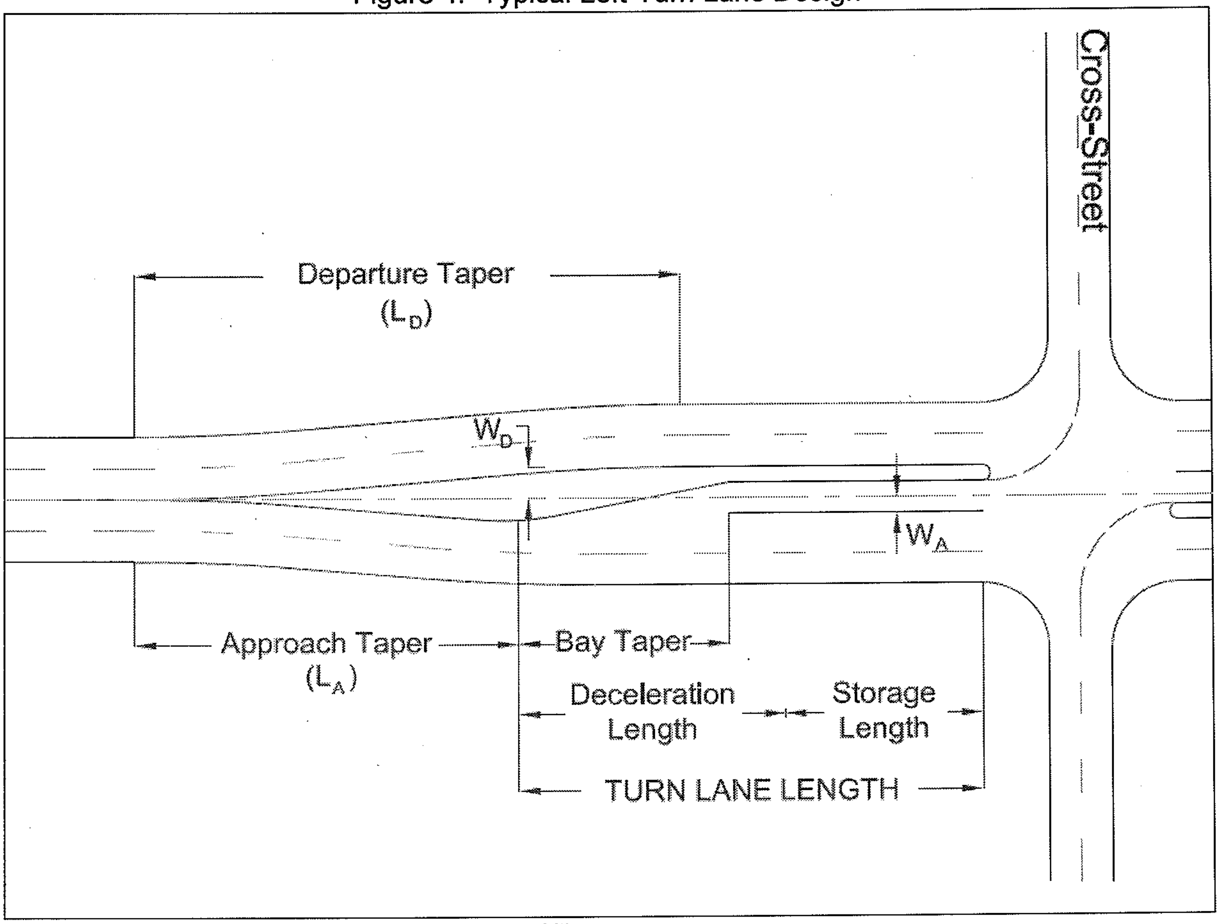


TURN LANE DESIGN

Auxiliary left-turn lanes have 3 primary components as shown in Figure 4:

- Approach Taper
- Bay Taper
- Turn Lane Length, which consists of
    - Deceleration Length
    - Storage Length

Figure 4: Typical Left-Turn Lane Design



Note: W_D = Departure taper width; W_A = Approach taper width

Dual left turn lanes may be formed in two ways, as shown in Figure 5 and 6. Figure 5 shows a simple design where the bay taper length is doubled as both lanes are formed simultaneously. The design in Figure 6 uses a single deceleration lane and then forms the dual storage lanes through the use of a second bay taper. This alternative may provide the opportunity to reduce overall pavement area on high speed approaches, which require long deceleration lengths. For both design options the storage length shown is ½ the calculated storage length for a single left-turn lane.

Figure 5: Dual Left-Turn Lane Design (Option1)

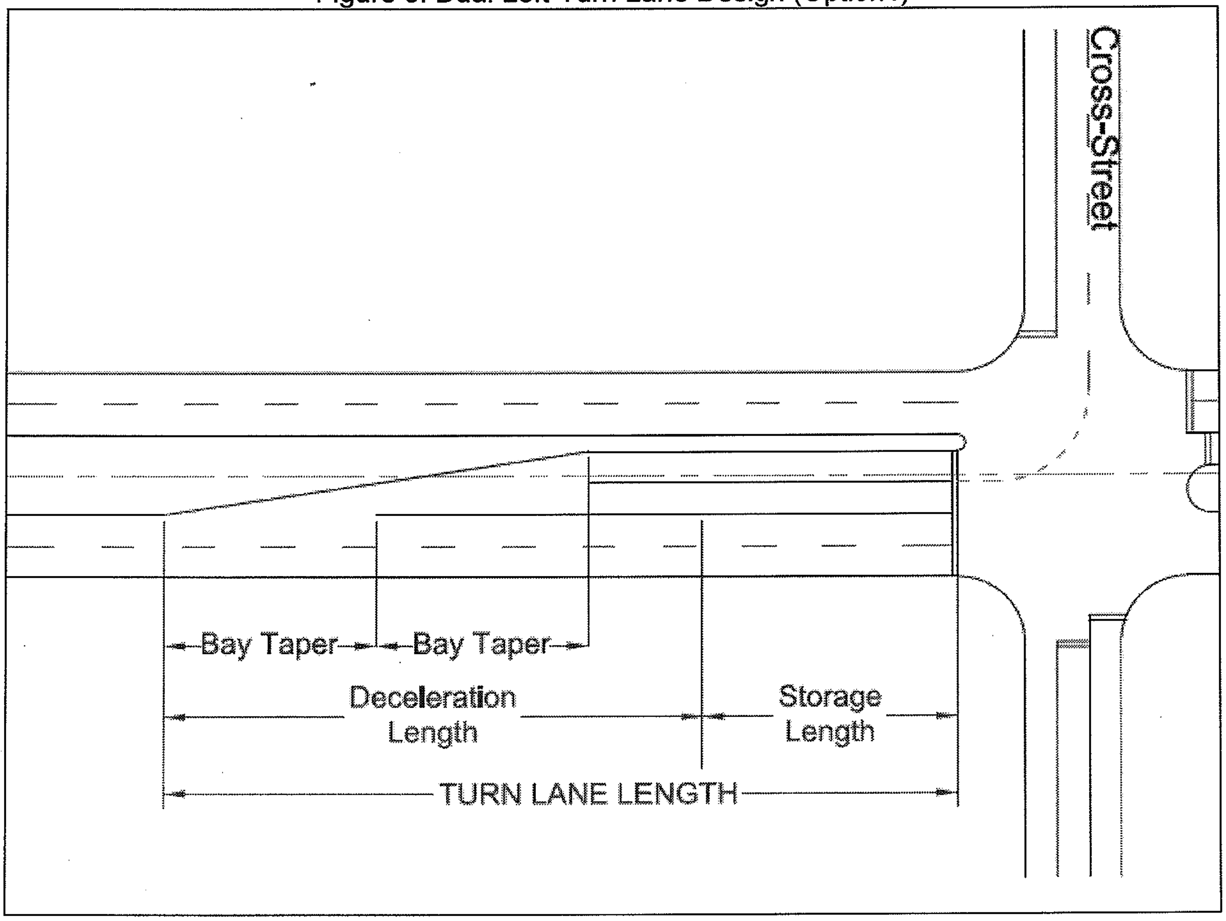
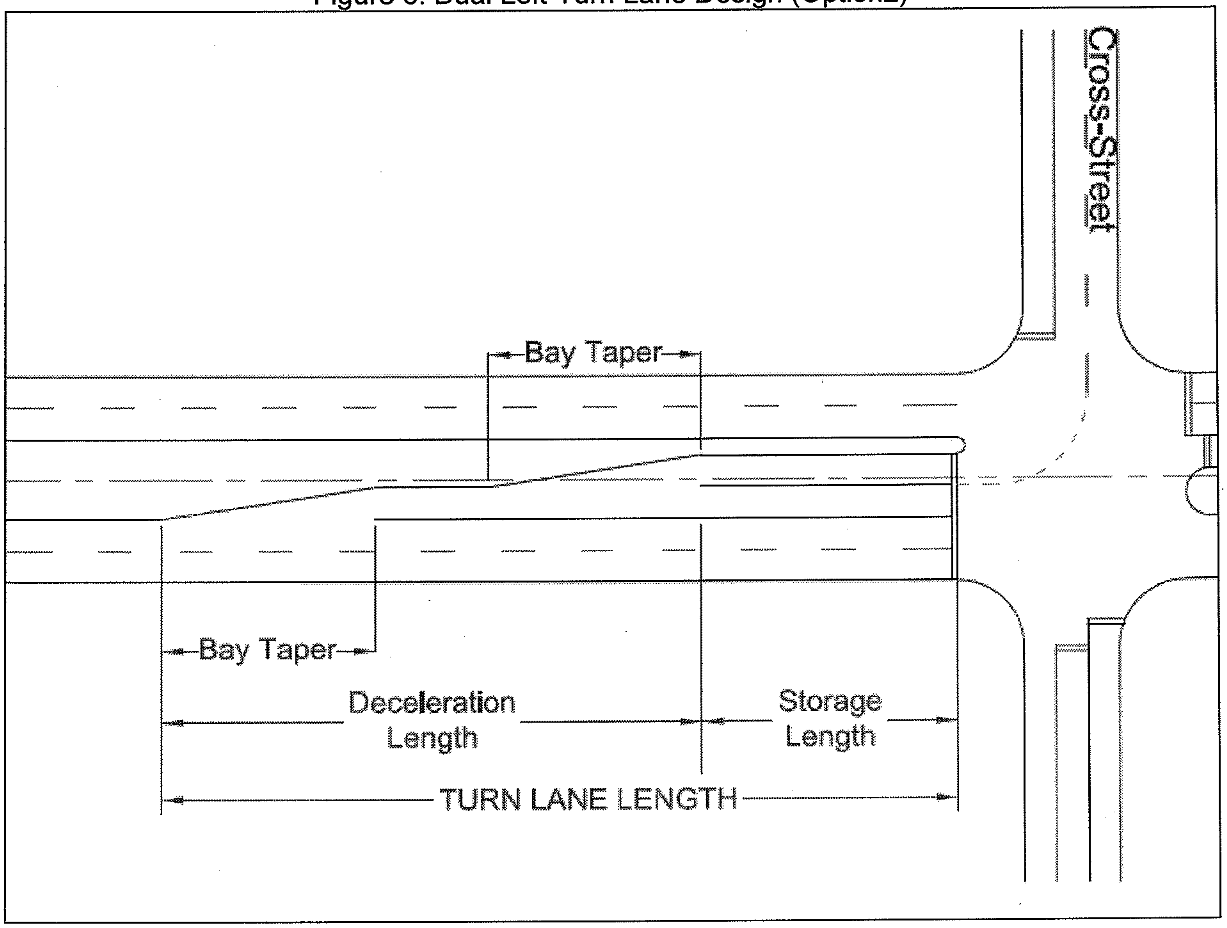


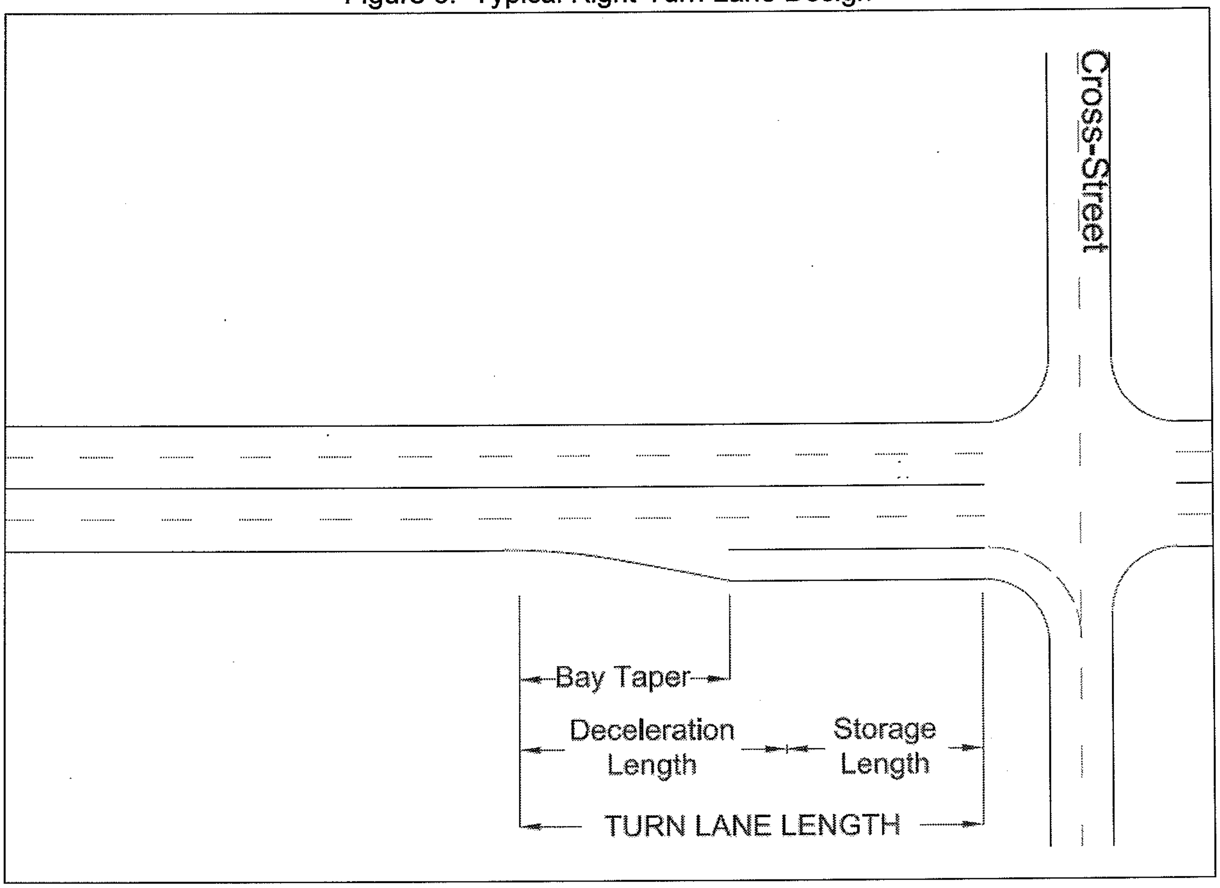
Figure 6: Dual Left-Turn Lane Design (Option2)



Auxiliary right-turn lanes only have 2 primary components as shown in Figure 6:

- Bay Taper
- Turn Lane Length, which consists of
    - Deceleration Length
    - Storage Length

Figure 6: Typical Right-Turn Lane Design



DEPARTURE/ APPROACH TAPER

When adding a left-turn lane, the designer shall use an approach and departure taper to widen the pavement to the required width based on the roadway speed. The approach and departure taper length should be calculated as follows:

Speed: $\geq$ 45 MPH, $L = W \times S$

$<$ 45 MPH, $L = \dfrac{WS^2}{60}$

Where:

L = Taper length in feet
W = Width of roadway offset for taper in feet
S = Speed in miles per hour (MPH)

BAY TAPER

Bay tapers are utilized to direct turning vehicles into the auxiliary lane. For left and right-turn lanes, a standard bay taper length based on the speed of the roadway should be used:

Speed: 45 MPH or greater, Bay Taper length = 100 ft

< 45 MPH, Bay Taper Length = 50 ft

TURN LANE LENGTH

The length of an auxiliary turn lane shall be based on the deceleration and storage requirements of the intersection control type. Table 1 summarizes the methods to be used in determining deceleration and storage length requirements for each intersection control type.

Table 1: Auxiliary Turn Lane Length by Turn Type and Intersection Control

Approach Control	Turn Type	Turn Lane length
Uncontrolled	Left-Turn	Greater of Method 1[A] or Method 2[A, B]
	Right-Turn	Method 1[A, B]
Stop Controlled	Left-Turn	Storage + Bay Taper
	Right-Turn	Storage + Bay taper
Signal Control [B]	Left-Turn	Greater of Method 1 or Method 2[A,B]
	Right-Turn	Greater of Method 1 or Method 2[A,B]

Notes: A: See Table 2 below.
B. For high speed rural arterials, turn lane length shall be determined by Method 3. See discussion on high speed rural roads below Table 2.

Table 2: Turn Lane Length by Speed

Speed (MPH)	Method 1: Deceleration Only[B]	Method 2: Moderate Deceleration + Storage[B]	Method 3: Full Deceleration + Storage (Rural Arterial ≥45 mph)[B]
20	125 ft	Storage + Bay Taper	N/A
25	125 ft	Storage + Bay Taper	
30	125 ft	Storage +Bay Taper	
35	125 ft	Storage +Bay Taper	
40	170 ft	70 ft + Storage	
45	220 ft	115 ft + Storage	340 ft + Storage
50	275 ft	170 ft + Storage	410 ft + Storage
55	340 ft	220 ft + Storage	485 ft + Storage
60	410 ft	275 ft + Storage	565 ft + Storage
65	485 ft	340 ft + Storage	645 ft + Storage

B: At signalized intersections the length of turn lanes should be extended so that it is not blocked by the queue of adjacent through traffic.

The deceleration lengths provided in Table 2 assume an approach grade of 3 percent or less. Approaches with grades greater than 3 percent should adjust the deceleration length (L_D) by applying Equation 2, below.

EQ 2. $L_D' = L_D\,[-0.046*(G)+0.822]$

where: L_D' = Adjusted deceleration length
L_D = Unadjusted deceleration length (from Table 2)
G = Percent grade

HIGH SPEED RURAL ROADS

On high-speed (≥45 mph) rural arterials, turn lane length should provide full deceleration and full storage as presented in Method 3. Furthermore, when deemed necessary by the engineer, the deceleration length may exclude the bay taper, further lengthening the total turn lane length.

Example: Left Turn Lane Length
Using the left turn lane warrant example above on KY 99, the turn lane requirements would be the greater of Method 1 and Method 2, presented in Table 2. KY 99 is an urban collector with a speed of 55 mph.

Method 1 = 340 ft

Method 2 = 220 ft + Storage

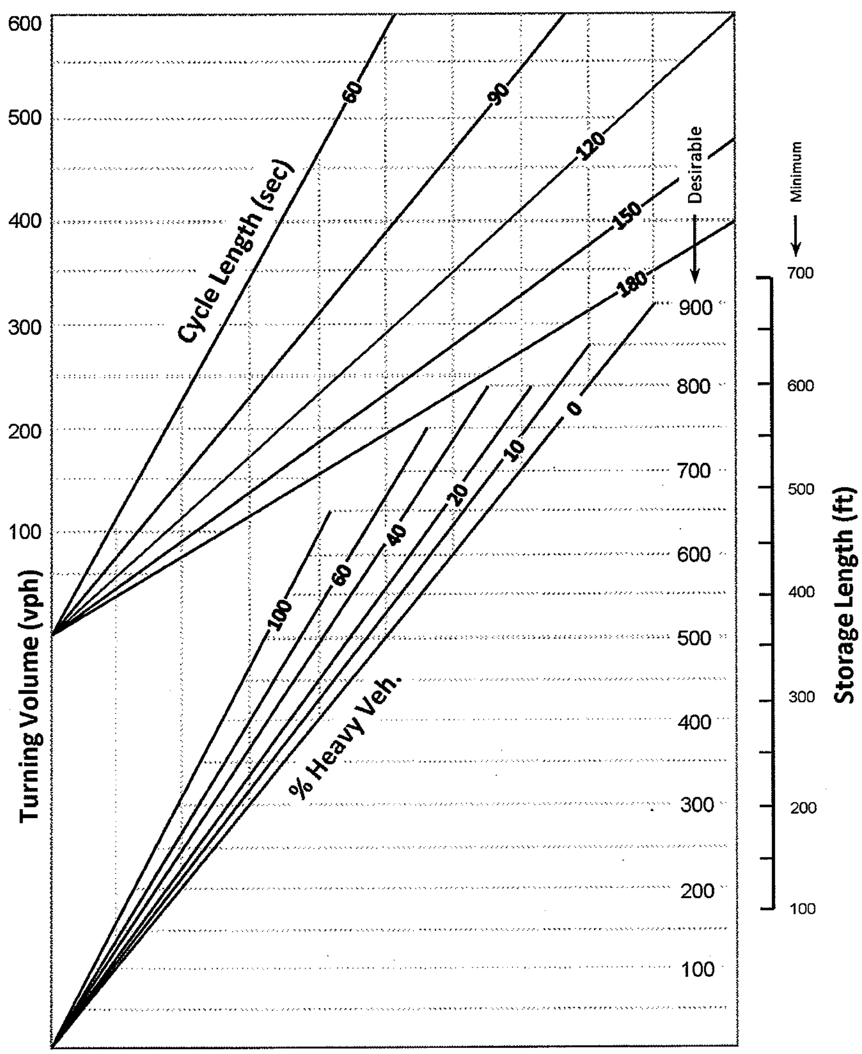
Storage requirements must be determined before a final turn length can be calculated. See Below

STORAGE LENGTH

The storage length of auxiliary turn lanes shall be determined based on the traffic control of the approach and the intersection volumes. The minimum storage length shall be 75 feet for all turn lanes.

- On uncontrolled approaches, storage length shall be 75 feet. If left turn volume at an uncontrolled approach exceeds 200 vehicles per hour, detailed storage length analysis should be conducted.
- On stop controlled approaches, storage length shall be determined by Figure 7, assuming a cycle length of 60 seconds.
- At signalized intersections, storage length shall be determined by Figure 7. More detailed storage requirements may be provided by capacity analysis provided the analysis reflects actual field conditions in terms of signal timing and phasing.

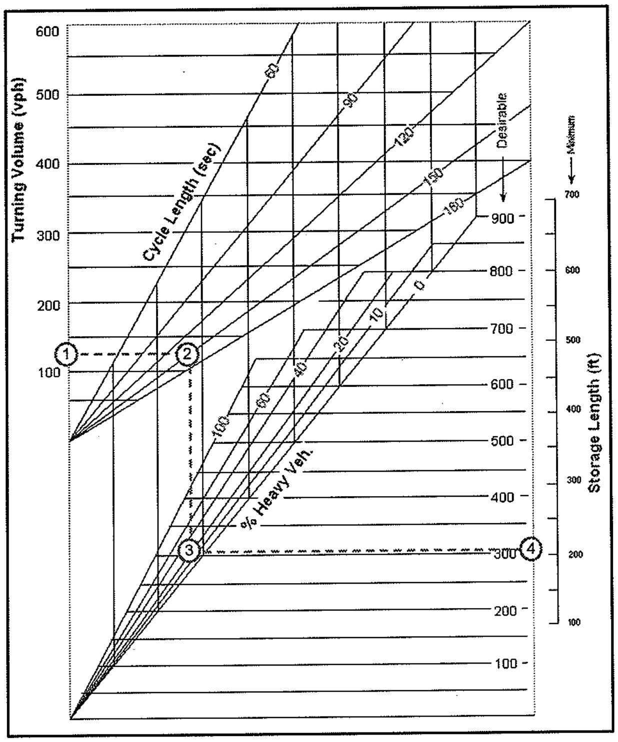
Figure 7: Controlled Intersection; Left-Turn Lane Storage Calculations



Note: Stop controlled intersection calculations should assume a cycle length of 60 seconds.

Example: Signal Controlled Storage Calculation
The following discussion presents the storage calculation for a right turn lane having a volume of 132 vph with 10 percent trucks, at a signalized intersection. The traffic signal operates on a cycle length of 150 seconds.

A turning volume of 132 is determined on the y-axis (pt 1). A horizontal line is plotted from the y-axis to 150 sec cycle length intercept (pt 2). The intercept is followed vertically until it crosses the heavy vehicle percentage (pt 3). Finally the storage requirement is read off the right Y-axis. In this example, a 310 foot storage length is desired.



Alternative Turn Lane Designs

The prescribed auxiliary turn lane warrants attempt to identify situations where safety or operational impacts may affect mainline operations due to the presence of left-turning vehicles. However, it is possible that situations may exist that do not meet the established warrants for left-turn lanes, but safety and/or operational issues exist. In such cases, an alternative to a full turn lane may be warranted. Alternative designs should attempt to reduce overall right of way and construction costs while improving safety and operations at the intersection.

Several options are available to address these situations. When required by the project conditions, the following should be considered as preferred solutions:

1. Utilization of a partial shadowed left-turn lane design.

2. Utilization of asymmetrical widening to avoid constrained quadrants at an intersection.

Examples of full and partial shadowed left-turn lanes with both symmetrical and asymmetrical widening about the centerline are shown in Figures 8-11.

Figure 8: Symmetrical Widening; Full Shadow (25 MPH Design Speed)

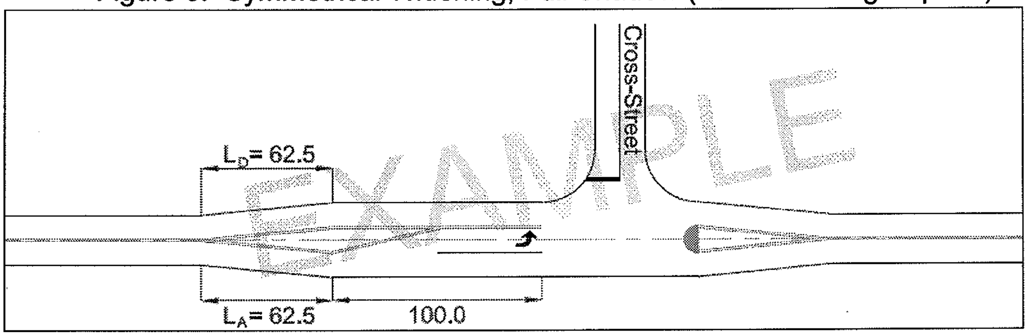


Figure 9: Asymmetrical Widening; Full Shadow (25 MPH Design Speed)

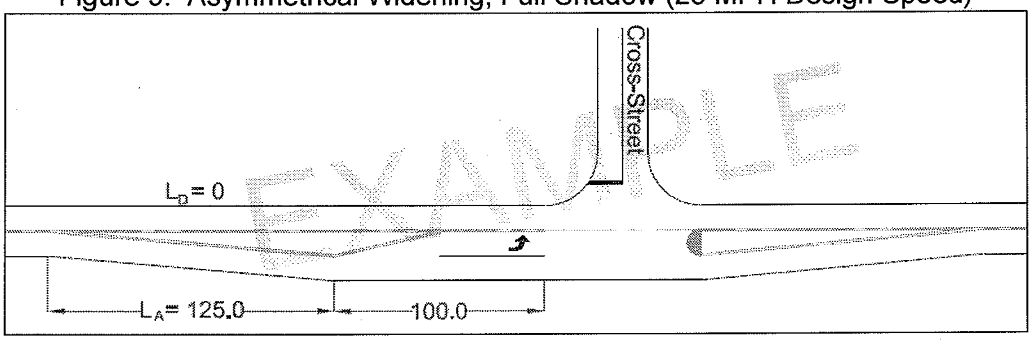


Figure 10: Symmetrical Widening; Partial Shadow (25 MPH Design Speed)

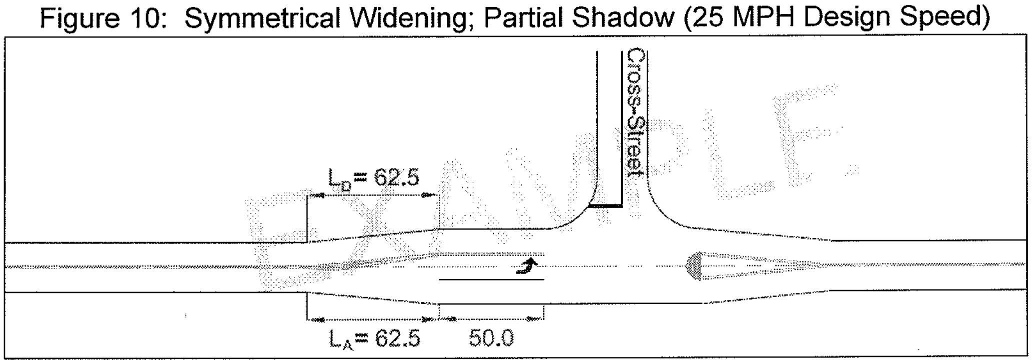
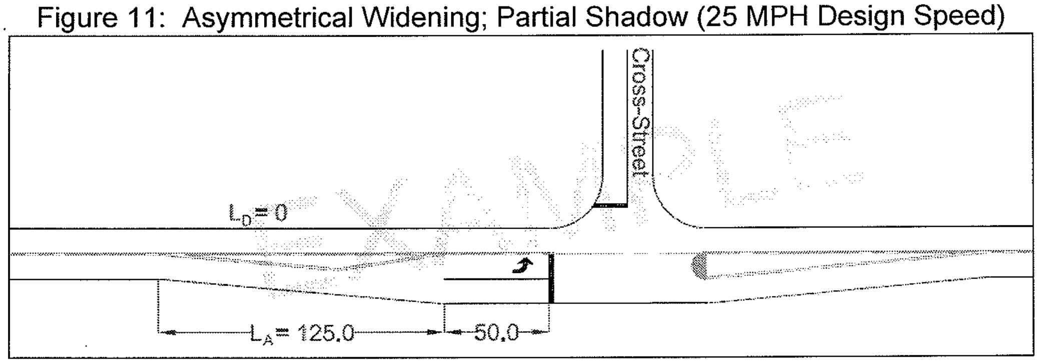


Figure 11: Asymmetrical Widening; Partial Shadow (25 MPH Design Speed)



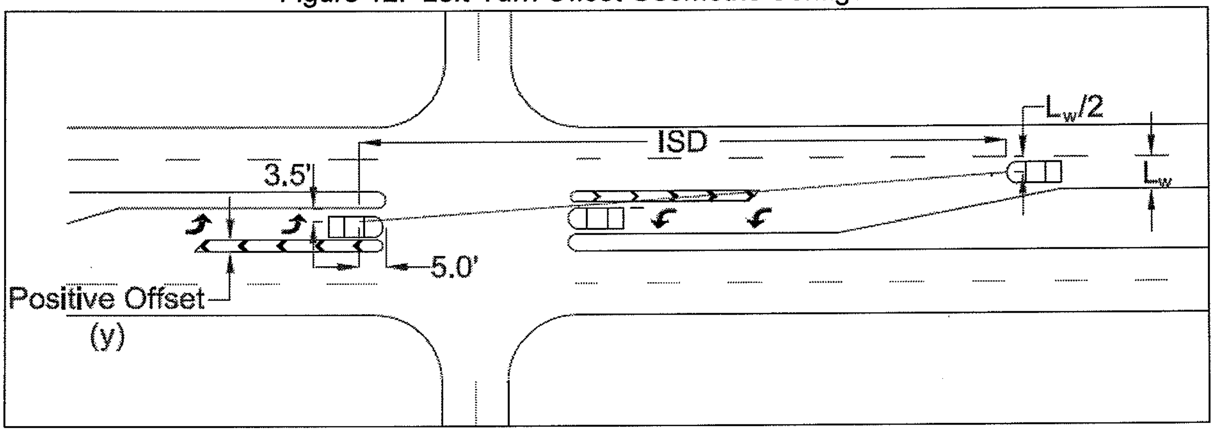
The following recommendations are made to guide constrained design of auxiliary turn lanes.

- In order to allow through traffic to negotiate roadway deflection, approach and departure tapers should not be reduced.
- Turn lane length should be maximized within the site constraints; a minimum turn lane length of 175 feet is recommended for high speed facilities and 125 feet for low speed facilities.
- Reduction of the turn lane length can lead to a reduction in the safety and operation of the mainline roadway as increased storage and deceleration will occur within the through traffic. Therefore, reduction of the turn lane length is recommended only when site constraints make it impractical to provide a full length turn lane. Reduced turn lane length should not be used for the sole purpose of reducing construction costs.

POSITIVE OFFSET OF TURN LANES

Left-turning vehicles can restrict the sight distance of opposing left-turns. Proper sight distance can be provided if the opposing lanes are positively offset to the right. Providing this positive offset will result in the separation of left-turning traffic and adjacent through traffic. The required positive offset for opposing left-turn lanes can be established by a geometric relationship as shown in Figure 12. Available sight distance should be checked graphically for all opposing left-turn lanes.

Figure 12: Left-Turn Offset Geometric Configuration



The positive offset (y) must be large enough to maintain the appropriate sight triangle when a vehicle is occupying the opposing left-turn lane. Required intersection sight distance is provided in Table 3, which summarizes the intersection sight distance for a passenger car, single unit truck and combination truck for various design speeds, based on Exhibits 9-66 and 9-67 from the *AASHTO Greenbook.*

Table 3: Intersection Sight Distance by Design Speed and Design Vehicle

Design Speed (MPH)	Intersection Sight Distance		
	Passenger Car (t_g = 5.5)	**Single Unit Truck (t_g = 6.5)**	**Combination Truck (t_g = 7.5)**
25	205	240	275
35	285	335	385
45	365	430	495
55	445	525	605
65	525	620	715
75	605	715	825

<u>Intersection sight distance should be checked graphically for all left-turn movements with an opposing left-turn movement.</u> In order to check the sight distance, the designer should assume a drivers eye position of 3.5 feet right of the edge of the travel lane and 5 feet behind the front of the vehicle at the anticipated point of the beginning of the turn. The sight obstruction should assume the entire lane width at the position of the opposing left-turn vehicle.

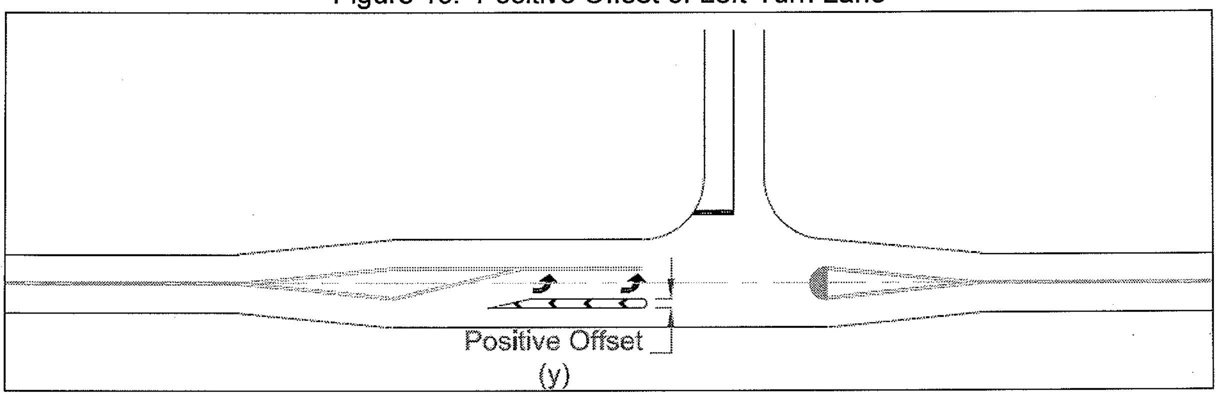
Table 4 summarizes the results, assuming an 11' foot turning lane, for median widths of 0 feet, 4 feet, and 12 feet assuming a passenger car design vehicle is used, with a 60 foot intersection width and an 11 foot lane width. These results also assume a ninety (90) degree intersection with tangent approaches. Curved approaches and skewed intersection alignments could significantly alter the necessary positive offset values specified in the table.

Table 4: Positive Offset by Design Speed

Design Speed	Positive Offset (y)		
	m = 0	m=4	m=12
35	2.0	5.0	11.5
45	2.5	6.0	12.5
55	3.0	6.5	13.0

Positive offsets are encouraged and should be considered as necessary on all high speed roadways and on high volume, congested corridors. The area of this separation should be demarcated though the use of chevron striping as shown in Figure 13. Where the narrow width of the offset makes it impractical to provide a proper chevron the left-turn channelizing line may be offset instead.

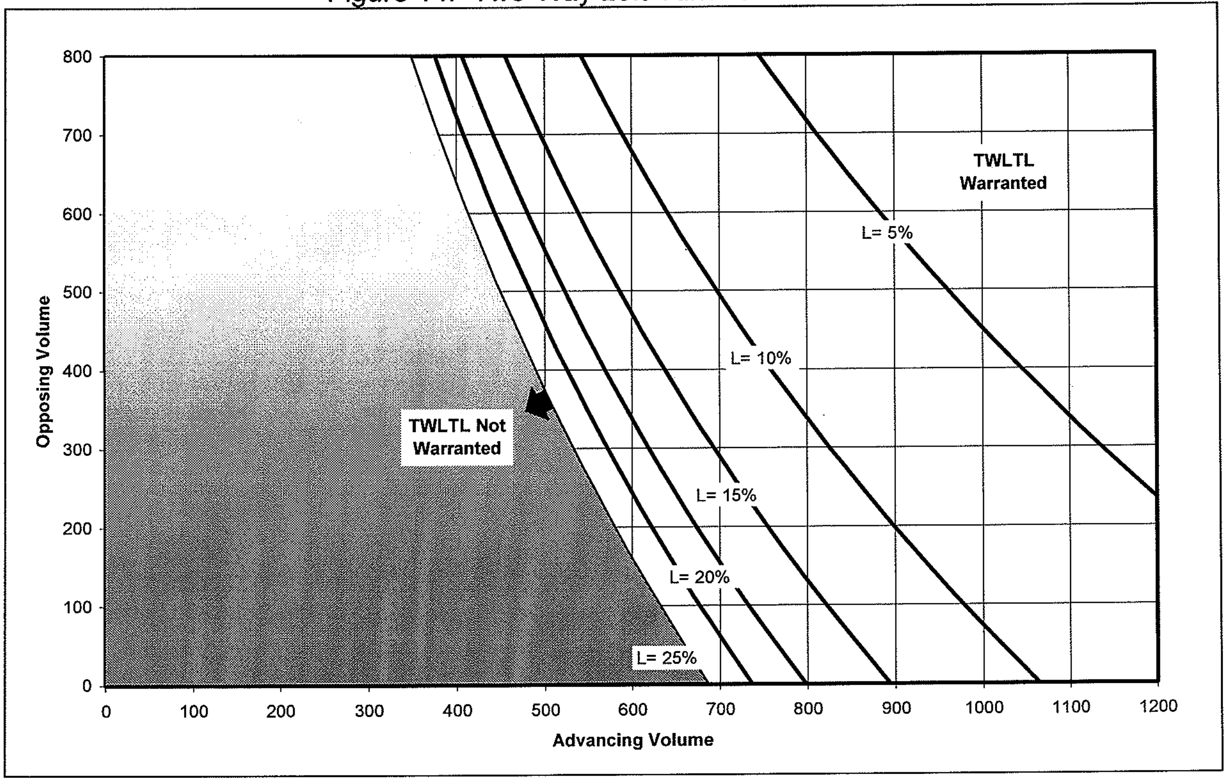
Figure 13: Positive Offset of Left-Turn Lane



TWO-WAY LEFT-TURN WARRANTS

Two-way left-turn lanes (TWLTL) may be used to mitigate delay to through traffic resulting from the cumulative impact of consecutive access points. As such, they may be used to address those scenarios when individual turn movements do not require a dedicated left-turn lane, but consecutive access points have a detrimental impact on traffic flow. TWLTLs should be considered on low speed corridors (≤ 45 MPH) if the design hour traffic volumes at the intersection meet the thresholds identified in Figure 14. For the purpose of these graphs, advancing volume is the volume of traffic entering the corridor; percent left-turns (L) is the quotient of the sum of all left-turns on the corridor and the advancing volume.

Figure 14: Two-Way Left-Turn Lane Warrant



In addition to the volume warrants defined above in Figure 13, the corridor should meet the additional criteria defined below as these situations may utilize less costly or more effective alternatives to a full TWLTL.

Operating Speed: Operating speeds on the corridor should be 45 MPH or less.

Number of Lanes. Two-way left-turn lanes are not recommended on roadway having 3 or more through lanes in one direction.

Average Daily Traffic: TWLTLs are not recommended on three lane roadways having an ADT greater than 17,000, and on multi-lane roadways having an ADT greater than 24,000. When a corridor exceeds the maximum ADT for a TWLTL, a non-traversable median is recommended.

Minimum Access Density: Access density must be greater than 10 access points per mile. (Access density is to be calculated using the number of access points on both sides of the street). When a roadway section meets the volume warrants, but does not meet minimum access density, selective use of dedicated left-turn lanes should be used at the heaviest use driveways to reduce the volume of traffic below the established TWLTL volume warrant.

Minimum TWLTL Length: TWLTL volume warrants and access density limits should be based on a minimum 425 foot typical section. This length is based on maximum access density between two intersections and providing adequate stopping sight distance at 35 MPH in advance of downstream intersections. Potential mitigation measures other than TWLTLs should be evaluated for congested areas that are less than 425 feet in length. In urban areas, the minimum spacing should be modified to match typical block lengths between major intersections.

Maximum Access Density: Access density must be less than 85 access points per mile. (Access density is to be calculated using the number of access points on both sides of the street). Higher access densities have the potential to significantly increase the likelihood of conflicts between turning traffic. When a corridor exceeds the maximum access density for a TWLTL, a non-traversable median is recommended.

Pedestrian Considerations. Two-way left-turn lanes can also provide opportunities for improved pedestrian facilities. Raised islands can be constructed within the TWLTL in order to provide a refuge to pedestrians at unsignalized crosswalks (Figures 15 and 16). Pedestrian islands may be located in suburban and urban areas, at logical crossing points, where pedestrian activity can be expected to concentrate. Placement of the islands should consider both visibility and accessibility for pedestrians as well as ensuring conflicts do not exist between turning movements served by the TWLTL.

Figure 15: Pedestrian Refuge Island

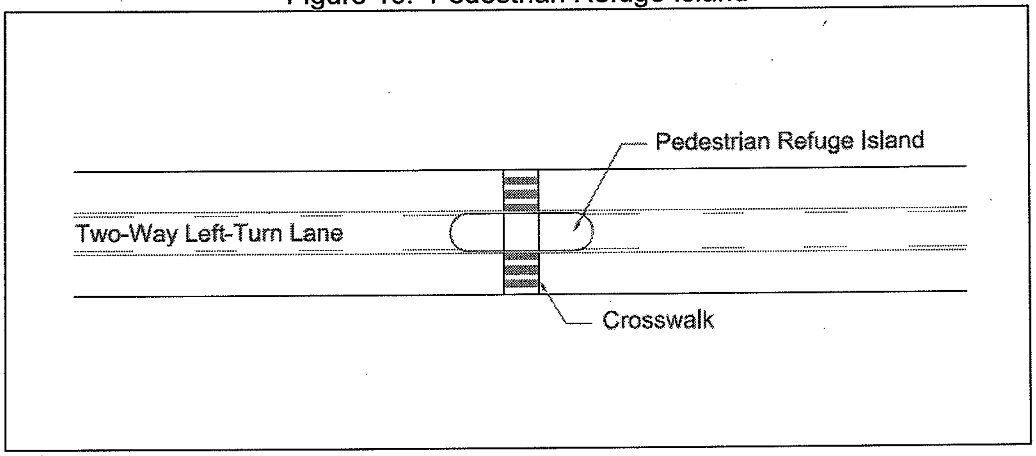
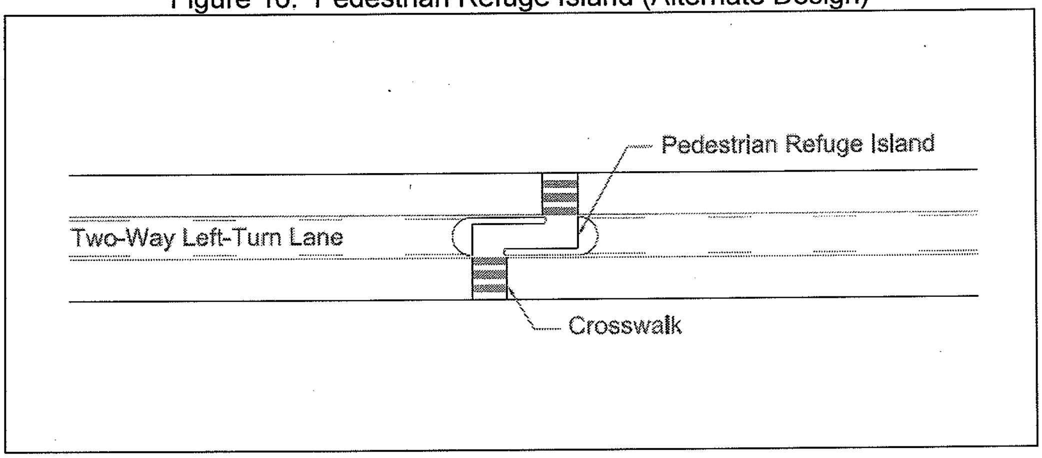


Figure 16: Pedestrian Refuge Island (Alternate Design)



◈◈◈