

Design Standards for Unobstructed Sight Lines at Left-turn Lanes

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16. Abstract Past research has clearly shown that obstructed sight lines at intersections lead to greater possibilities of collisions between left-turning vehicles and opposing oncoming vehicles. Evaluations of the effects of left-turn lane offsets, reported that positive left-turn lane offsets were more effective in reducing intersection left-turn crashes than zero and negative left-turn offsets. Several researchers have developed guidelines for geometric design elements of left-turn offset. The majority of states provide only a limited discussion on this topic. Florida DOT provides the most comprehensive policies and guidance for assuring unobstructed sight lines at left-turn lanes. Recommendations developed in this project center on general policies and guidance for designing offset left-turn lanes for a new edition of MnDOT's <i>Road Design Manual</i> . Recommendations are organized to provide standards, policies, and guidance for new/reconstruction projects and for preservation projects. Topics covered include definition of left-turn lane offset, design factors impacting offset, suggested designs for urban and rural multilane roadways and expressways, accommodating U-turns, pedestrian and bicyclist considerations as well as winter maintenance considerations. Additional recommendations are offered to improve consistency among all MnDOT manuals and guides used for intersection design and operation.			
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FINAL REPORT

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EXECUTIVE SUMMARY

In Minnesota, 42% of all the severe crashes from 2008 through 2012 occurred at intersections. A considerable share of intersection crashes is related to left-turning vehicles. At unsignalized intersections and at signalized intersections with permissive left turn phases, left-turning vehicles in the opposing lane may block the view of a left-turning motorist. Blocked sight lines can increase crash risk since motorists may not see vehicles approaching in the opposing through lanes and misjudge the available gap. If motorists decide not to proceed because of the obstructed sight line, delays for left-turning vehicles will increase and intersection capacity will decrease. Studies dating back to the 1970s and 1980s found that left-turn lanes brought more crashes, primarily due to sight-line obstructions caused by opposing left-turn vehicles.

Offset left-turn lanes are one solution to improving a left-turning motorist's visibility of opposing through and right-turning traffic. Left-turn lateral offset distance is defined as the distance between the left edge of the turn lane and the right edge of the opposing turn lane. If opposing left-turn lanes are aligned directly across from each other, this is termed no or zero offset. When lanes are offset from one another and block the view of at least a portion of the opposing oncoming traffic, this is considered a negative offset. Currently, the Minnesota Department of Transportation's (MnDOT) *Road Design Manual* does not provide any guidance on the use of offset turn lanes at intersections.

Evaluations of the effects of left-turn lane offsets, with data from multiple states in the United States, reported that positive left-turn lane offsets were more effective in reducing intersection left-turn crashes than zero and negative left-turn offsets. Empirical Bayes analyses were conducted to evaluate the impacts of offset improvements made at intersections in Florida, Nebraska, and Wisconsin. In Florida and Nebraska, little or no safety improvement was observed because the improvements did not result in a positive offset. In Wisconsin, all the improvements were major reconstructions resulting in significant positive offsets. Substantial and significant crash reductions were observed in total (34%), injury (36%), left-turn (38%), and rear end crashes (32%). Other studies have also reported that positive left-turn lane offsets are effective in reducing injury and fatal crashes at intersections. Field data collections have demonstrated that at intersections with negative offsets, the critical gap of motorists increases, and when motorists take risks to accept smaller gaps, likelihood of conflicts with opposing through vehicles increases.

Multiple studies have examined the impact of the presence of vehicles in opposing left-turn lanes on motorist gap acceptance and found that critical gap and follow-up headway increased by about one second. The increases in critical gap and follow-up headway resulted in capacity decrease, ranging from 34% to 70% depending on traffic volumes. An evaluation of the SHRP2 Naturalistic Driving Study (NDS) data showed that critical gap was longer for negative offset than for zero and positive offset intersections. Also, post encroachment time, which is a measure of motorist risk-taking, was shortest at negative offset locations.

Offset turn lanes improve safety and operational efficiency and are applicable to both signalized and unsignalized intersections. Therefore, to achieve the best opportunity for obtaining adequate sight distance when vehicles are in opposing turn lanes, the use of offset left-turn lanes is recommended.

Twenty-three states' road design manuals and intersection design guides were reviewed to identify policies and design guidance pertaining to left-turn lane offsets. The majority of states provided only a limited discussion on this topic and when guidance was offered it was typically only on one or two aspects of left-turn lane design, such as briefly mentioning safety consideration if sight lines were restricted from opposing left-turn lanes, optimum median widths, protected versus protected/permitted traffic signal phasing, and optimum sight distance and gap acceptance. Several states, including North Dakota, South Dakota, Iowa, North Carolina, Michigan, Florida, and Nebraska, had policies and/or guidance promoting the use of positive offsets at left-turns, at least under certain conditions. Florida DOT provided the most comprehensive policies and guidance on design standards and guidance for assuring unobstructed sight lines at left-turn lanes. However, the Florida DOT material was in several different manuals and guidance resource documents. There was minimal guidance or discussion offered by states regarding pedestrian and bicycle safety at intersections with left-turn lanes, and no guidance on this topic related to left-turn lane offsets. There was no guidance found relating to winter maintenance on left-turn lanes.

Minnesota-specific design standards and guidance for offset turn lanes to provide or improve unobstructed sight lines at left-turn lanes have been developed. The standards and guidance recommendations consider safety, operational efficiency, pedestrian impacts, and accessibility needs, and are applicable to both signalized and unsignalized intersections. An introduction provides information on the concept behind the need for lateral offset left-turn lanes and the impact offsets have on motorist sight distance. Definitions and schematic drawings illustrate negative, zero, and positive offsets, and the impact vehicle positioning has on sight distance when motorists make left-turns. Recommendations and guidance are different and separate for new and reconstruction projects and for preservation projects. New construction and reconstruction projects give an opportunity to consider and provide optimum six-foot, positive offset lanes, which should greatly improve older and inexperienced driver safety. Since preservation projects have greater limitations due to cost and right-of-way availability, the recommendations provide factors to consider when studying the existing conditions and providing guidance for enhancing the safety and operation at less than the new construction offset left-turn lane standard. Guidance is presented to provide the ability of motorists to make U-turns at positive offset left-turns. While no recommendations are given on a preferred method to construct channelization island construction, pro and con issues are presented for designers to consider on whether the islands should be constructed only with pavement markings or raised islands with curb and gutter, including impacts on winter maintenance. No bicycle specific guidance regarding positive offset left-turn lanes is offered since no research or other state practices are currently available. Additional recommendations are offered to improve consistency in other MnDOT manuals and guides used for intersection design and operation.

CHAPTER 1: INTRODUCTION

In Minnesota, 42% of all severe crashes from 2008 through 2012 occurred at intersections (Minnesota DOT, 2014). As shown in Figure 1.1, a considerable share of intersection crashes is related to left-turning vehicles. At unsignalized intersections and at signalized intersections with permissive left-turn phases, left-turning vehicles in the opposing lane may block the view of a left-turning motorist as illustrated in Figure 1.2. Blocked sight lines can increase crash risk since motorists may not see vehicles approaching in the opposing through lanes and misjudge the available gap. If motorists decide not to proceed because of the obstructed sight line, delays for left-turning vehicles will increase and intersection capacity will decrease. Early and more recent studies showed that at left-turn lanes, of both signalized and unsignalized intersections, obstructed sight lines could cause higher possibilities of collisions between left-turning vehicles and oncoming vehicles from the opposing through travel direction.

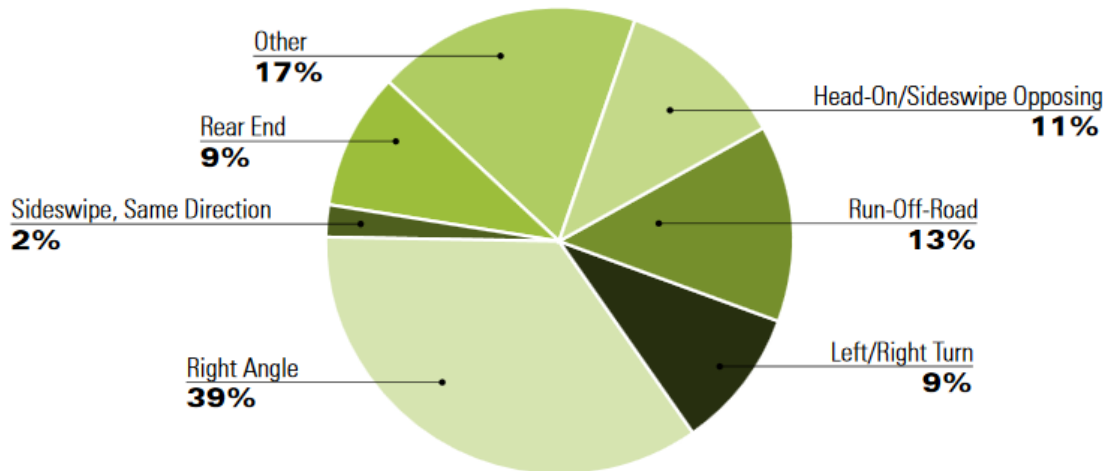


Figure 1.1 Minnesota intersection crash distribution. [Minnesota Strategic Highway Safety Plan, 2014]

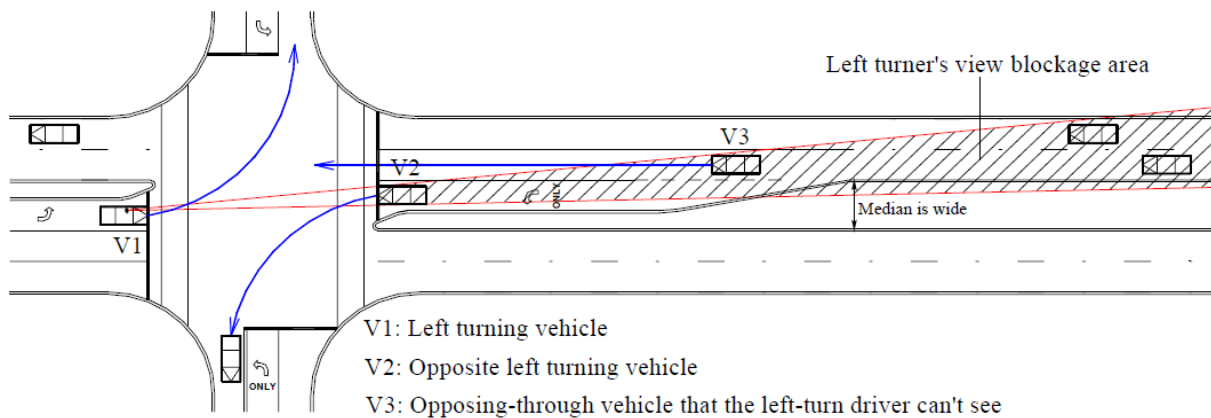


Figure 1.2 Left-turning motorist's view blocked by vehicles in opposing left-turn lane. [Radwan & Yan, 2006]

Offset left-turn lanes are one solution to improving a left-turning motorist's visibility of opposing through and right-turning traffic. Left-turn lateral offset distance is defined as the distance between the left edge of the turn lane and the right edge of the opposing turn lane. If opposing left-turn lanes are aligned directly across from each other, this is termed no offset. When lanes are offset from one another and block the view of at least a portion of the opposing oncoming traffic, this is considered a negative offset. Positive offset allows motorists a better view and more time to observe oncoming vehicles in the approaching through lanes. Definitions for different types of offsets are illustrated in Figure 1.3.

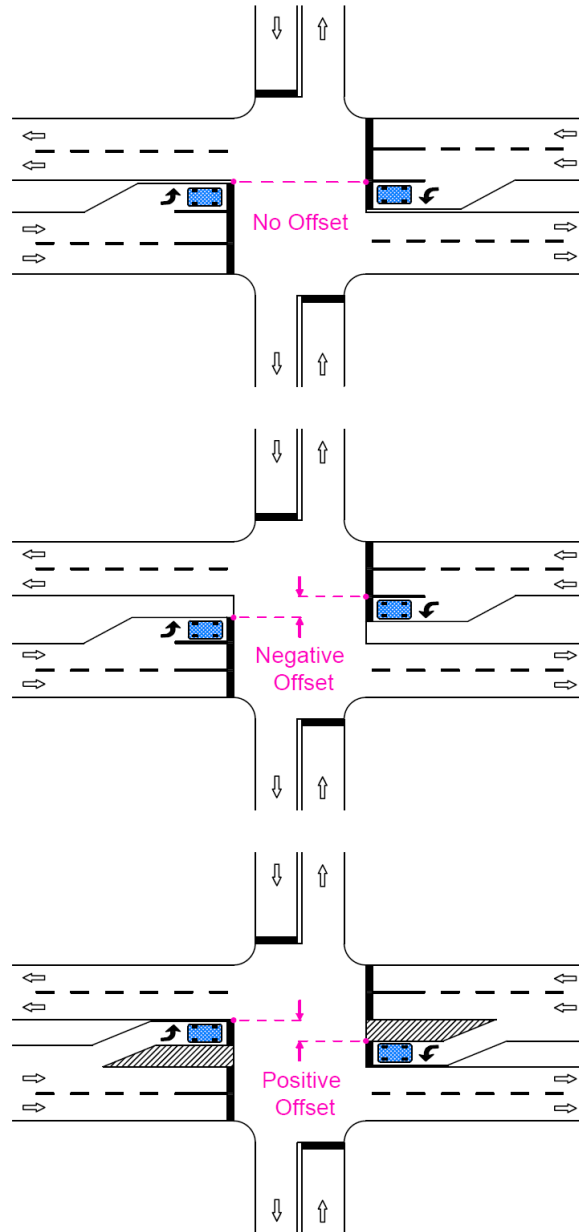


Figure 1.3 Different types of offsets.

Offset turn lanes improve safety and operational efficiency and are applicable to both signalized and unsignalized intersections. Evaluations of the effects of left-turn lane offsets, with data from multiple states in the United States, reported that positive left-turn lane offsets were more effective in reducing intersection left-turn crashes than zero and negative left-turn offsets. In terms of effects on intersection traffic operations, providing positive left-turn offset helps reduce the sight line obstruction situations and leads to higher capacities of left-turn movements. Therefore, to achieve the best opportunity for obtaining adequate sight distance when vehicles are in opposing turn lanes, the use of offset left-turn lanes is recommended. Currently, the Minnesota Department of Transportation's (MnDOT) *Road Design Manual* (Minnesota DOT, 2019) does not provide any guidance on use of offset turn lanes at intersections.

The objective of this research is to develop Minnesota-specific design standards for offset turn lanes to provide unobstructed sight lines at left-turn lanes considering safety, operational efficiency, bicycle and pedestrian impacts, accessibility needs and construction and maintenance impacts. The rest of the report is organized into the following chapters:

- Chapter 2: A review of various research studies on operational and safety impacts as well as on design of offset left-turn lanes
- Chapter 3: A review of various state practices and design guidelines for offset turn lanes
- Chapter 4: Recommended design guidelines for Minnesota
- Chapter 5: Conclusions

CHAPTER 2: LITERATURE REVIEW

This chapter summarizes research studies relevant to offset turn lanes, regarding the safety effects, operational effects, and geometric design elements, which are essential for developing design guidelines for addressing sight line obstruction issues at intersection left-turn lanes.

2.1 Safety

Concerns about obstructed sight line at left-turn lanes were raised as early as 1970s and 1980s, when research studies comparing crash rates at signalized and unsignalized intersections with left-turn lanes (and opposing left-turn lanes) with the ones without, reported results indicating that left-turn lanes (and opposing left-turn lanes) brought intersections more left-turn crashes which were primarily attributed to sight-line obstructions caused by opposing left-turn vehicles (David and Norman, 1975; Foody and Richardson, 1973; McCoy et al. 1984). Based on the concerns about potential safety issues associated with blocked sight-lines at intersection left-turn lanes, guidelines for offsetting left-turn lanes were developed by researchers starting from the 1990s, which covered left-turn lane treatments on divided roadways at linear and curved intersections (Easa and Ali, 2005; Easa et al., 2005; McCoy et al., 1992; Tarawneh and McCoy, 1997). The Manual on Uniform Traffic Control Devices (MUTCD) also provided a brief guideline about offsetting left-turn at median-divided intersections, in its Section 9.7.3 (Federal Highway Administration, 2009).

Despite multiple guidelines for intersection left-turn lane offsets, only a handful of research studies have evaluated the effects of different left-turn lane treatments on the intersections' safety performance. In 2004, Khattak et al. evaluated six treated intersections in Nebraska. The treated intersections had their left-turn lanes offset by widening left-turn lane lines or adding a line to create a narrow, painted island between left-turn lane and through lane. Two other intersections without the treatment were used as a comparison group. The left-turn lane line widths of the six treated intersections were increased from 0.3 feet to a width ranging from 0.5 to 2.3 feet. To accommodate these changes, left-turn lane widths were reduced accordingly. An example of the left-turn lane treatment is shown in Figure 2.1. Crash data of the treated intersections and comparison sites, from 1994 to 2002, were evaluated. Before-after analyses were completed using naïve and comparison group (C-G) methods. The naïve before-after study showed an overall 1% reduction in total crashes after the left-turn lane treatments were implemented, and the C-G before-after study showed a 27% reduction in total crashes. A Poisson regression model was also developed and indicated that the treatments reduced the expected crash frequency by 0.285%, which was not statistically significant (Khattak et al., 2004).

Another study in 2009 by Naik et al. investigated the safety effects of the same type of left-turn lane line widening (or painted island) treatments at 3 signalized intersections, with a total 12 approaches, in Nebraska (Naik et al., 2012). Empirical Bayes (EB) before-after study method was used. Thirty-six signalized intersections without the treatment were used as a reference group. Nine years (1994-2003) of crash data were used for the analysis. The analysis results showed an overall 1.5% reduction (not statistically significant) in number of crashes after the treatments were applied.



Figure 2.1 Left-turn lane line treatment at 48th and 'O' St, line width increased from 0.3 feet to 1.5 feet. [Khattak et al., 2004]

The Federal Highway Administration (FHWA) sponsored a study, exploring the safety effectiveness of left-turn lane offset improvements in Florida, Nebraska, and Wisconsin (Persaud et al., 2009, 2010). The offset improvements implemented in these three states varied, but all fell in the three categories: positive offset (TYPE I), lateral separation with no offset (TYPE II), and lateral separation with reduced negative (with initial offset being negative) offset (TYPE III). Most of the Wisconsin implementations resulted in a positive offset at left-turn lanes. Many of the Florida and Nebraska implementations did not result in positive offsets, but lesser negative or no offset, which were still improvements compared with the conditions before treatments. The EB before-after study method was used. In terms of data, 13 treated intersections (TYPE II: 8; TYPE III: 5) and 39 untreated intersections were selected in Florida as the treated group and reference group for the analysis. Crash data from 1985 to 2005 was obtained for the Florida study. For the Nebraska study, 92 treated sites (TYPE I: 9; TYPE II: 44; TYPE III: 39) and 64

reference sites were selected. Crashes from 1994 to 2006 were analyzed. For the Wisconsin study, 12 treated sites (TYPE I: 10; TYPE II: 2) and sites with available traffic data were selected. Crashes from 1994 to 2006 were analyzed. The study results are listed in Table 2-1.

Table 2-1 Results for Florida, Nebraska, and Wisconsin sites [Persaud et al., 2009]

State	Crash Type	EB Estimate of Crashes in After Period Without Strategy	Observed Crashes in After Period	Estimate of Percent Reduction	Standard Deviation of Percent Reduction
Florida					
	Total	969.91	938	3.4	4.7
	Injury	471.66	472	0.2	6.6
	Left-turn opposing	118.78	106	11.4	11.2
	Rear-end	257.89	273	-5.3	9.9
Nebraska					
	Total	2,795.81	2,811	-0.5	2.4
	Injury	1,536.12	1,441	6.2	3.0
	Left-turn opposing	478.96	695	-45.0	6.7
	Rear-end	1,248.64	1,335	-6.9	3.6
Wisconsin					
	Total	233.77	155	33.8	6.0
	Injury	95.88	62	35.6	9.0
	Left-turn opposing	94.85	59	38.0	8.9
	Rear-end	72.76	50	31.7	10.9

Note: A negative sign (-) indicates an increase in crashes. Boldface denotes those safety effects that are significant at the 95-percent confidence level. Unlike Nebraska and Florida, left-turn opposing crashes could not be precisely identified in Wisconsin; thus, the analysis includes all non-rear-end crashes involving a left-turning vehicle.

The total crash numbers at each state’s treated intersections reduced after the left-turn lane treatments were implemented. In Wisconsin, most of the treated intersections received TYPE I improvement, all categories of crashes reduced after the treatments. That includes a 33.8% reduction in total crashes, a 35.6% reduction in injury crashes, a 38.0% reduction in left-turn crashes, and a 31.7% reduction in rear-end crashes. However, in Florida and Nebraska, as the majority of treated sites did not receive TYPE I improvement, thus some types of crashes had numbers increased after the treatments, such as the rear-end crashes (increased by 5.3%) in Florida, as well as the left-turn opposing (increased by 45.0%) and rear-end crashes (increased by 6.9%) in Nebraska. Florida had the total crashes reduced by 3.4%, the injury crashes reduced by 0.2%, and the left-turn crashes reduced by 11.4%. Nebraska had the total crashes increased by 0.5%, with the only reduced category being the injury crashes, which were reduced by 6.2%. An economic analysis was also conducted in the study, which indicated that at intersections with at least nine expected crashes per year, offset improvements through reconstruction were cost-effective.

In terms of left-turn lane offset improvements’ effects on crash severity, Wang and Abdel-Aty carried out a study using ordered logit regression analysis on the crash history (from 2000 to 2005) of 197 four-leg signalized intersections in Florida (Wang and Abdel-Aty, 2008).

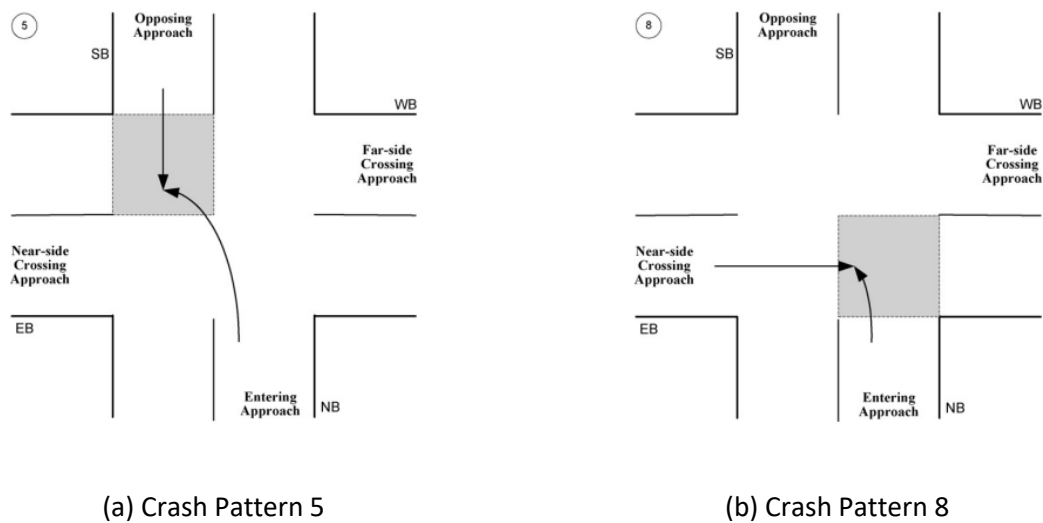


Figure 2.2 Collision diagram and data arrangement for patterns 5 and 8 left-turn crashes. [Wang and Abdel-Aty, 2008]

Two types of left-turn crashes, which were referred in the paper as Pattern 5 and Pattern 8 (see Figure 2.2) were analyzed, as these two types of left-turn crashes were the most frequent, accounting for respectively 72.5% and 14.1% of all left-turn crashes. For the ordered logit regression analysis, the crash severity levels were coded as: 1 = no injury, 2 = possible injury, 3 = non-incapacitating injury, 4 = incapacitating injury, and 5 = fatal injury. The models estimated the effects of multiple variables on Pattern 5 and 8 left-turn crash severity, and left-turn lane offset (positive, zero, or negative) was one of the variables. From the Pattern 5 crash model, positive left-turn lane offset was found to be significantly effective in reducing crashes with severity levels 3, 4, and 5, comparing with zero and negative offsets. For Pattern 8 crashes, when comparing with negative left-turn offset, positive and zero offsets were both effective in reducing crashes with severity levels 3, 4, and 5.

From Wang and Abdel-Aty's model estimations, it was also found that older motorists (> 65 years old) tended to suffer more severe injuries from left-turn crashes than younger motorists (Wang and Abdel-Aty, 2008). The National Cooperative Highway Research Program (NCHRP) Report 500, Volume 9, also noted that older motorists had more left-turn crashes at signalized intersections than young motorists do, as older motorists tended to make errors such as "misjudging the oncoming vehicle speed, misjudging the available gap, assuming that the oncoming vehicle was going to stop or turn, and simply not seeing the other vehicle" (Potts et al., 2004). A 1997 study by Staplin et al. was cited in the NCHRP Report 500, and the study findings indicated that positive left-turn lane offset could help increase sight distance which could be beneficial to left-turning motorists, particularly older left-turning motorists (Potts et al., 2004).

There are several studies investigating the effects of blocked sight line at left-turn lanes on the left-turning motorist behavior. The researchers of those studies believed that the process of blocked sight line at left-turn lanes leading to crashes is: blocked sight line -> motorist behavior change -> risks

increase (more near-misses) -> crash number increases. Tarawneh and McCoy studied left-turn lane offset's effects on motorist performance in 1996. The research evaluated 100 motorists' performance on three test circuits, with critical gap (or critical headway as used in the Highway Capacity Manual, referring to the average size gap in the conflicting traffic stream that a controlled motorist will choose to pass through), clearance time, left-turn conflict, longitudinal and lateral positioning, and percentage positioned left-turns (percentage of left-turning motorists who positioned themselves within the intersection when waiting for a gap in the opposing traffic) as measures of effectiveness (MOEs). The study results showed that motorist performance could be adversely affected by negative left-turn offsets less than -0.9 m. Critical gaps at more negative offset left-turn lanes were longer, and the likelihood of conflicts between left-turning vehicles and opposing through traffic was higher.

Yan and Radwan further studied the effects of obstructed sight line on motorist behavior during unprotected left-turn phase at signalized intersections using video data (Yan and Radwan, 2007). Left-turning motorist's gap acceptance behavior was specifically evaluated in the research. The results confirmed once again that blocked sight lines at left-turn lanes affected traffic operations and safety at such intersections negatively. With sight line obstruction, the critical gap and left-turn follow-up time both increased, compared with situations without the obstruction issue. Left-turning and U-turning motorists also tended to accept smaller gaps when their sight was obstructed, leading to an increased possibility of conflicts.

Hutton et al. evaluated the effects of left-turn lane offset on motorist behavior with surrogate safety measures including critical gaps, post-encroachment time, near crashes, and crash avoidance maneuvers (Hutton et al., 2015). The Strategic Highway Research Program 2 (SHRP 2) Naturalistic Driving Study (NDS) data were used in the study, with 3350 gaps at 14 two-way stop-controlled intersections and 44 signalized opposing left-turn pairs evaluated. The duration of each gap and whether the motorist accepted the gap were extracted from the videos. Logistic regression analysis was performed to estimate whether a gap was accepted by the motorists given the gap length and the left-turn lane offset distance. The results indicated that at both two-way stop-controlled and signalized intersections, sight obstruction would lead to motorists accepting longer gaps than they do when there was no sight obstruction. At intersections with negative left-turn lane offsets, there is a higher chance of sight obstruction for left-turning vehicles than at intersections with positive or zero left-turn lane offsets. The critical gaps were longer at left-turn lanes with negative offsets than at left-turn lanes with positive or zero offsets. However, motorists had a higher likelihood of accepting shorter gaps at negative-offset intersections, leaving a very short amount of clearance time between their turn and the arrival of the next opposing through vehicle. The researchers attributed such motorist behavior to difficulties in assessing risk and hesitation when left-turning motorists' sight line was obstructed.

2.2 Operations

Apart from the effects on intersection safety performance, obstructed sight lines' operational effects were also investigated by several studies (Hutton et al., 2015; Ogallo and Jha, 2014; Yan and Radwan, 2008). Yan and Radwan (2008) evaluated the impact of restricted sight distance on the left-turn capacity. Videos were collected at a selected signalized intersection, where the major road approaches had 20-foot wide medians. A median wider than 18 feet causes sight distance problems. Logistic regression models used in the study estimated the probabilities of motorists accepting a gap and make left-turn with sight line obstructed and not obstructed, as shown in Figure 2.3. The distributions of follow-up time and gap acceptance response time were also estimated. The results showed that restricted sight line can significantly affect critical gap and follow-up times.

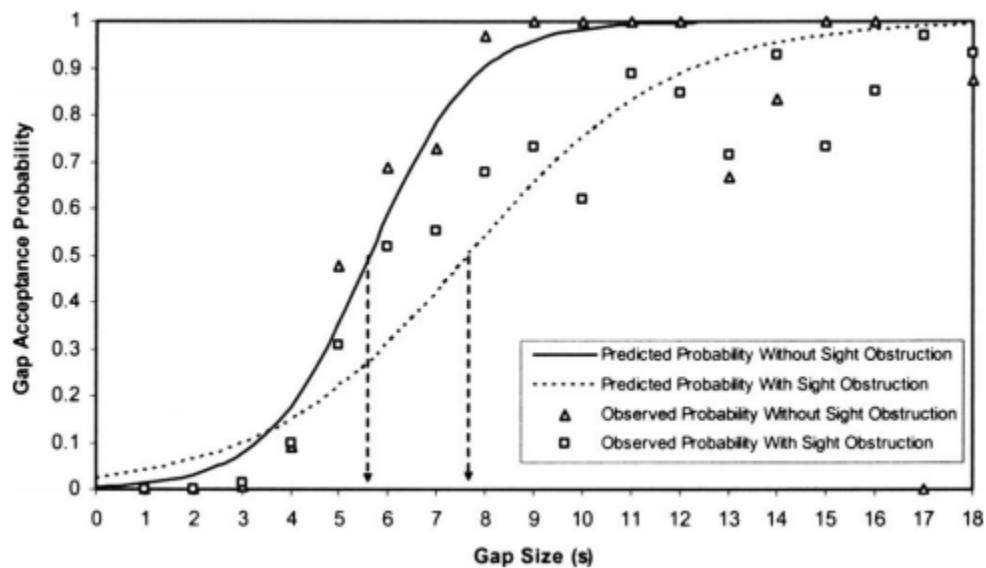


Figure 2.3 Probability that motorists accept gaps to make left-turns. [Yan and Radwan, 2008]

Based on the equations for capacity calculation from the Highway Capacity Manual (HCM), and the estimated distributions of critical gap, follow-up time, and response time, the left-turn capacities were estimated for restricted sight line situation and unrestricted sight line situation, under conditions of different opposing through traffic volumes. The equations are listed in Table 2-2.

Left-turn capacities were estimated using an example data set of an isolated signalized intersection. The results are shown in Table 2-3. When opposing through traffic volume increases up-to 1800 vehicles per hour (vph), capacity may drop by 70% with sight problem, comparing without sight problem.

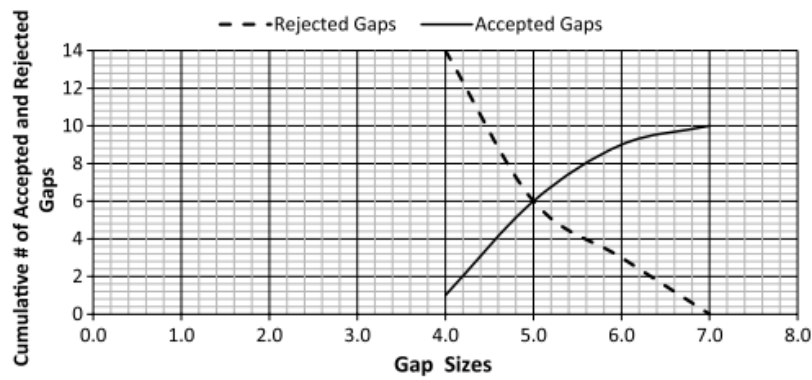
Table 2-2 Equations for left-turn capacity calculation considering sight-distance problem [Yan and Radwan, 2008]

Equation	Variables
$s_{LT} = V_o \frac{\exp(-\frac{V_o t_c}{3600})}{1 - \exp(-\frac{V_o t_f}{3600})}$	<p>s_{LT} = filter saturation flow of permitted left-turns (vehicles/h/lane); V_o = opposing-through traffic flow rate (vehicles/h); t_c = critical gap (s); and t_f = follow-up headway (s).</p>
$C_{LT} = s_{LT} \frac{g - g_q}{c}$	<p>C_{LT} = left-turn capacity of an exclusive permitted left-turn group (vehicles/h); s_{LT} = filter saturation flow of permitted left-turns (vehicles/h/lane); g = effective green time for subject permitted left-turn (s); g_q = portion of effective green blocked by the clearance of an opposing queue of vehicles (s); and c = length of the cycle (s).</p>
$g_q = \frac{\frac{v_o}{c} \left(1 - \frac{g}{c}\right)}{0.5 - \frac{v_o}{c} \left(1 - \frac{g}{c}\right)} - t_L$	<p>$\frac{v_o}{c}$ = adjusted opposing flow rate per lane per cycle; g = effective green time for subject permitted left-turn (s); c = length of the cycle (s); and t_L = lost time for opposing lane group (s).</p>
$C_{LT} = C_{LT,min}P + C_{LT,max}(1 - P)$	<p>C_{LT} = left-turn capacity of an exclusive permitted left-turn group; $C_{LT,min}$ = minimum left-turn capacity with sight distance problem; $C_{LT,max}$ = maximum left-turn capacity without sight distance problem; and P = probability that the opposing left-turning traffic will operate in a queue state.</p>
$P = \frac{V_{OLT}}{C_{OLT,min}}$	<p>P = probability that the opposing left-turning traffic will operate in a queue state; V_{OLT} = opposing left-turn flow rate during the permitted left-turn phase; and $C_{OLT,min}$ = minimum opposing left-turn capacity with sight distance problem</p>

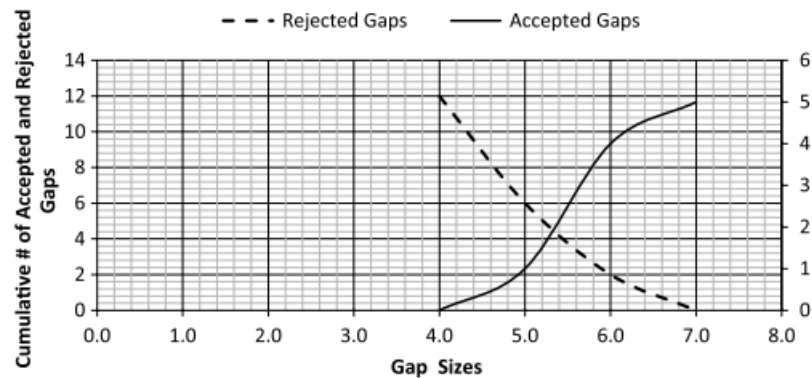
Table 2-3 Left-turn capacity estimations [Yan and Radwan, 2008]

Opposing Through Volume (vehicles/h)	Capacity Estimation				Percent Capacity Reduction Rate (%)
	Without Sight Problem		With Sight Problem		
	(vehicles/h)	(vehicles/cycle)	(vehicles/h)	(vehicles/cycle)	
1,800	58	1.5	18	0.4	70
1,600	90	2.2	30	0.8	66
1,400	132	3.3	49	1.2	62
1,200	186	4.7	78	1.9	58
1,000	259	6.5	119	3.0	54
800	354	8.8	181	4.5	49

Ogallo and Jha (2014) proposed a methodology for critical gap analysis at signalized intersections with permissive opposing left-turn movements. Video data of left-turning movements from Baltimore and Annapolis, Maryland were collected. The gap acceptance distribution across gap sizes are shown in Figure 2.4.



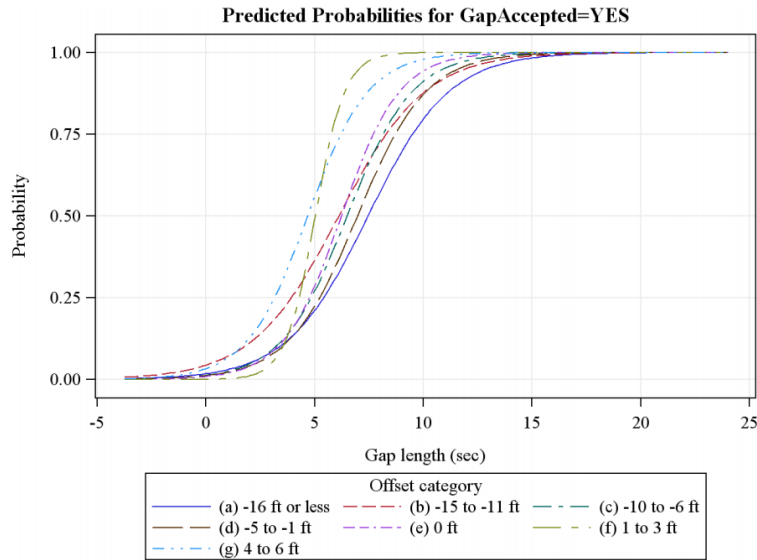
(a) Sight line not obstructed



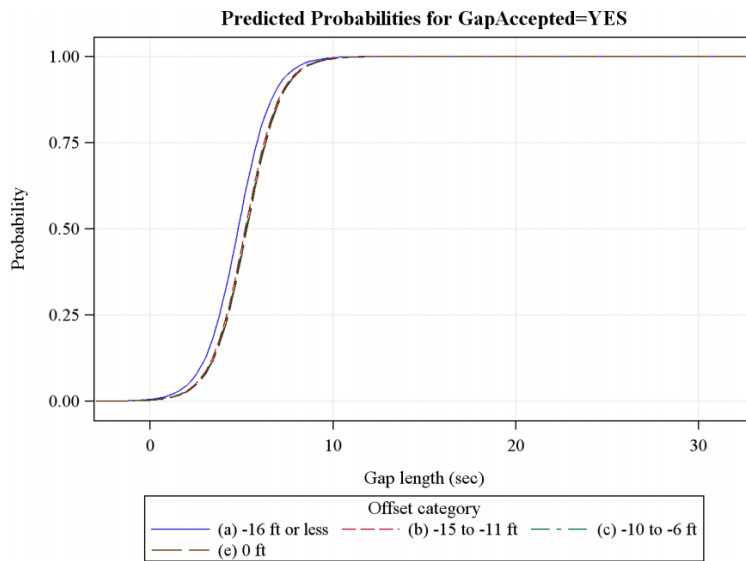
(b) Sight line obstructed

Figure 2.4 Graph of gap sizes versus cumulative rejected and accepted gaps. [Ogallo and Jha, 2014]

Hutton et al. also conducted operational analysis in addition to their safety analysis of left-turn offset and sight line obstruction issues (Hutton et al., 2015). The predicted probabilities of gap acceptance for different gap lengths and different left-turn lane offsets are shown in Figure 2.5, with the critical gaps and associated 95% confidence intervals shown in Figure 2.6.



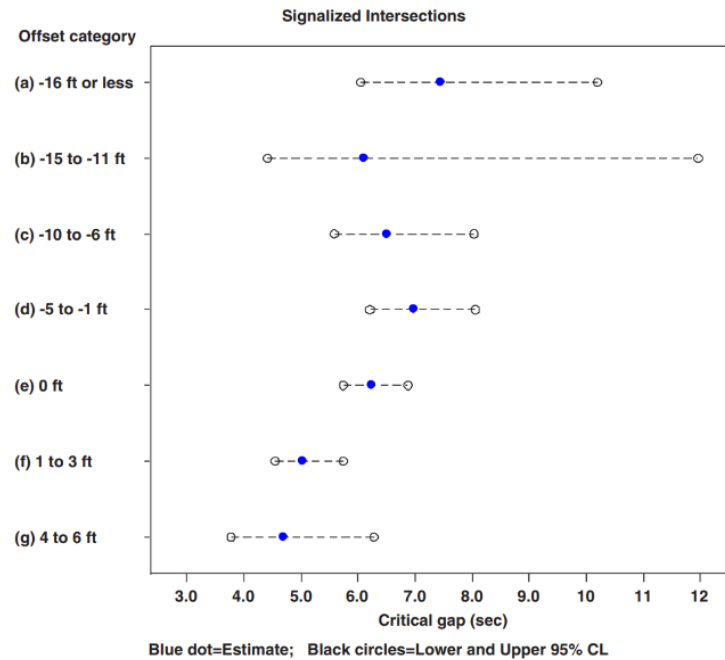
(a) Signalized Intersections



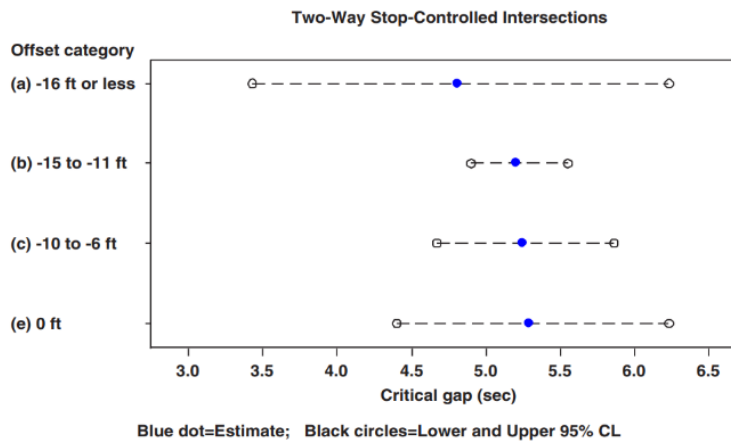
(b) Unsignalized Intersections

Figure 2.5 Predicted probability of accepting gap as function of gap length and offset category. [Hutton et al., 2015]

It shows that for signalized intersections, when the left-turn offset goes from positive 4 to 6 feet to negative 16 feet or less, the critical gap increased from 4.7 s to 7.5 s. For unsignalized intersections, the change was not statistically significant. The results indicate that at signalized intersections, as left-turn offset became more negative, critical gaps increased. The increased critical gaps thus consequently decrease operational efficiency.



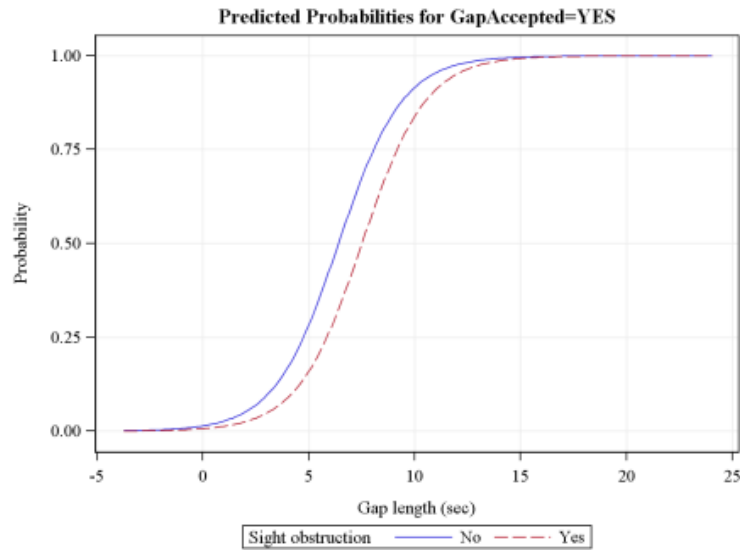
(a) Signalized Intersections



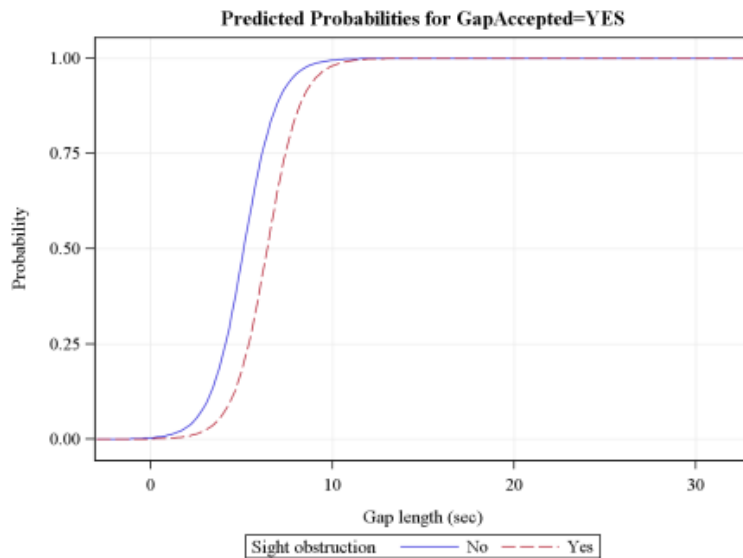
(b) Unsignalized Intersections

Figure 2.6 Critical gaps and 95% confidence intervals by offset category. [Hutton et al., 2015]

For all offsets combined, the probabilities for gap acceptance at left-turn lanes with and without sight obstruction were predicted for signalized intersections and unsignalized intersections. The results are shown in Figure 2.7. The critical gaps and 95% confidence intervals are shown in Figure 2.8. These results show that when sight lines were obstructed, critical gaps were 2 seconds longer than when sight lines were not obstructed.



(a) Signalized Intersections – All Offsets Combined



(b) Unsignalized Intersections – All Offsets Combined

Figure 2.7 Predicted probability of accepting gap vs gap length and presence of sight obstruction. [Hutton et al., 2015]

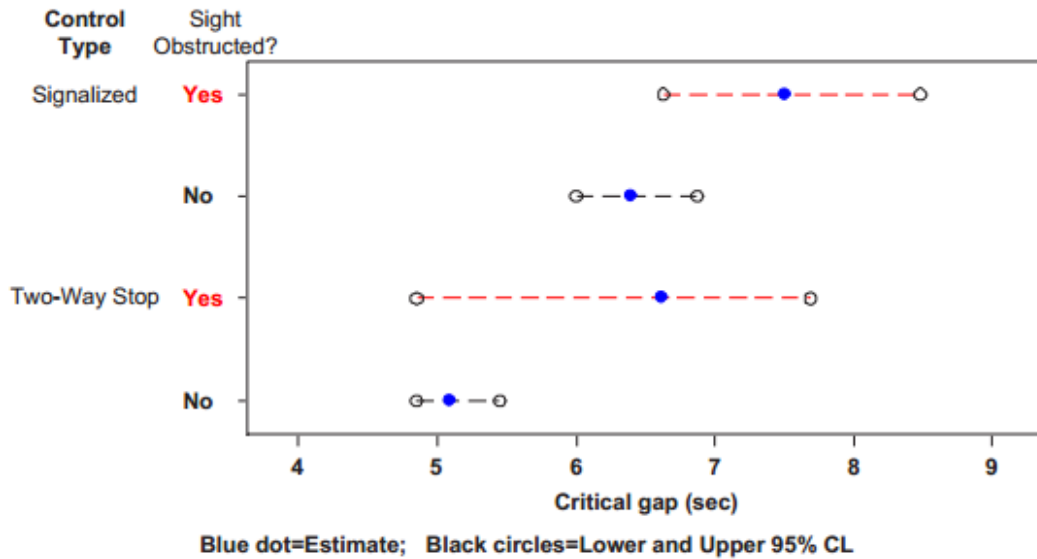


Figure 2.8 Critical gaps and 95% confidence intervals by intersection type and presence of sight obstruction—all offsets combined. [Hutton et al., 2015]

2.3 Design Elements

There are several studies investigating the offset required between opposing left-turn lanes. McCoy et al. (1992) and Tarawneh and McCoy (1997) provided some guidelines for offsetting opposing left-turn lanes on divided roadways in their 1990s studies.

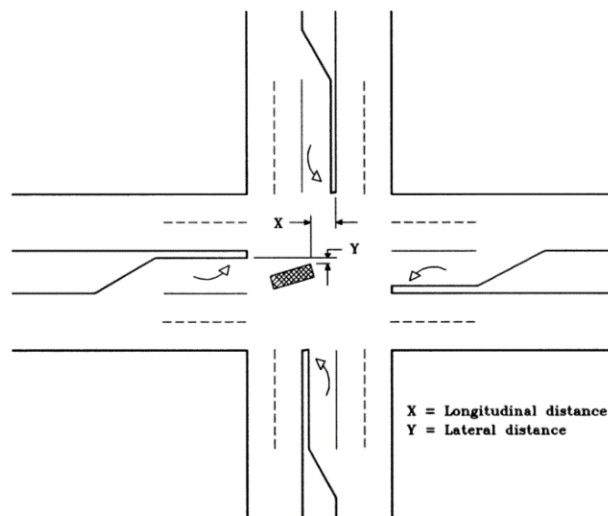


Figure 2.9 Longitudinal and lateral distances used to define vehicle positioning. [Tarawneh and McCoy, 1997]

Vehicle positioning data was collected and analyzed in these two studies. Vehicle positioning is the location within an intersection that a left-turning vehicle place itself at when waiting for an acceptable

gap in the opposing traffic to accomplish the left-turn maneuver. In Tarawneh and McCoy's (1997) study, vehicle positioning was measured with a longitudinal distance and a lateral distance as shown in Figure 2.9. Vehicle positioning affects left-turn motorists' sight distance directly, as when the left-turning vehicle is positioned more into the intersection, the sight distance increases, and when the opposing left-turning vehicle is positioned more into the intersection, the sight distance of the left-turn motorist reduces. In both studies, the distributions of left-turn vehicle positions when there is at least one opposing left-turning vehicle were estimated using video data collected. The design values of vehicle positioning measures used in developing the guidelines in the two studies are listed in Table 2-4. In addition to vehicle positioning measures, the design values of maneuver time for a left-turn vehicle to traverse the intersection, and perception-reaction time from the two studies are also listed. Both of these two studies used 95th percentile values as design values, but because the data sources of these two studies were different, some design values were different. Thus, when developing guidelines, local data are essential for determining the design values to accommodate local conditions and motorist behaviors.

Table 2-4 Design values used to develop left-turn lane offset guidelines

Variable	McCoy et al. (1992)	Tarawneh and McCoy (1997)
Longitudinal Position of Positioned Left-turn Vehicle	7.0 feet	16.4 feet
Lateral Position of Positioned Left-turn Vehicle	2.0 feet	1.6 feet
Lateral Position of Positioned Left-turn Vehicle	3.5 feet	3.9 feet
Maneuver Time of Positioned Left-turn Vehicle	6.5 s	3.8 s
Maneuver Time of Un-positioned Left-turn Vehicle	6.5 s	6.7 s
Perception-Reaction Time	2.0 s	2.0 s

The equation to calculate minimum left-turn lane offset for intersections of four-lane divided roads, developed by McCoy et al. (1992), is:

$$X_o = 2.0 - \frac{549}{12.5V - 51}$$

where X_o = minimum offset between left-turn lanes (feet); and

V = design speed of roadway being crossed (mph).

When the opposing left-turn vehicle is a truck, the equation is:

$$X_o = 3.5 - \frac{457.5}{12.5V - 51}$$

The minimum length of left-turn lane plus taper is:

$$L = \frac{X_i - X_o + L_w - 2}{X_i - X_o + 1.5L_w} (SD_r + Y_i) - W - Y_i$$

where L = minimum length of left-turn lane plus taper (feet);

X_i = lateral distance of motorist's eye from left edge of left-turn lane (feet);

X_o = offset between left-turn lanes (feet);

L_w = lane width (feet);

SD_r = sight distance needed (feet), calculated as $SD_r = 1.47V(J + t_a)$, with V = the design speed, J = perception-reaction time (2.0 s), and t_a = time required to traverse the intersection (s);

Y_i = longitudinal distance from the front of left-turn vehicle to motorist's eye (feet); and

W = width of intersection (feet).

Most of the variables in the above equations are labeled in Figure 2.10 (which shows a configuration with negative left-turn lane offset). The equation provides a result of sufficient left-turn lane storage length by replacing the SD_a in the figure to SD_r .

The minimum and desirable left-turn lane offsets for four-lane divided roadways, suggested by McCoy et al. (1992), are listed in Table 2-5.

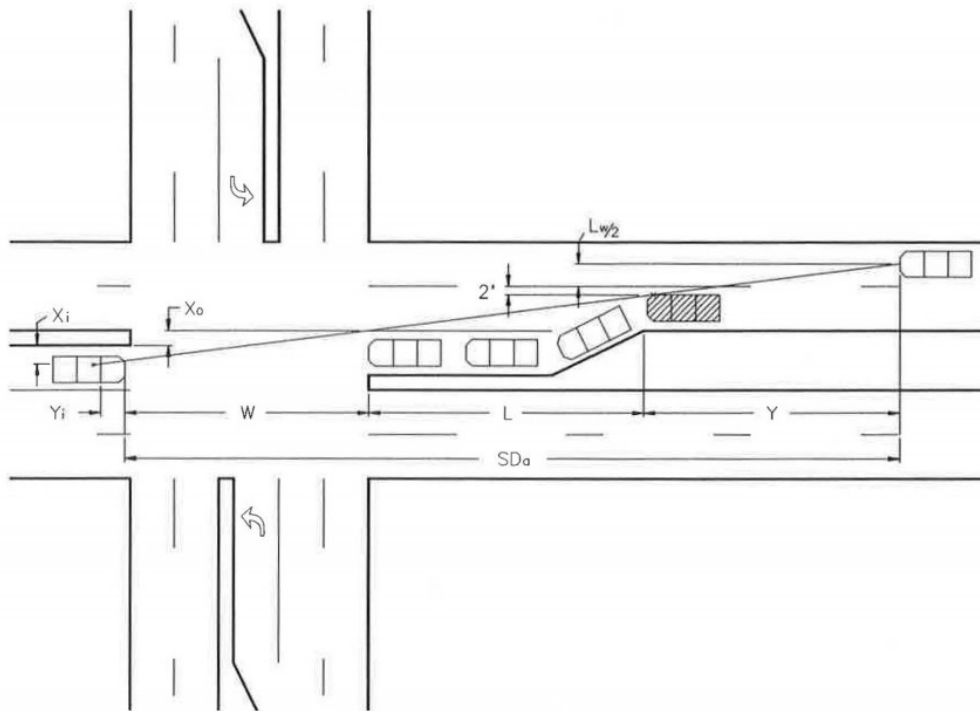


Figure 2.10 Effect of insufficient left-turn lane storage capacity. [McCoy et al., 1992]

The equations for minimum left-turn offset calculation, suggested by Tarawneh and McCoy (1997), are listed in Table 2-6. The suggested minimum and desirable left-turn lane offsets for divided roadways are listed in Table 2-7.

Table 2-5 Guidelines for left-turn lane offsets for four-lane divided roadways [McCoy et al., 1992]

Design Speed (mph)	Minimum Offset (feet)		Desirable Offset (feet)	
	Passenger Car ^a	Truck ^b	Passenger Car	Truck
40	1.0	2.5	2.0	3.5
45	1.0	3.0	2.0	3.5
50	1.5	3.0	2.0	3.5
55	1.5	3.0	2.0	3.5
60	1.5	3.0	2.0	3.5
65	1.5	3.0	2.0	3.5
70	1.5	3.0	2.0	3.5

Note: a. opposing vehicle is a passenger car; b. opposing vehicle is a truck.

Table 2-6 Minimum offset equations [Tarawneh and McCoy, 1997]

Vehicle Positioning		Opposing Left-turn Lane Vehicle Type	
Left-turn Vehicle	Opposing Left-turn Vehicle	Passenger Car	Truck
Un-positioned	Un-positioned	$X_o = 4.3 - \frac{177.9}{2.4V - 12.2}$	$X_o = 5.6 - \frac{140.7}{2.4V - 12.2}$
	Positioned	$X_o = 2.0 - \frac{211.4}{2.4V - 11.0}$	$X_o = 3.6 - \frac{177.4}{2.4V - 11.0}$
Positioned	Un-positioned	$X_o = 2.0 - \frac{163.6}{1.6V - 11.0}$	$X_o = 3.6 - \frac{129.6}{1.6V - 11.0}$
	Positioned	$X_o = -0.1 - \frac{197.6}{1.6V - 10.0}$	$X_o = 1.3 - \frac{165.7}{1.6V - 10.0}$

Note: X_o = offset between opposing left-turn lanes (feet); V = design speed of roadway (mph);

Table 2-7 Guidelines for left-turn lane offsets for divided roadways [Tarawneh and McCoy, 1997]

Design Speed (mph)	Minimum Offset (feet)			
	Un-positioned Passenger Car	Positioned Passenger Car	Un-positioned Truck	Positioned Truck
31	3.3	0.7	5.0	2.6
37	3.3	1.0	5.0	2.6
43	3.6	1.0	5.0	3.0
50	3.6	1.3	5.3	3.0
56	3.6	1.3	5.3	3.0
62	4.0	1.3	5.3	3.3
68	4.0	1.3	5.3	3.3
Desirable Offset (feet)	4.3	2.0	5.6	3.6

The Texas Transportation Institute (TTI), in their Urban Intersection Design Guide, cited the study by Tarawneh and McCoy, and proposed the minimum and desirable left-turn lane offset values shown in

Table 2-7 as the suggested guidelines to the National Association of City Transportation Officials (NACTO) (Fitzpatrick et al., 2005). These guidelines, as stated in the TTI guide, would usually involve reconstruction of the left-turn lanes, but there are economical alternatives like increasing the width of the lane line (or inserting painted island) between the left-turn lane and the adjacent through lanes, which is also effective in terms of improving left-turning motorist's sight distance. The TTI guide also proposed two types of commonly used offset left-turn lanes are, parallel and tapered, as shown in Figure 2.11. The parallel type is suitable for both signalized and unsignalized intersections, and the tapered type is typically only for signalized intersections.

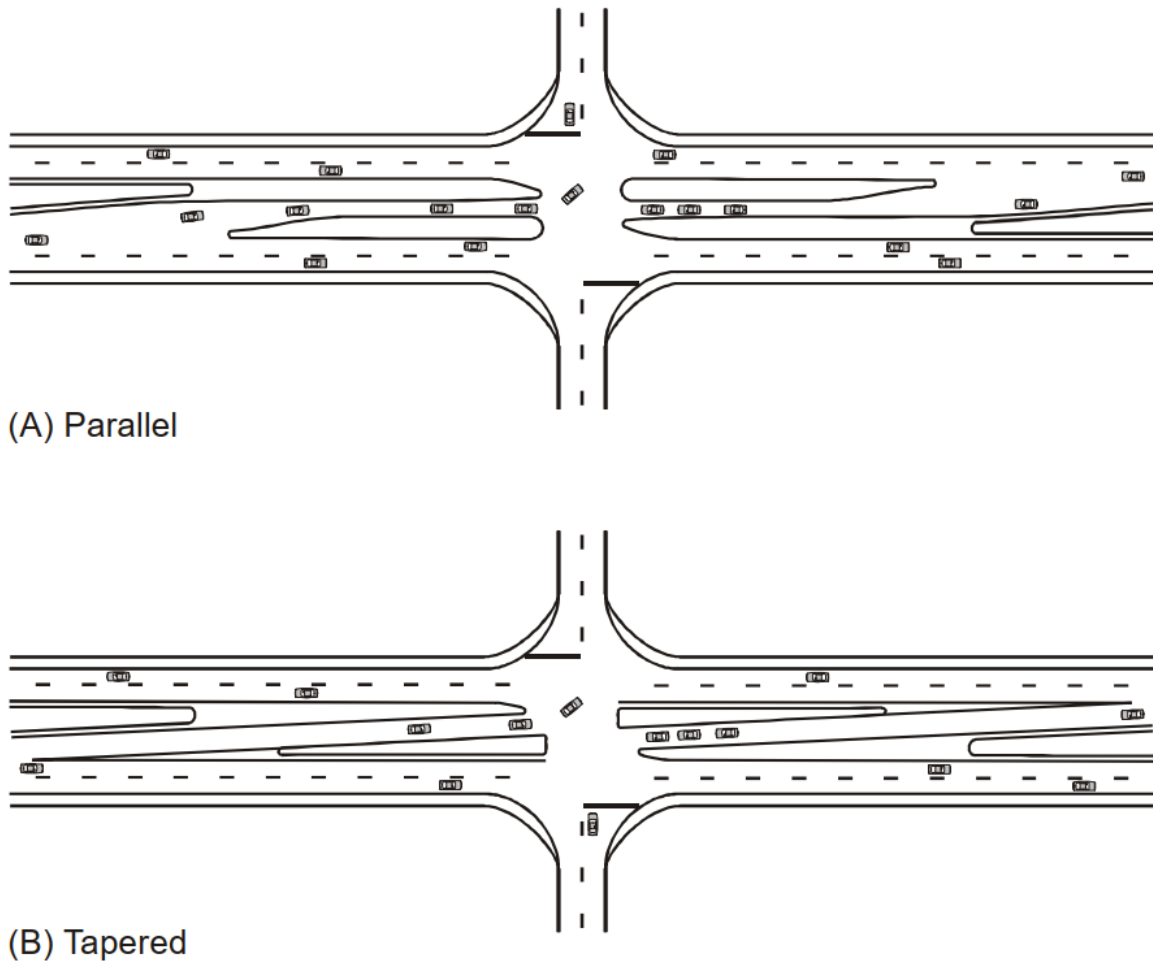


Figure 2.11 Parallel and tapered offset left-turn lanes. [Fitzpatrick et al., 2005]

McCoy et al., in a 2001 study, investigated an alternative for left-turn lane offsetting without involving reconstruction. The alternative was widening the left-turn lane line. McCoy et al. (2001) found a relationship between the left-turn lane-line width and available sight distance beyond opposing left-turn

vehicle. Guidelines were then developed based on that relationship, and by plugging in the required sight distances to the equation and calculating the corresponding left-turn lane-line widths. The guidelines were provided in forms of charts.

Easa and Ali (2005) developed modified analytical models and guidelines for left-turn lane offsets. Left-turn sight distance was measured from the conflict point between left-turning vehicle and oncoming through vehicle, rather than from the point where the left-turn motorist initiates the left-turn maneuver, which was used to develop guidelines by the McCoy studies (McCoy et al., 1992, 2001; Tarawneh and McCoy, 1997). The proposed measure by Easa and Ali is shown in Figure 2.12, where the sight distance measure starts from point D.

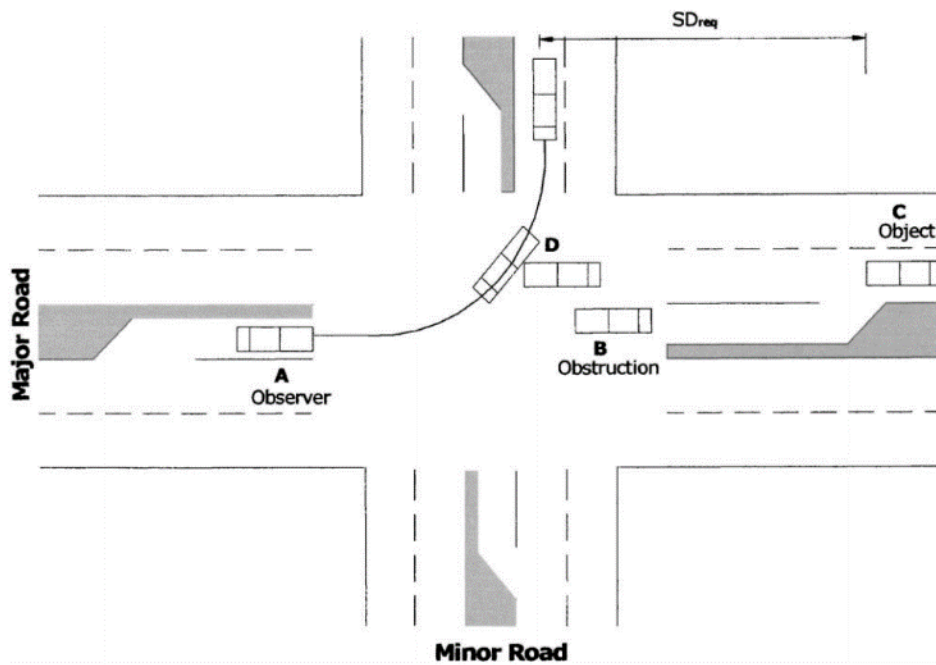


Figure 2.12 Measure of sight distance from conflict point D. [Easa and Ali, 2005]

The modified guidelines for left-turn lane offset and length (including taper length) by Easa and Ali, 2005 (and previous guidelines for comparison) are listed in Table 2-8 and Table 2-9, respectively.

Table 2-8 Modified and previous guidelines for minimum left-turn lane offset [Easa and Ali, 2005]

Design Speed on Major Road V (mph)	Minimum Required Offset X_o (feet)				Desirable Offset X_o (feet)	
	Opposing Vehicle (Passenger Car)		Opposing Vehicle (Truck)		Opposing Vehicle (Passenger Car)	Opposing Vehicle (Truck)
	Previous	Modified	Previous	Modified		
25	0.0	0.3	2.0	2.3	2.0	3.6
30	0.3	0.7	2.3	2.6	2.0	3.6
35	0.7	1.0	2.6	2.6	2.0	3.6
40	1.0	1.0	2.6	2.6	2.0	3.6
45	1.0	1.3	2.6	3.0	2.0	3.6
50	1.3	1.3	3.0	3.0	2.0	3.6
55	1.3	1.3	3.0	3.0	2.0	3.6
60	1.3	1.3	3.0	3.0	2.0	3.6
65	1.3	1.7	3.0	3.0	2.0	3.6
70	1.7	1.7	3.0	3.3	2.0	3.6

Note: Boldface indicates that the modified and previous guidelines are different.

Table 2-9 Modified and previous guidelines for minimum left-turn lane length [Easa and Ali, 2005]

Design Speed on Major Road V (mph)	Required Sight Distance (feet)	Left-turn Lane Length, L (feet)			
		(Offset = 2 feet)		(Offset = 4 feet)	
		Previous	Modified	Previous	Modified
40	500.0	201.8	242.5	181.1	219.5
45	562.4	240.5	281.2	217.5	255.6
50	625.0	278.9	319.9	253.6	291.7
55	687.4	317.6	358.6	289.7	328.1
60	750.0	356.3	397.3	325.8	364.2
65	812.4	395.0	436.0	362.2	400.3
70	875.0	433.7	474.8	398.3	436.4

Easa et al. (2005) also investigated left-turn lane offsetting at intersections on horizontal curves. Mathematical models were developed for the calculation of required minimum offset and median width. The models are presented in graphs showing the required minimum left-turn lane offsets for combinations of speeds and radii of curvature and position of opposing left turning vehicle. An example minimum offset chart is shown in Figure 2.13.

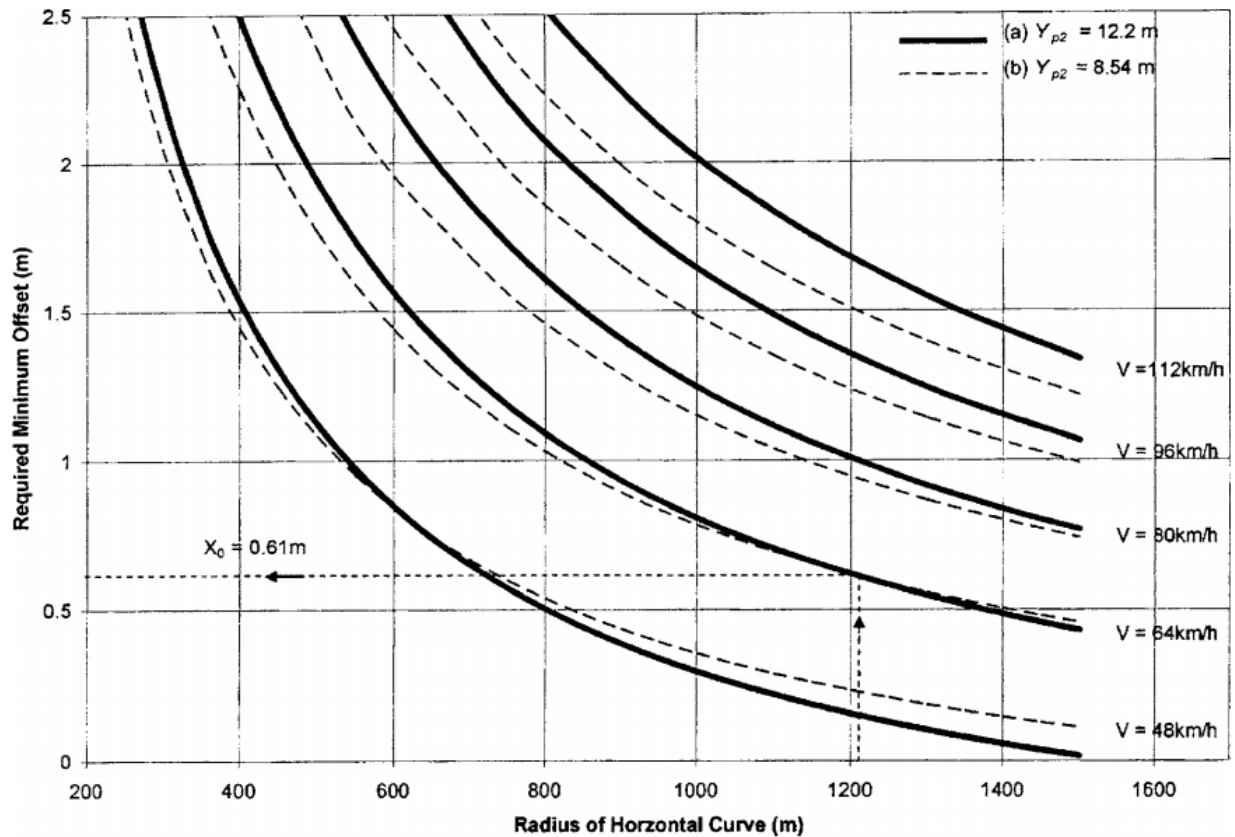


Figure 2.13 Required minimum left-turn lane offset for different horizontal curves. Graphs are developed for 5 different design speeds. Calculations are based on 2 lanes in each direction on major and minor road and median width of 4.88 m (16.1 feet) on each roadway. [Easa et al., 2005]

There are extensive studies on geometric models for left-turn lane sight distance calculation (Yan and Radwan, 2004; Yan et al., 2006 a, b; Hussain and Easa, 2015). Yan and Radwan (2004) developed sight distance model for unprotected left-turning traffic at linear intersections. Later Yan et al. (2006 a, b) developed sight distance models for left-turning traffic at intersections with horizontal curves, and summarized sight distance models for left-turning traffic at several different geometric designs of intersections, including linear approach, curve approach, linear approach leading to a curve, and curve approach leading to a linear segment. Hussain and Easa (2015) conducted a reliability analysis of left-turn sight distance, developed a probabilistic approach for sight distance calculation. Hussain and Easa (2015) found that the deterministic method used to provide very conservative offset suggestions, and the offset was most sensitive to vehicle width and lateral distance-related variables and less sensitive to longitudinal distance-related variables. These models can be used to address different geometric features of intersections, and to help provide sufficient sight distance and enhance operational efficiency of left-turning traffic.

In terms of cost-effectiveness of providing left-turn lane offsets, a 2003 research study sponsored by the United States Department of Transportation (USDOT) provided guidelines for selecting left-turn lane deceleration lane designs for rural, unsignalized, four-lane expressways (Schurr et al., 2003). Cost of

both offset left-turn lane and conventional left-turn lane designs, in terms of construction, maintenance, traffic operations, and safety, were analyzed. A spreadsheet procedure for determining the lowest cost left-turn lane design using various variables such as annual average daily traffic (AADT), speed limit, percentage of left-turn movements, and percentage of heavy trucks was suggested. Geometric design recommendations were provided for offset left-turn lanes on rural, unsignalized, four-lane expressways, including providing adequate offset that will assure minimum intersection sight distance for a worst-case situation for critical time gap; ensuring feasible allocations for through-lane separator width, left-turn lane width, medial separator width, and offset to opposing left-turn lane meet or exceed the criteria listed in NCHRP 375; beginning using 20:1 taper; and using gradual widened left-turn lane/through lane separation line on revised traditional left-turn lanes.

2.4 Summary

Studies on left-turning sight line obstruction and offsetting left-turn lanes review in this report can be dated back to 1970s. Early and more recent studies showed that at left-turn lanes, of both signalized and unsignalized intersections, obstructed sight lines could cause higher possibilities of collisions between left-turning vehicles and oncoming vehicles from the opposing direction. Evaluations of the effects of left-turn lane offsets, with data from multiple states in the United States, reported results indicating that positive left-turn lane offsets were more effective in reducing intersection left-turn crashes than zero and negative left-turn offsets. In terms of effects on intersection traffic operations, providing positive left-turn offsets help reduce the sight line obstruction situations, and lead to higher capacities of left-turn movements. Guidelines were developed for the geometric design elements of left-turn offset, based on different sight distance models, and considering different vehicle types and vehicle positioning situations. These studies will serve as valuable references for the development of left-turn lane offset guidelines to satisfy the Minnesota needs.

CHAPTER 3: STATE PRACTICE REVIEW

A review of state Department of Transportation (DOT) Design and/or Guidance Manuals was conducted to identify existing guidance and policies with respect to offset turn lanes at intersections. “Left-turn offset” was used to search the documents. A total of 23 states (shown in Figure 3.1) DOT design manuals, including the largest states, all of the states surrounding Minnesota, and from states that have generally been considered progressive were reviewed. During the review, interest was given to identify warranting criteria for requiring or recommending installing offset left-turn lanes, and under what conditions or circumstances needed to be present at the intersection.

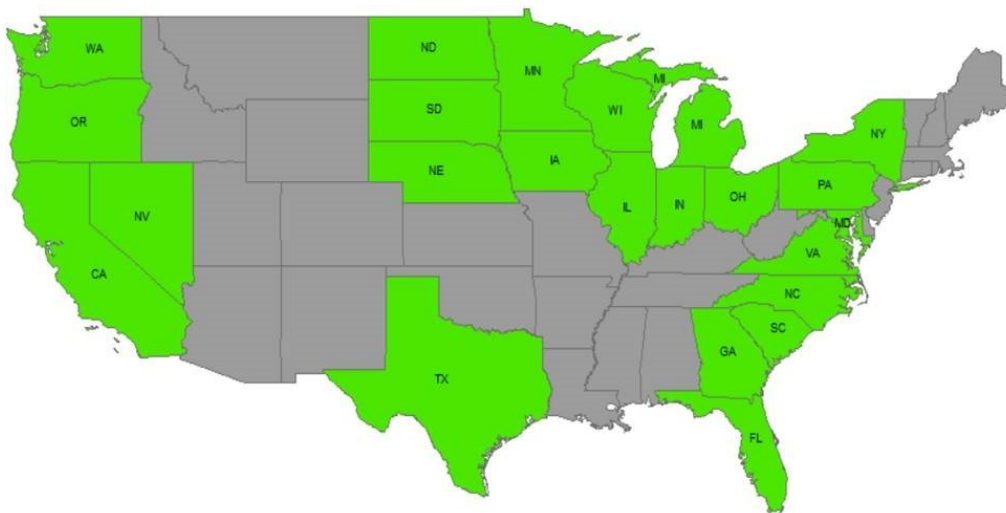


Figure 3.1. Review states

The majority of state DOT Design manuals have either no mention or minimal discussion about sight distances or left-turn safety at intersections, and instead rely on the AASHTO Geometric Design of Highways and Streets 2011 Edition, referred to as the Green Book, for covering this design topic. While most state manuals give an overview of basic highway design, especially for use by new designers, the topics modified or expanded upon, are topics that are unique or have special interest to their state, design issues that arise more frequently, modify design values that better accommodate their users based on past experience, or are not covered in detail in the Green Book. If a state DOT is comfortable with using the same design treatment, for most situations, then there is generally minimal interest in expanding their design manual.

An overview of findings for guidance and policies for left-turn lane offsets from state DOT design manuals and guidance documents is in Appendix A. Guidance on left-turn lane offsets provided in the Green Book is discussed, along with a breakdown description on topics of interest that were found in state DOT manuals relating to left-turn offset design treatments.

3.1.1 Left-turn Lane Offsets

Information and discussions about left-turn lanes and left-turn offset design treatments in the Green Book are contained in two sections. The first offset reference deals with left-turn lanes in medians on divided arterials. In Chapter 7 Section 2.11 Divided Arterials, the following statement is given, “For intersections with medians wider than 5.4 m [18 feet], it is desirable to offset any left turn lanes provided to reduce sight restrictions due to opposing left turn vehicles.” However, the ability to have offset lanes on medians wider than 18 feet comes with disadvantages. The Green Book cautions that wider medians may increase crashes and lead to undesirable driving behavior at intersections on urban arterials. A further recommendation is not to use medians wider than 18 feet at rural intersections that are likely to undergo urban or suburban development in the foreseeable future.

The second Green Book reference to offset left-turn lanes on roadways with medians is in Chapter 9 Section 7.3 Design Treatments for Left-Turn Maneuvers. This section reiterates the desirability of having medians wider than 18 feet which allows for offsetting left-turn lanes. This median width will allow the divider to be in the range of 6 to 8 feet immediately before the intersection. “This alignment will place the vehicle waiting to make the turn as far to the left as practical, maximizing the offset between the opposing left-turn lanes, and thus providing improved visibility of opposing through traffic. The advantages of offsetting the left-turn lanes are (1) better visibility of opposing through traffic; (2) decreased possibility of conflict between opposing left-turn movements within the intersection; and (3) more left-turn vehicles served in a given period of time, particularly at a signalized intersection.” (This Green Book information is referenced from NCHRP Report 375, entitled Median Intersection Design.)

Green Book has guidance on the use of parallel and tapered left-turn lanes. “Parallel offset left turn lanes may be used at both signalized and unsignalized intersections.” An illustration of parallel turn lanes is shown in Figure 3.2.

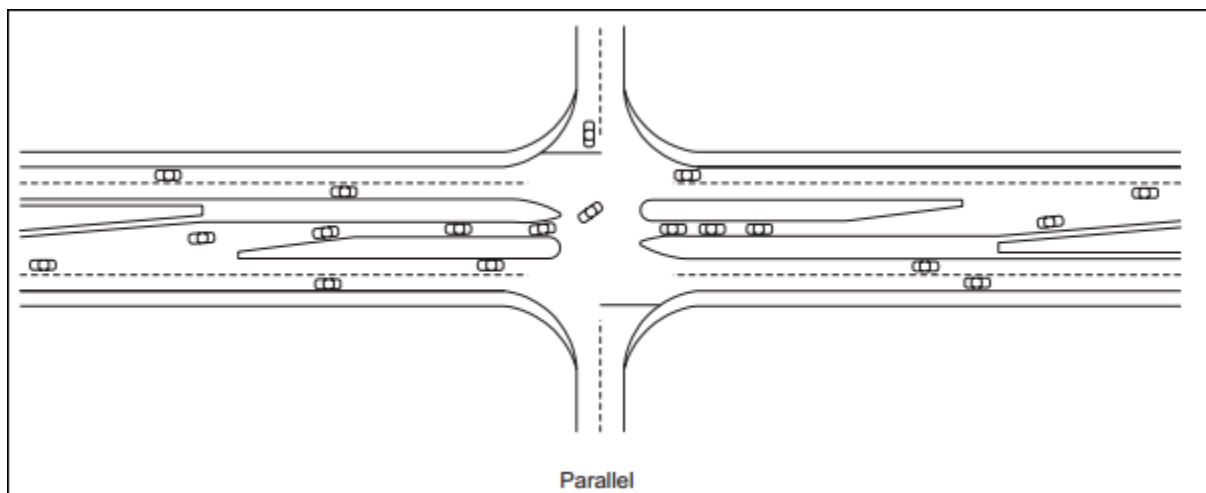


Figure 3.2. Green Book Figure 9-52A – parallel offset left-turn lane.

Tapered offset left-turn lanes diverge from the through lanes and cross the median at a slight angle. This type of geometry provides the same advantages as a parallel left-turn lane, but has several additional benefits over parallel left-turn lanes. Tapered alignments reduce the potential for side swipe conflicts with opposing left-turn vehicles, especially long vehicles or vehicles with long over hanging loads, such as log trucks. Another advantage of tapered lanes is increased efficiency of traffic signal operation. Green Book Figure 9-52B illustrates the tapered geometry for offset left-turn lanes and is shown in Figure 3.3. “Tapered offset left-turn lanes are normally constructed with a four-foot nose between the left-turn lane and the opposing through lanes. Tapered offset left-turn lanes have been used primarily at signalized intersections.” Since there is no discussion about pedestrian movements in this section, it would appear that a wider nose would be acceptable for the purpose of pedestrian storage.

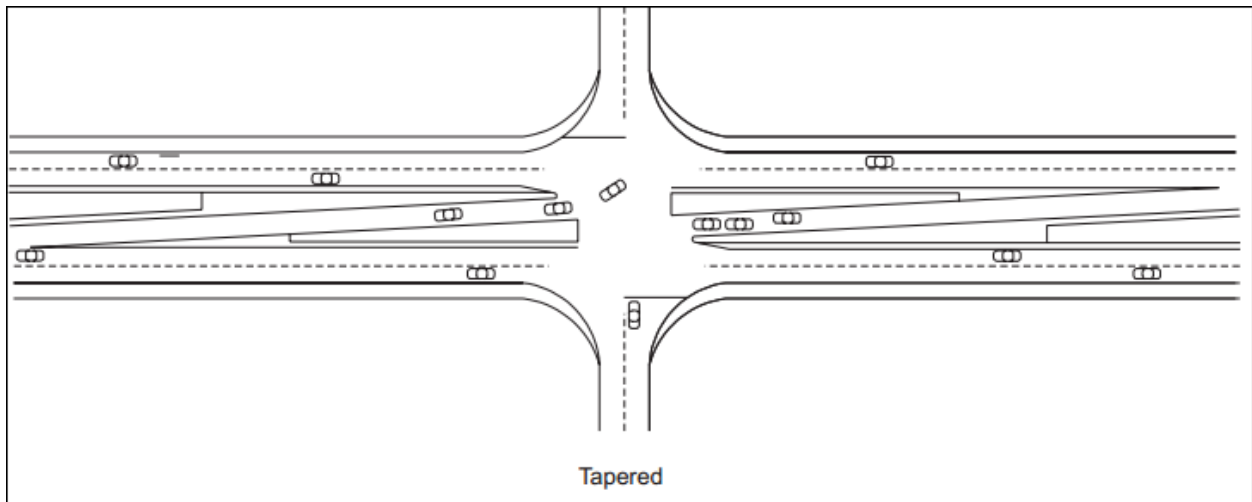


Figure 3.3 . Green Book Figure 9-52B – tapered offset left-turn lane.

The Green Book recognizes that “local conditions and the cost of right-of-way often influences the type of intersection selected as well as many of the design details. Limited sight distance may make it desirable to control traffic by yield signs, stop signs, or traffic signals when the traffic densities are less than those ordinarily considered for such control.”

The Green Book recommends separating either type of offset left-turn lanes from adjacent through traffic lanes by either painted or raised channelization.

3.1.2 Left-turn Lane Sight Distance and Gap Acceptance

The Green Book policies for sight distances at intersections are discussed in Chapter 9 Section 5.1 and 5.3. The various types of intersection sight distances have been given a designation type by the Green Book, and left-turn sight distances from the major road are identified as Case F.

Motorists turning left across opposing traffic need to decide when sufficient sight distance is available to safely make the maneuver. For designers, calculating the needed sight distance along the major road to accommodate left-turns is determined by the distance traversed at the design speed on the major road

in the travel time for the design vehicle. The travel time is based on field observation research of the gaps in major road traffic actually accepted by motorists turning across the major road. The Green Book Table 9-13 for the time gaps for Case F is shown in Figure 3.4. These values provide sufficient time for the minor-road vehicle to accelerate from a stop and complete a left-turn without unduly interfering with major road traffic operations. The gap acceptance time does not vary with approach speed on the major road. Studies have indicated that a constant value of time gap, independent of approach speed, can be used as a basis for intersection sight distance determinations. The sight distance is based on a stopped vehicle in the left-turn lane, since a vehicle that turns left without stopping would need less sight distance.

Design Vehicle	Time Gap (t_g)(s) at Design Speed of Major Road
Passenger car	5.5
Single-unit truck	6.5
Combination truck	7.5

Note: *Adjustment for multilane highways*—For left-turning vehicles that cross more than one opposing lane, add 0.5 s for passenger cars and 0.7 s for trucks for each additional lane to be crossed.

Figure 3.4 . Green Book time gap values for Case F, left-turns from the major road.

The sight distance needed is calculated using the formula in the Green Book and is provided in Figure 3.5.

$$ISD = 1.47 V_{\text{major}} t_g$$

where:

ISD = intersection sight distance (length of the leg of sight triangle along the major road) (ft)

V_{major} = design speed of major road (mph)

t_g = time gap for minor road vehicle to enter the major road (s)

Figure 3.5 . Green Book formula for calculating intersection sight distance.

The Green Book Table 9-14, shown as Figure 3.6, provides the calculated unadjusted time gap sight distances for passenger cars.

Design Speed (mph)	Stopping Sight Distance (ft)	Intersection Sight Distance	
		Passenger Cars	
		Calculated (ft)	Design (ft)
15	80	121.3	125
20	115	161.7	165
25	155	202.1	205
30	200	242.6	245
35	250	283.0	285
40	305	323.4	325
45	360	363.8	365
50	425	404.3	405
55	495	444.7	445
60	570	485.1	490
65	645	525.5	530
70	730	566.0	570
75	820	606.4	610
80	910	646.8	650

Figure 3.6 . Green Book intersection sight distance for Case F-left-turns from the major road.

3.2 STATE DOT GUIDANCE MODIFICATIONS TO THE GREEN BOOK FOR LEFT-TURN LANES

3.2.1 Left-turn Lane Offset Definitions and Diagrams

A common theme used in some state DOT Design Manuals to expand upon the Green Book offset guidance is to provide a more descriptive definition and explanation, along with figures and photos, to define positive and negative offset at median left-turns. A relatively short, but precise description example of positive and negative left-turn offsets is provided on page 12-40 in the South Dakota Road Design Manual. “Vehicles turning left from opposing left turn lanes can restrict each other's sight distance unless the lanes are sufficiently offset. Offset is defined as the lateral distance between the left edge of a left turn lane and the right edge of the opposing left turn. When the right edge of the opposing left turn is to the left of the left edge of the left turn lane, the offset is negative. If it is to the right, it is a positive offset.” Along with these definitions, South Dakota provides two simple diagrams that illustrate negative and positive offset. These diagrams are shown in Figure 3.7 and Figure 3.8.

The 2018 Florida Department of Transportation (FDOT) Design Manual provides an even shorter definition. “The offset distance is defined as the distance between the left edge of the turn lane and the right edge of the opposing turn lane.” An almost identical diagram illustrating negative and positive offsets used by South Dakota is also included in the FDOT Design Manual. The FDOT Design Manual provides the criteria and requirements for the state Highway System.

The Nevada Strategic Highway Safety Plan provides diagrams that illustrate negative, positive, and no offsets.

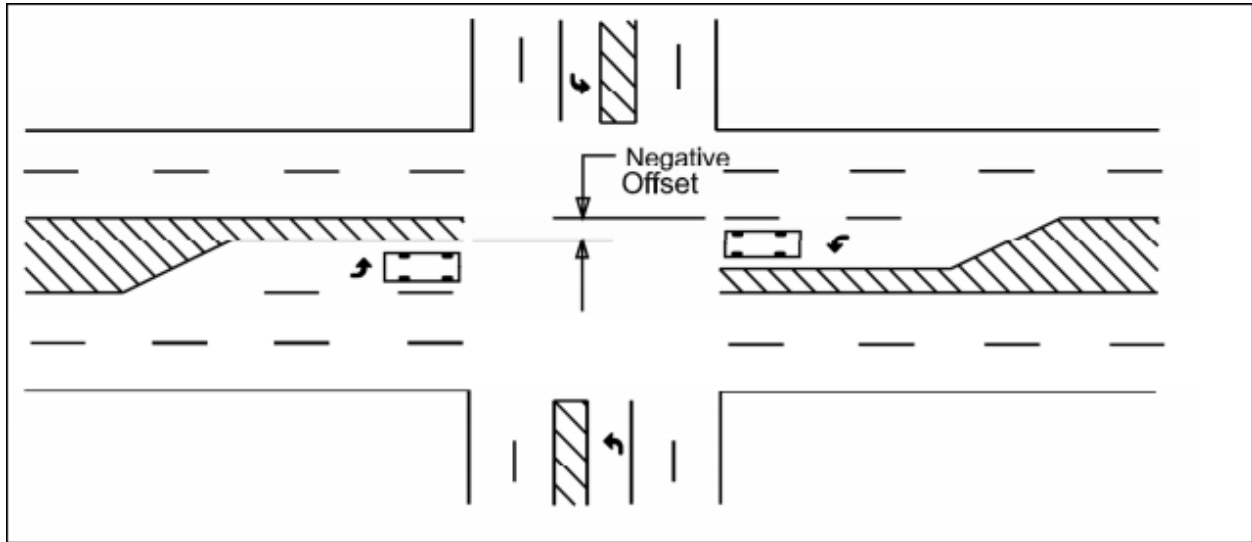


Figure 3.7. South Dakota Road Design Manual figure showing negative offset.

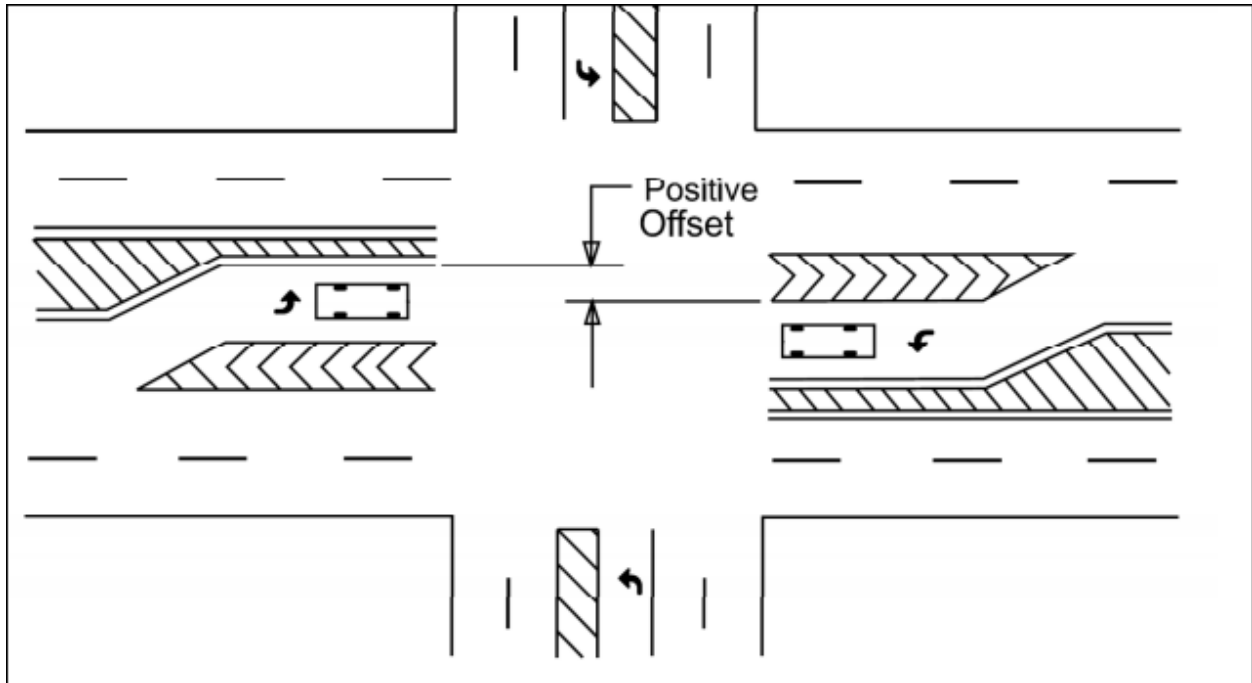


Figure 3.8. South Dakota Road Design Manual figure showing positive offset.

The Wisconsin Department of Transportation (WisDOT) Facilities Development Manual (FDM) provides a separate sketch for demonstrating the definition of positive and negative offset of opposing left-turn lanes, shown as Figure 3.9.

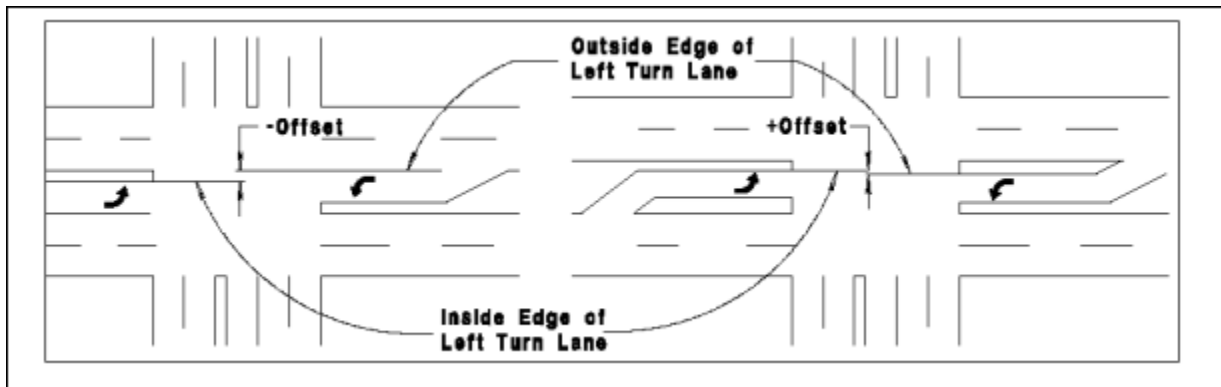


Figure 3.9. WisDOT FDM sketch defining positive and negative offsets of opposing left-turn lanes.

The Florida DOT 2014 Median Handbook contains several photos that illustrate examples of left-turn lane positive offsets, and are shown as Figure 3.10.



Figure 3.10. FDOT Median Handbook illustrations of positive offset.

3.2.2 Left-turn Lane Offset Distance

The South Dakota Road Design Manual guidance states that “typically a 2-foot positive offset will provide improved sight distance to motorists; however, intersections should be evaluated on a case by case basis.” In Nebraska, a one-foot offset is considered adequate in 18-foot wide medians.

The WisDOT FDM does not provide a positive offset value, but does specifically recommend providing a positive offset for opposing left-turn lanes, if possible. The WisDOT generic design details for left-turn lanes at urban intersections indicating the positive offset is provided in Figure 3.11.

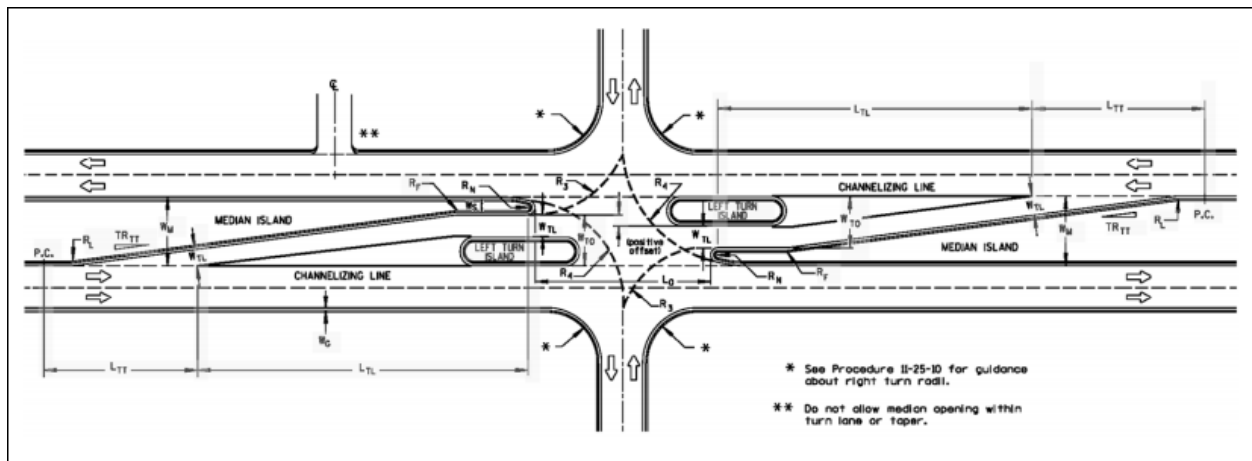


Figure 3.11. WisDOT design details for slotted left-turn lanes at urban intersections.

The 2017 Florida DOT Plans Preparation Manual provides guidance on the benefits of providing adequate sight distance for opposing left-turn lanes. Besides sight restrictions caused by vehicles blocking the view of oncoming vehicles, the designer is reminded about checking horizontal and vertical curvature sight distance restrictions. Two illustrations are provided showing offset sight distances on a roadway with a 22-foot wide median, the first with a negative 10-foot offset which results in only 70 feet of sight distance, and the second with a negative one-foot offset resulting in 725 feet of sight distance. The guidance is to provide whatever offset is available, even if positive offset is not possible. The Manual does provide left-turn offset guidance in a chart taken from the 2001 FHWA Older Driver Highway Design Handbook, and is shown as Figure 3.12. The positive offset values are based on the major road design speed.

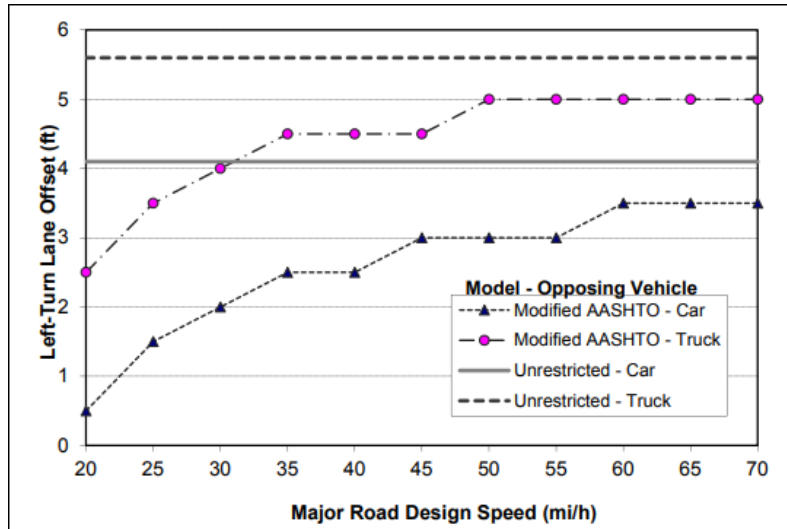


Figure 3.12. FDOT plan preparation manual left-turn offset guidelines.

The 2018 FDOT Design Manual, in Chapter 212.14.4, contains language taken from the FDOT 2017 Plans Preparation Manual, but eliminates some of the offset explanation, which makes some of the Design Manual language and illustrations rather ambiguous. An example is the illustration of opposing left-turn lanes with a negative one-foot offset and sight distance of 725 feet. However, clear guidance is provided in the form of a table. “At locations where the full offset distances cannot be obtained, it is recommended that the minimum offset distances shown in Table 212.14.1 be provided to achieve minimum required sight distances according to design speed. It is recommended that the “Opposing Truck” values be used where the opposing left-turn traffic includes a moderate to heavy volume of large trucks.” It is assumed the designers must calculate the full offset distances using the AASHTO Green Book, but there is no mention on the method to calculate the “full offset distances.” The FDOT Table 212.14.1 with recommended minimum offset distances is shown as Figure 3.13. It is assumed these minimum offset values are all positive offset distances, but the manual is not definitive or clear, since the illustration of a negative one-foot offset can potentially have a sight distance of 725 feet.

Design Speed (mph)	Minimum Offset (feet)	
	Opposing Car	Opposing Truck
≤ 30	1.0	3.0
35	1.5	3.5
40 - 45	2.0	4.0
50 - 55	2.5	4.5
60 - 65	3.0	4.5
70	3.0	5.0

Figure 3.13. FDOT recommended minimum offset distances for left-turn lanes.

The 2014 Florida DOT Median Handbook provides guidance on left-turn lane offsets. This handbook is a guide for designing medians and median openings, primarily for unsignalized median openings, but also applicable for offsetting left-turn lanes at signalized intersections. The handbook is not a FDOT standard or procedure guide, but intended to help designers make the best decisions on median planning. Positive and negative offset are defined and illustrated. Guidance for offsetting left-turn lane distances is provided. “Desirable offsets should all be positive with a recommended minimum 2- foot offset when the opposing left turn vehicle is a passenger car and a recommended minimum 4-foot offset when the opposing left turn vehicle is a truck. In both cases, the left turn vehicle is assumed to be a passenger car.”

The Indiana Design Manual guidance, while limited to use on medians 24 feet wide or greater, shows positive offsets on their typical drawings. However, it does not include offset dimensions or amount of sight distance required. The drawing appears more intended for illustrating turn lane deceleration length and storage distance.

3.2.3 Warrants or Basis for Installing Left-turn Lanes

While slightly outside the scope of this project, guidance on when to consider installing left-turn lanes is of interest because once the decision is made to install a left-turn lane, then the designer must consider whether to provide offset values. Several states, including South Dakota, provide general warranting statements or conditions, such as “high volume of left turns” or “where vehicular speeds are high” for rationale to install left-turn lanes. North Dakota provides warranting criteria for signalized and unsignalized intersections, along with numeric values for speed, traffic volumes, and crash history, plus engineering judgement based on an engineering study. In addition to volumes of left-turning traffic and opposing traffic volumes, New York DOT Highway Design Manual also includes a discussion on crash history, crash potential, anticipated operating speeds, and sight distance on the mainline that affects the ability to see a vehicle waiting to turn, construction costs, and right-of-way impacts.

Nebraska differentiates between signalized and unsignalized intersections, and whether the facility is a two-lane highway or a divided arterial. At signalized intersections, left-turn lanes are provided, if warranted. Exclusive left-turn lanes are provided if left-turn signal phasing will be provided, or where left-turn volumes exceed 100 vehicles per hour and space is available. At unsignalized intersections on two-lane highways, only “where traffic volumes are high” is offered for guidance to install left-turn lanes. On divided arterials, “and/or vehicle speeds are high” is added as a reason to install left-turn lanes.

The Iowa DOT Design Manual provides a numeric based methodology as part of the warrant for establishing turn lanes on rural two-lane highways. When left-turn lanes are justified, the centerlines of the left-turn lanes can be offset by the median width. A typical drawing shows how to establish a four foot median width with 12-foot left-turn lane widths. The drawing does not show or discuss left-turn positive offsets, but if vehicles in the opposing left-turn lanes move to the left most part of their lane, some positive offset should result.

3.2.4 Median Width Guidance

In discussing turning lane design, the New York Highway Design Manual does not infer median design width be developed based on turning lanes. Rather, their Manual offers guidance on the design of turning lane geometry when median widths are designed between 16 feet to 24 feet. “Provide a flush divider to the right of the left-turn lane to direct the left-turning vehicle as far to the left as possible thereby reducing the potential for opposing left-turning vehicles to obstruct each other’s view of opposing through traffic. Manual Exhibit 5-35, included as Figure 3.14, shows the minimum median width requirement of six feet when the median is raised, as well as the left-turn lane design geometry guidance. When median widths are greater than 24 feet, additional guidance is offered for handling traffic operations and safety including, a design treatment for left-turn lanes. Manual Exhibit 5-36, included as Figure 3.15, demonstrates the key geometry requirements, and the significant sight distance improvements that can be achieved.

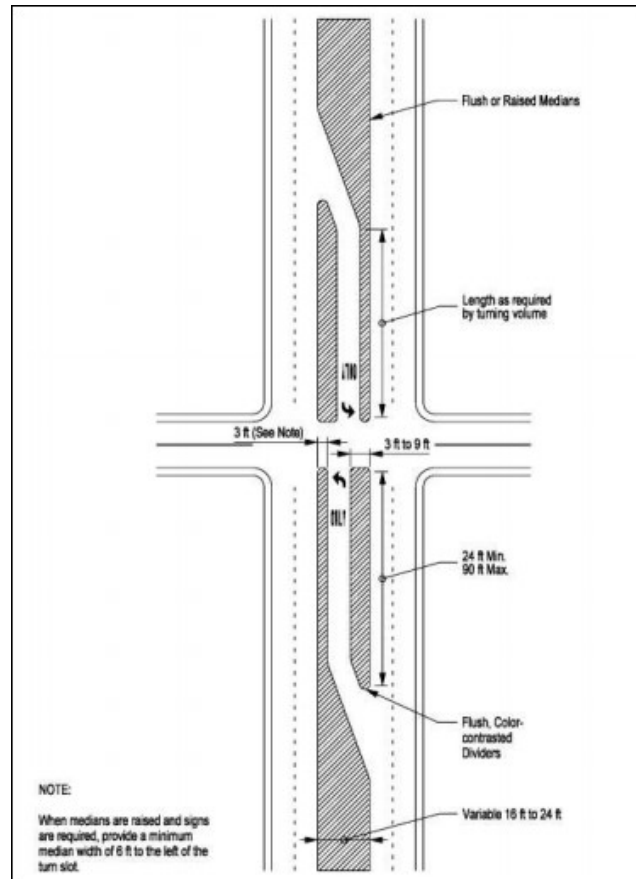


Figure 3.14 . New York DOT left-turn slot design with divider on right.

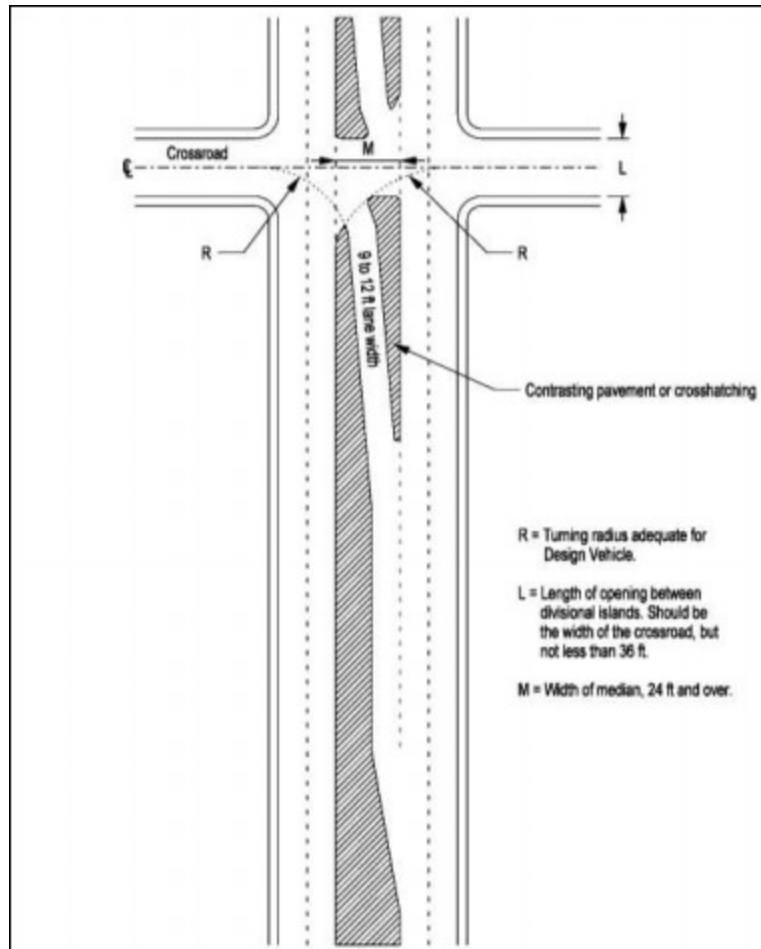


Figure 3.15. New York DOT design treatment for medians over 25 feet.

The South Carolina Access and Roadside Management Standards reiterates the Green Book guidance for using offset left-turn lanes when medians are wider than 17 feet, but adds that the median nose width can vary between 1 foot to 6 feet.

South Dakota DOT recommends different offset guidance when slightly different median widths are used.

Indiana DOT recommends slotted left-turn lanes where the median width is 24 feet or greater on four lane facilities.

The Iowa DOT Design Manual recommends that if left-turn offset lanes are used on four lane expressway intersections, the median width should be reduced to 30 feet. Additionally, “potential median drainage issues should be addressed before offset turn lanes are incorporated.” A typical drawing is included in the guidance showing the area between the left-turn lane and the through lane should be flush and paved, but no dimensions are shown for this flush median.

The 2014 FDOT Median Handbook does contain guidance for several median widths. “On all urban designs, offset left turn lanes should be used with median widths greater than 18 feet. A 4-foot wide

traffic separator should be used when possible to channelize the left turn movement and provide separation from opposing traffic.” “On median widths 30 feet or less, an offset left turn lane parallel to the through lane should be used and the area between the left turn lane and the through lane where vehicles are moving in the same direction should be channelized with pavement markings. On medians greater than 30 feet, a tapered offset should be considered.”

The FDOT Design Manual does not dictate specific median widths for divided facilities designs but provides guidance on turn lanes for several different median widths, using some of the language from the FDOT Median Handbook. “Offset left turn lanes should be used with median widths greater than 18 feet” and also recommends using a 4-foot traffic separator when possible to channelize the left-turn and provide separation from opposing traffic.

FDOT Design Manual also provides guidance to “consider offset left turn lanes at rural intersections with high turning movements. For median widths 30 feet or less, use a parallel offset left turn lane. Stripe the area between the offset left turn lane and the traffic lane where vehicles are moving in the same direction. For medians wider than 30 feet, consider a tapered offset left turn lane.” Note that this paragraph does not use the words “positive” or “negative” offset left turn lanes, but it is assumed the desired offset turn lanes are designed as positive offsets, if possible.

A chart describing relationships of median widths to the use of offset left-turn lanes is presented in Table 3-1.

Table 3-1 . Parameters for Using Offset Turn Lanes Based on Median Width Dimensions

AASHTO	>18 feet, but not recommended at urban intersections or rural intersections likely to undergo urban or suburban development in near future.
Florida	Curbed roadways >18 feet. Use 4-foot traffic separator from opposing traffic.
Indiana	≥ 24 feet
Iowa	On expressways with 30 feet median
New York	When median widths are 16 feet to 24 feet, use a 6-foot separator to left of the parallel turn lane. When median widths are >25 feet use tapered turn lanes with contrasting pavement on the right side of turn lane.
North Carolina	≥20 feet
South Carolina	>17 feet
South Dakota	No specific median width provided but does recommend a tapered turn lane where wider medians allow.

3.2.5 Operational Guidance for Sight Distance and Critical Time Gap

The 2016 Florida DOT (FDOT) Manual of Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways (referred to as the “Florida Greenbook” strengthens the policy language in the AASHTO Green Book for sight distance at left-turn lanes off a major road. “All locations along a major road from which vehicles are permitted to turn left across opposing traffic **shall** have sufficient sight distance to accommodate the left turn maneuver. In this case, the Intersection Sight Distance (ISD) is measured from the stopped position of the left turning vehicle.” FDOT provides a figure illustrating the ISD, and is shown as Figure 3.16. By Florida state statute and Administrative code, the Florida Greenbook manual is intended for all projects not on the state and national highway systems.

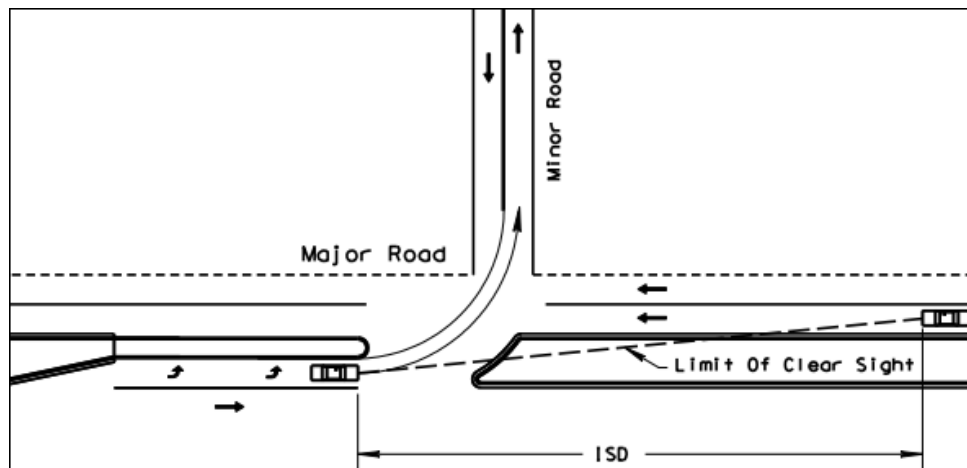


Figure 3.16 . FDOT Greenbook figure illustrating sight distance for vehicle turning left from major road.

The Florida Greenbook uses the same design time gap values and adjustment factors for number of opposing lanes crossed as the AASHTO Green Book. The intersection sight distance required for left-turns from the major road for passenger vehicles are calculated and illustrated in a chart, provided as Figure 3.17. The speed shown in the chart for the opposing vehicles is inferred from earlier material in the Florida Greenbook as the “design speed” for the major roadway, the same definition as used by AASHTO.

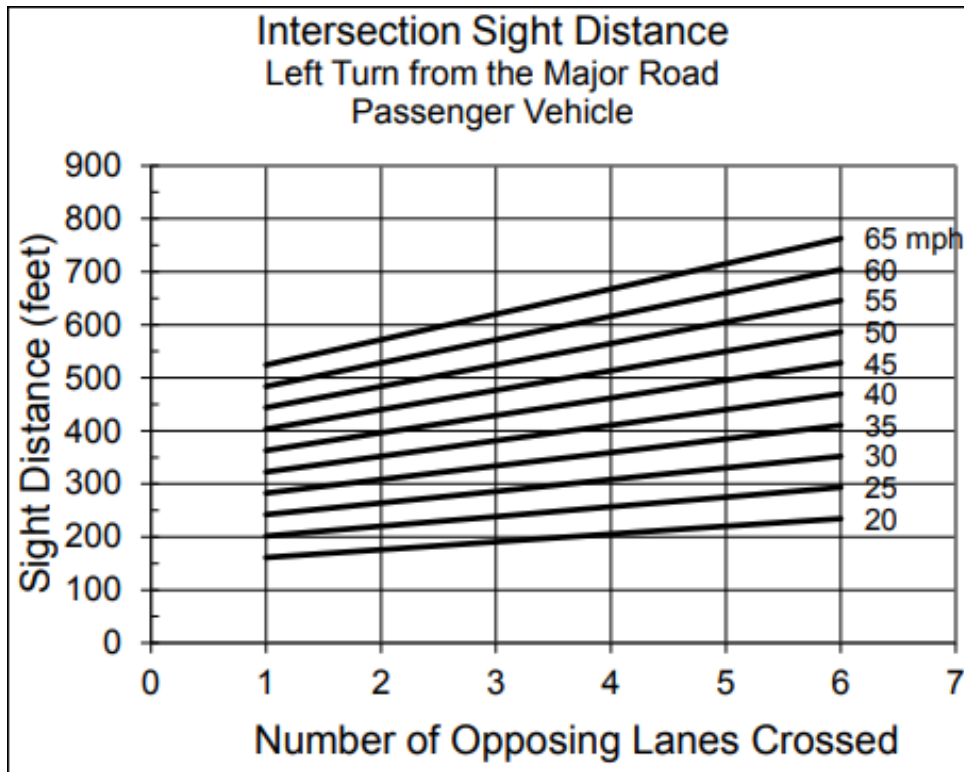


Figure 3.17. FDOT Green book ISD for left-turn passenger cars crossing opposing lanes.

The WisDOT Facilities Development Manual uses the Green Book policies for calculating intersection sight distances for Case F, left-turns from major roads, except an increase in the desirable time gap values to 8 seconds for all design vehicles. The WisDOT manual allows the Green Book time gap and sight distances as minimum values if necessary. The WisDOT manual references the FHWA report, FHWA-RD-01-051, Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians as the basis for increasing the desirable time gaps.

The Minnesota Department of Transportation (MnDOT) policy in the MnDOT Road Design Manual for providing sight distance at intersections is in Chapter 5-2.02. The MnDOT policy for intersection sight distance is as follows: “A vehicle operator approaching or entering an intersection needs adequate sight distance to safely conduct a turning maneuver. One research study concluded that of all intersection geometrics which may be related to accident experience, sight distance was most often the contributing factor. Providing sufficient sight distance deserves special attention, and the additional costs and impacts to remove sight obstructions generally are justified. An analysis of the intersection accident experience can also warrant the additional construction costs. Conversely it may be impractical or too costly to remove an obstruction even though inadequate sight distance and/or adverse accident history exists. The designer should then assess providing traffic controls, turn lanes, etc., that would not otherwise be warranted. This should be done in conjunction with the District Traffic and/or Right of Way Engineer as appropriate.”

In Chapter 5-2.02.02, MnDOT's policy is further described, "to provide sufficient sight distance (for the intersection characteristics) at each intersection in accordance with AASHTO's Green Book." Since the MnDOT Road Design Manual is dated June 2000, older AASHTO terminology was used for defining the different types of intersection movements and is outdated. It appears MnDOT refers to Case IV for describing left-turn movements from a major road across the opposing major road onto a minor road and the policy is to check this sight distance only at signal-controlled intersections. There is no mention of the term, "offset left-turn lane" in the MnDOT Road Design Manual.

3.2.6 Positive Offset Left-turn Lane Warrants

The North Dakota Guidelines for the Installation of Turn Lanes along state Highways, July 2014, recommends installing positive offset or zero offset left-turns at:

- intersections with left-turn crash trends,
- intersections with sight distance issues,
- unsignalized intersections where the mainline left-turn lanes each have a left-turn Passenger Car Equivalent (1) of 300 or more,
- signalized intersections with permissive-only or protected-permissive left-turn phasing.

(1) PCE Turning Volume = AADT Turning Volume * Tadj

$$Tadj = 1 + PT*(ET - 1)$$

where Tadj = truck adjustment factor. PT = the percentage of trucks (expressed as a decimal).

ET = passenger car equivalent for trucks based on TRB's Highway Capacity Manual (page 14-15 2010 Ed.). for level terrain (grade ≤ 2%) it is 1.5 and for rolling terrain (grade ≥ 2%) it is 2.5.

The Iowa DOT Design Manual recommends "the use of offset (tapered) left turn lanes on four lane expressways should be limited on rural intersections. They should be considered only if traffic signals will likely be installed or opposing left turning vehicles create a significant sight distance problem."

The North Carolina Roadway Design Manual requires positive offset left-turn lanes on median divided facilities where the median width is greater than 20 feet, and at all proposed signalized intersections with exclusive movements due to inadequate horizontal and vertical alignment and there is adequate cross section width available. Positive offset left-turns are required at unsignalized intersections with median widths greater than 20 feet if 10-year traffic projections satisfy any signal warrant or the major route left-turns meet or exceed 60 vehicles per hour. A more general warrant allows a design engineer to provide positive offset left-turn lanes at locations where the lanes will provide safer or more efficient traffic operations.

One state, Washington State, believes left-turning traffic at signalized intersections can operate more efficiently when the opposing left-turn lanes are directly opposite each other. The rationale offered in

their design manual is “when a left turn lane is offset into the path of an opposing through lane, the left turning driver may assume the opposing vehicles are also in a left turn lane and fail to yield.”

3.2.7 Safety Benefits

The Nevada Strategic Highway Safety Plan (HSP) summary includes a crash reduction strategy by offsetting left-turn lanes. The HSP paper recommends the strategy for use at “signalized intersections with permissive left turn and unsignalized intersections with high volumes of left turns and/or high speed.” No numeric values are suggested on what constitutes high volumes of left-turns or high speeds. The paper also reports on a two-star crash modification factor (CMF) of 0.50 from the Crash Modification Clearinghouse for installing positive offset left-turn lanes. The paper notes CMF’s with fewer than four stars are generally not used in crash reduction evaluation studies, but suggests positive offset left-turn lanes should be considered where space is available.

3.2.8 Signalized versus Unsignalized Intersections

The Indiana Design Manual provides typical drawings for signalized rural and urban intersections for installing slotted left-turn lanes. The tapered and parallel left-turn lane drawings both provide a six-foot wide positive offset. Improved visibility with opposing traffic, decreased possibility of conflict with opposing left-turning vehicles, and increase in left-turn capacity are given as advantages for the slotted left-turn lanes. However, there is no guidance or discussion about unsignalized intersections.

The Michigan Intersection Guide provides a discussion on ways to reduce conflicts at signalized intersections with permissive, protected, and permissive/protected; and lead versus lag signal phasing. In order to further reduce frequency and severity of signalized intersection conflicts, geometric enhancements are discussed, including providing positive offsets for left-turn lanes. Reducing view obstructions caused by opposing left-turn vehicles can improve gap acceptance, “especially for older drivers who have difficulty judging gaps between oncoming vehicles.” “The effectiveness of this strategy is greatest where permissive and permissive/protected signal phasing” are used. While offset left-turn lanes have been used more extensively at signalized intersections, they are suitable for use at unsignalized intersections to improve sight distance. However, no further discussion or guidance for unsignalized intersections is provided.

When traffic signals are intended for an intersection, the Washington state DOT Design manual recommends “left turning traffic can operate more efficiently when the opposing left turn lanes are directly opposite each other. When a left turn lane is offset into the path of an opposing through lane, the left turning motorist may assume the opposing vehicles are also in a left turn lane and fail to yield.”

However, Washington State does offset left-turn lanes in some situations. An important desirable design element is that signalized intersection turning movement designs are large enough to accommodate opposing left-turning vehicle paths with a 4-foot minimum (12- foot desirable) separation between them to allow opposing left-turns to operate concurrently. Where this separation cannot be achieved, less efficient signal phasing may be required to accommodate opposing left-turns. In smaller sized

intersections to operate concurrent phase signaling for opposing left-turn lane, offsetting a left-turn lane may be necessary to provide sufficient turning vehicle separation. The shifting (offsetting) of the left-turn lane is achieved by reducing (or eliminating) the median width. The problem of vehicle path intrusion and solution by using an offset lane is illustrated by their Manual Exhibit 1330-5, shown as Figure 3.18.

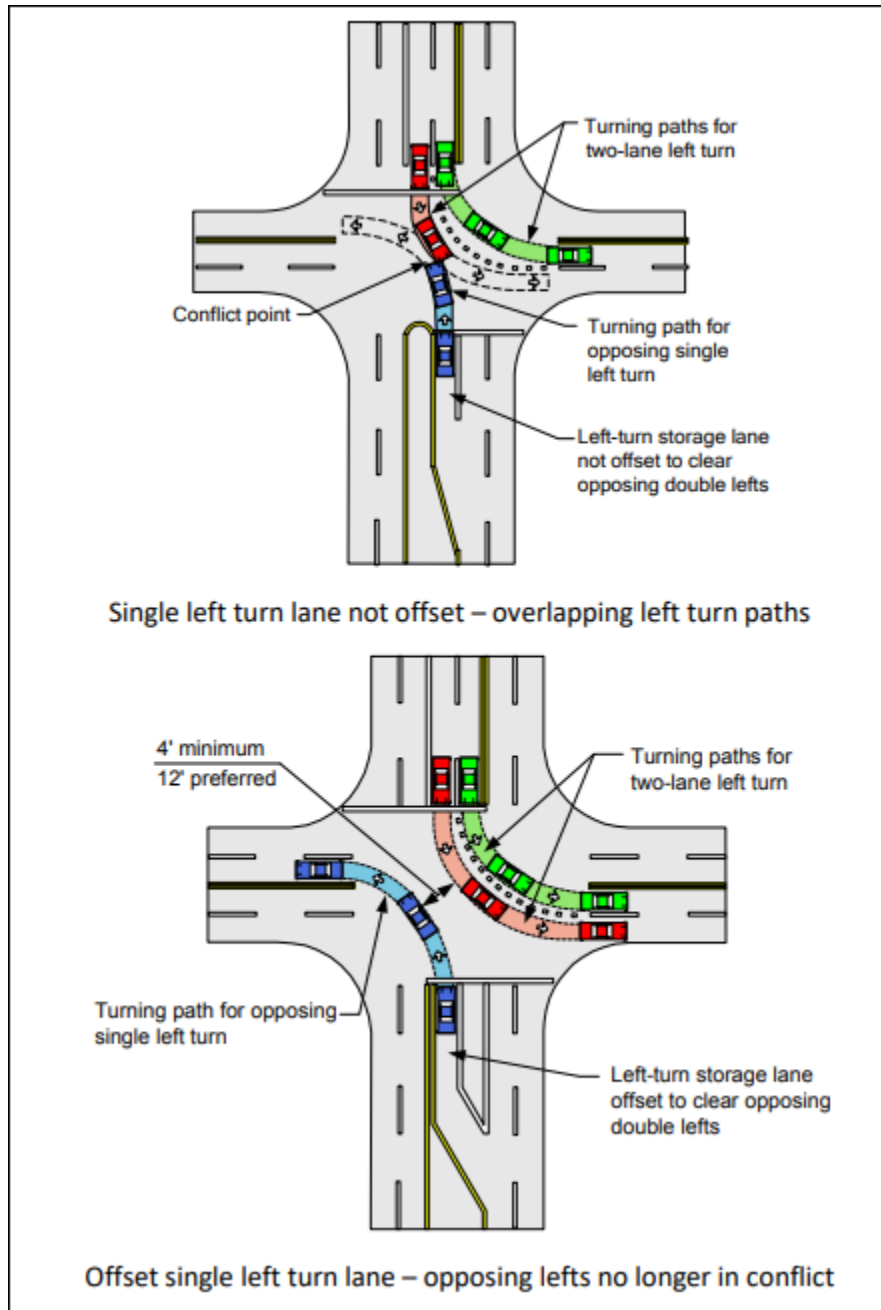


Figure 3.18. Washington State signaled left-turn lane configuration examples.

The Washington state Design Manual guidance for determining whether to use permitted, protected, or protected/permitted left-turn phasing does include sight distance beyond the intersection as one of the

decision factors on selecting the type of phasing to use. The Manual recommends using the sight distances arrived in the AASHTO Green Book. However, the Manual does not include any discussion on the concept of increasing the left-turn offset distance to increase the sight distance.

3.2.9 Protected versus Protected/Permitted Left-turn Treatment

The 2013 Florida DOT Intersection Design Guide is for new construction and major reconstruction projects of at-grade intersections on the Florida state Highway System. The Guide provides guidance on signalized intersections providing protected only turn lanes versus protected/permitted left-turn treatment. When one or more of the following conditions are going to be present, protected only signal operation for left-turn movements is required: two or more left-turn only lanes are provided; geometric conditions and resulting sight distance necessitate protected only mode; the approach is the lead portion of a lead/lag intersection phasing sequence; the use of offset left-turn lanes to a degree that the cone of vision requirements in Section 4D.13 of the MUTCD for the shared signal display cannot be met; and the outside tracking paths of opposing left-turning vehicles overlap. In addition, a general guideline is protected only phasing may be preferred when: the posted speed is greater than 45 mph; the left-turns must cross three or more lanes of through traffic; there are more than six left-turn crashes per year on an approach; or the intersection geometric configuration is unusual or complex.

The Intersection Design Guide addresses the importance of considering pedestrian and bicycle when evaluating whether to use protected versus protected/permitted or permitted signal operation. During permitted operation periods conflicts with left-turning vehicles may develop. “Bicycles are especially vulnerable to these conflicts because of their higher speeds and the greater challenge to the reaction times of motorists who are expected to yield to them.”

3.2.10 Pavement Marking/Striping

Nebraska Roadway Design Manual recommends installing wide pavement marking striping on the right side of the left-turn lane to encourage traffic to move closer to the median.

The Michigan Intersection Guide suggests laterally shifting left-turn vehicles can be accomplished by narrowing the left-turn lane widths using pavement markings at signalized intersections. This movement can be accomplished by painting a wide pavement marking stripe at the right side of the left-turn lane, with lines ranging from 6 inches to 3 feet wide. The guidance suggests “the wider the left turn lane stripe used to offset vehicles, the greater the effect on improving sight distance.”

3.2.11 U-Turn Guidance

The North Carolina (NC) Roadway Design Manual provides guidance and typical drawings for accommodating U-turns at Tee intersections and conventional 4 legged intersections. Typical drawings are provided for divided roadways with medians of 20 feet, 30 feet, 36 feet and 46 feet. A U-turn bulb out is shown on the side without an approaching side road and a radius widening on the side with an approaching side road. A note is shown indicating the U-turn should be designed for passenger vehicles

unless project information dictates otherwise. The typical drawings for the 30-foot wide median is shown as Figure 3.19 and the design detail turn lane and median layout dimensions are shown as Figure 3.20.

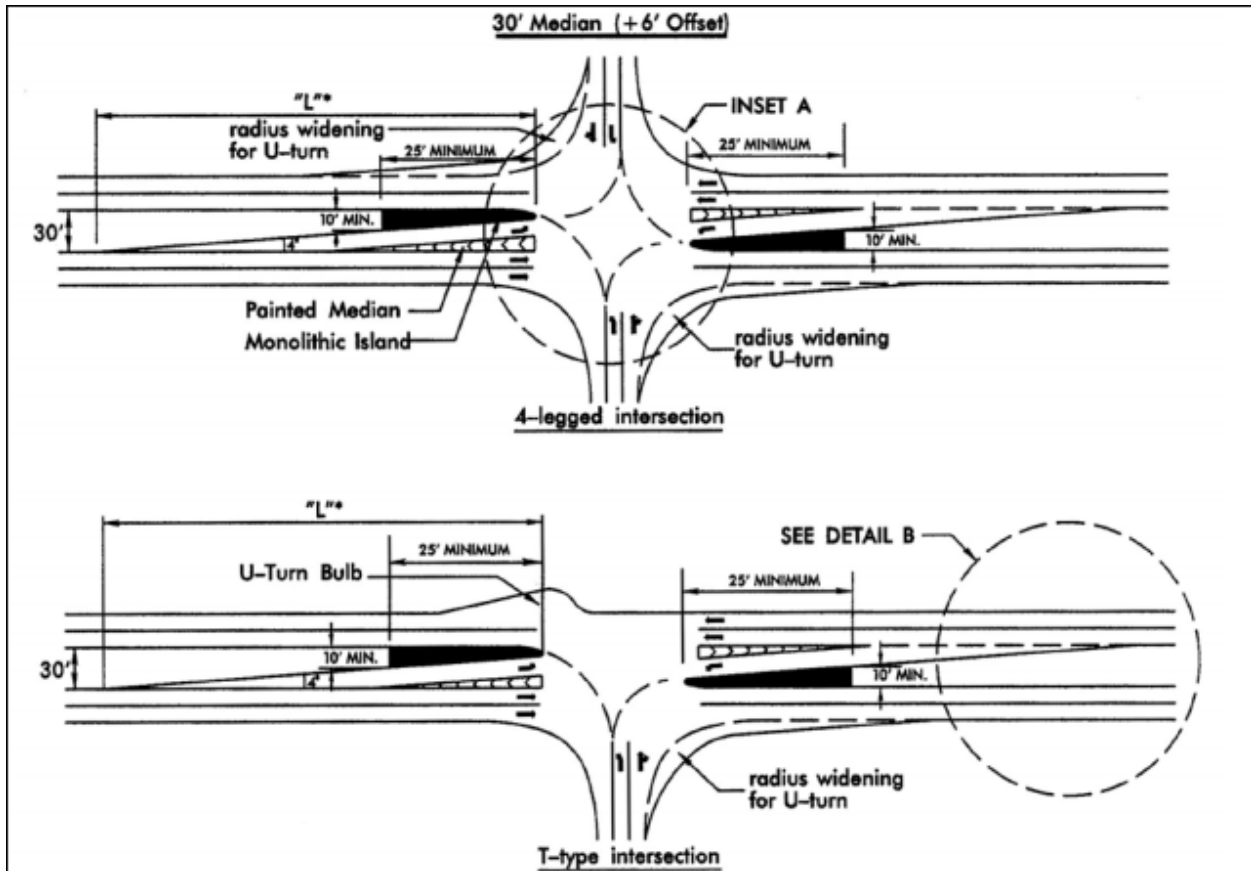


Figure 3.19. NC DOT Roadway Design Manual typical drawing showing guidance for accommodating U-Turns at offset left-turn lanes on divided roadways.

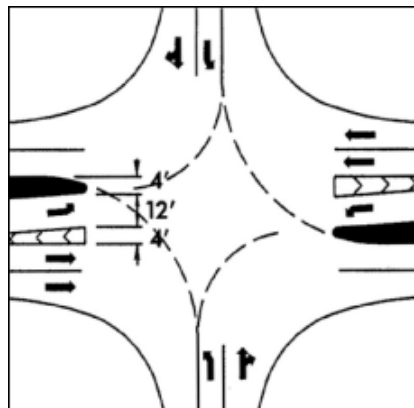


Figure 3.20. NC DOT Design Details for turn lane and median layout dimensions.

The FDOT Median Handbook provides guidance on sight distances for U-turns. The sight distances for unsignalized median openings are provided in a table, and is shown as Figure 3.21 and an illustration sketch drawing showing the sight distance for a U-turn on a 45 mph divided highway is shown in Figure 3.22.

<i>Speed (mph)</i>	<i>Sight Distance (ft)</i>
35	520
40	640
45	830
50	1,040
55	1,250
60	1,540

Figure 3.21. FDOT Median Handbook sight distances for U-turns at unsignalized median openings.

The sight distances in Figure 3.21 are for passenger vehicles and are calculated based on 2 seconds of reaction time, an acceleration from zero miles per hour from the end of the turn lane, and the AASHTO Green Book speed, distance, and acceleration figures are used, as well as a 50 feet clearance factor.

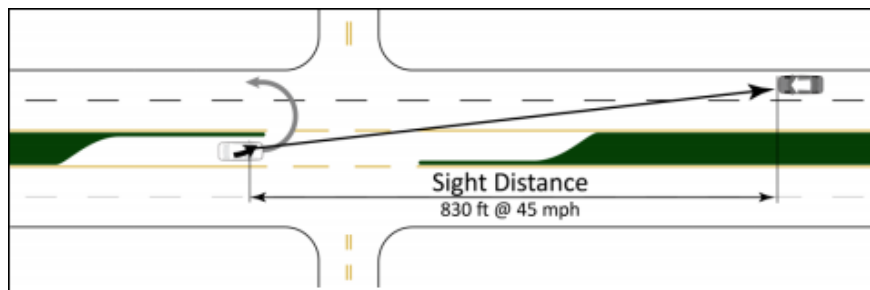


Figure 3.22. FDOT Median Handbook illustration sketch of the sight distance needed for making a U-turn at an unsignalized median opening.

3.2.12 Offset Left-turn Lanes Effects on Pedestrian and Bicycle Safety

While not specifically mentioning left-turn lane geometry, the Washington state DOT Design Manual addresses pedestrian and bicycle safety at intersections with an interesting discussion about accommodating versus designing for vehicles. “Accommodating for a vehicle allows encroachment of other lanes, shoulders, or other elements to complete the required maneuver. Designing for a vehicle does not require encroachment on those elements.” In order to better accommodate pedestrians, design treatments are suggested such as reducing intersection areas and accommodating for large vehicles instead of designing for them, where appropriate. The manual does not provide any guidance on how to decide ‘where appropriate’ means. These treatments are intended to reduce pedestrian crossing distances.

The Washington state manual also provides a brief mention of pedestrian consideration at intersections permitting turning movements and suggests considering a roundabout or responsive signal in an urban downtown area.

The 2013 Florida DOT Intersection Design Guide discusses pedestrian and bicycle safety at signalized intersections, but only in terms of deciding whether to use protected versus permitted signal operation. There is no guidance or discussion about pedestrian or bicycle safety regarding offset turn lane geometry.

3.2.13 Offset Left-turn Lanes Effects on Winter Maintenance Operations

No state design manuals or guides were identified that discussed or provided guidance regarding the effect offset left-turn lanes have on winter maintenance operations, including snow storage or snow plowing.

3.3 SUMMARY

Based on a review of the largest states' road design manuals and intersection design guides, only Florida DOT provides the most comprehensive policies and guidance on design standards and guidance for assuring unobstructed sight lines at left-turn lanes. However, the Florida DOT material is in several different manuals and guidance resource documents. Several states, including North Dakota, South Dakota, Iowa, North Carolina, Michigan, Florida, Nebraska, do have policies and/or guidance promoting the use of positive offsets at left-turns, at least under certain conditions. One state, Washington state, believes left-turning traffic at signalized intersections can operate more efficiently when the opposing left-turn lanes are directly opposite each other.

The majority of states provide only a limited discussion on this topic and if guidance is offered it is typically only on one or two aspects of left-turn lane design, such as briefly mentioning safety consideration if sight lines are restricted from opposing left-turn lanes, optimum median widths, protected versus protected/permitted traffic signal phasing, and optimum sight distance and gap acceptance. Several states provide useful guidance to their designers for defining and illustrating positive and negative offsets at left-turn lanes, most notably South Dakota, Wisconsin, and Florida.

There was minimal guidance or discussion offered by states regarding pedestrian and bicycle safety at intersections with left-turn lanes, and no guidance on this topic related to left-turn lane offsets. There was no guidance found relating to winter maintenance on left-turn lanes.

The most relevant section in the 2018 AASHTO Green Book regarding offset left-turn lanes is in Chapter 9, Sections 5.1 and 5.3, which deal with left-turn lane sight distance and gap acceptance for left-turn lane vehicles crossing oncoming traffic, referred to as a Case F intersection condition. AASHTO provides guidance on how to calculate the desirable safe sight distance for left-turns. In addition, AASHTO provides charts for recommended time gaps for design vehicles and calculated sight distance for passenger cars at different design speeds.

CHAPTER 4: RECOMMENDATIONS

Recommendations developed in this project center on general policies and guidance for designing offset left-turn lanes for a new edition of the MnDOT Road Design Manual (Minnesota DOT, 2019). The primary goal is for designers to have a better understanding of the concern and need for providing optimum sight lines at left-turn lanes on mainline highways. Recommendations are organized to provide recommended standards, policies, and guidance for new and reconstruction projects and for preservation projects. Besides the changes to the MnDOT RDM, other recommendations are included for changes to the MnDOT Traffic Engineering Manual (Minnesota DOT, 2017) and the MnDOT Traffic Control Signal Design Manual (Minnesota DoT, 2014b). These suggested recommendations are offered in order to improve consistency among all MnDOT manuals and guides used for intersection design and operations of left-turn lanes on mainline streets and highways. *Material italicized in this chapter serves as background information and commentary to assist in discussion and explanation on the topic of current and future intersection design policies and guidance in Minnesota.*

4.1 MINNESOTA DOT ROAD DESIGN MANUAL (MNDDOT RDM) INTERSECTION DESIGN

A common Minnesota design treatment for divided median highways and streets provides for opposing left-turn lanes directly across from each other, or sometimes offset even further to the right of each other. This type of design can create a situation where the opposing left-turn can fully block a left-turning motorist from seeing around an opposing left-turn vehicle when stopped at the median nose.

The MnDOT RDM currently does not discuss the concept of sight distance for left-turning vehicles or vehicle offset. The MnDOT Traffic Control Signal Design Manual currently contains a short explanation on positive and negative left-turn offset and the importance sight distance plays in making safe left-turns.

This study provides discussion, exhibits and definitions of offset left-turn lanes which could be added to the MnDOT manuals to provide greater clarity for discussion and consideration of improving sight lines. The exhibits proposed by the University of Wisconsin-Madison Traffic Operations and Safety Laboratory (UW-TOPS Lab) for showing left-turn offsets are based on examples and concepts used in the MnDOT Traffic Control Signal Design Manual (Minnesota DoT, 2014b), the South Dakota Road Design Manual, and the Wisconsin Facilities Development Manual (WisDOT FDM). Discussion and figures for definitions on how to measure left-turn sight distance, the three offset terms, and the impact of location of left-turning vehicle on determining available sight distance are included. The definitions and influence the type of improvement project has on left-turn lane design process are also provided.

4.1.1 Lateral Offset Left-turn Introduction

At unsignalized intersections and at signalized intersections with permissive left-turn phases, left-turning vehicles in the opposing lane may block the view of a left-turning motorist. Blocked sight line can increase crash risk since motorists may not see vehicles approaching in the opposing through lanes and

misjudge the available gap. If motorists decide not to proceed because of the obstructed sight line, delays for left-turning vehicles will increase and intersection capacity will decrease. Early and more recent study results showed that at left-turn lanes, of both signalized and unsignalized intersections, obstructed sight lines caused higher possibilities of collisions between left-turning vehicles and oncoming vehicles from the opposing direction. Evaluations of the effects of left-turn lane offsets, with data from multiple states in the United States, reported that positive left-turn lane offsets were more effective in reducing intersection left-turn crashes than zero and negative left-turn offsets. In terms of effects on intersection traffic operations, providing positive left-turn offset helps reduce the sight line obstruction situations, and leads to higher capacities of left-turn movements. Therefore, to achieve the best opportunity for obtaining adequate sight distance when vehicles are in opposing turn lanes, the use of offset left-turn lanes can usually help achieve this goal.

4.1.1.1 Discussion and definitions for measuring sight distance for left-turns at intersections and medians

Left-turning motorists must use their driving experience and skills to judge oncoming traffic speed and distance between gaps of oncoming traffic. Motorists use this information to make a decision on whether there is a sufficient gap between oncoming traffic adequate to safely complete the turning maneuver. Available sight distance (illustrated in Figure 4.1) in a left-turn lane impacts the ability of motorists to identify acceptable gaps in opposing through traffic lanes in order to complete the turning maneuver safely. In addition, providing adequate sight distance will enhance the efficiency of the intersection allowing greater capacity.

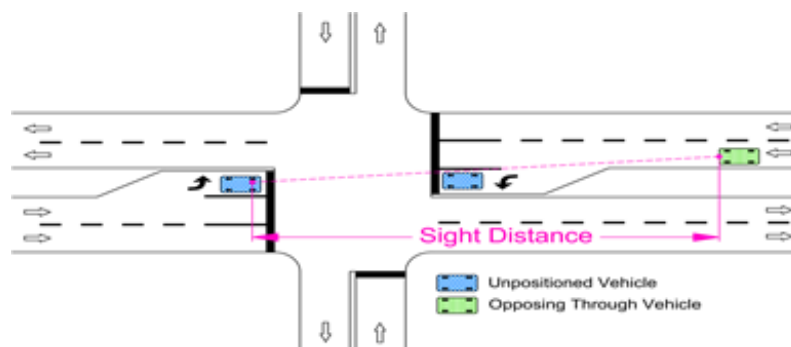


Figure 4.1 Available sight distance for left-turning vehicle

4.1.1.2 Discussion and definitions for left-turn lateral offsets

A significant factor in determining sight distance at left-turn lanes is offset distance. Left-turn lateral offset distance is defined as the distance between the left edge of the turn lane and the right edge of the opposing turn lane. If opposing left-turn lanes are aligned directly across from each other, this is termed as no offset. When lanes are offset from one another and block the view of at least a portion of the opposing oncoming traffic, this is considered a negative offset. Positive offset allows motorists a better view and more time to observe oncoming vehicles in the approaching through lanes. Definitions for different types of offsets are illustrated in Figure 4.2.

Other important factors impacting available left-turn sight distance include type of vehicle and horizontal/vertical geometry. A truck in the opposing left-turn lane can make it more difficult to view past than if the opposing vehicle were a passenger vehicle. Horizontal and vertical geometrics of the intersection heavily influence the available sight distance. Modeling the geometry of the approach intersection is commonly used to determine the sight distance if significant sight distance issues are anticipated.

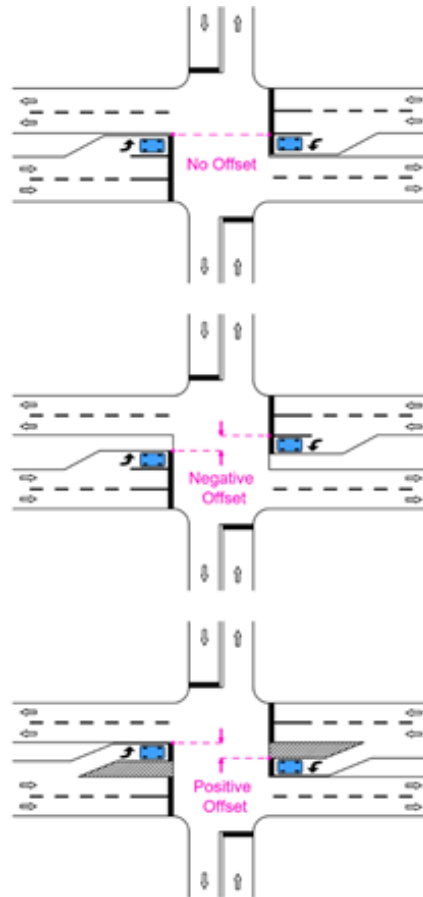


Figure 4.2 Left-turn Lane Offset definitions

4.1.1.3 Locations of left-turning vehicles before completing turning maneuver

Another important concept in discussing and measuring sight distance for left-turning vehicles is the left-turn vehicle placement at or in the intersection. After initially stopping their vehicle at the stop bar in the left-turn lane, many experienced motorists move their vehicle forward into the intersection to view around a stopped vehicle in the opposing left-turn lane to view further in advance for opposing mainline traffic. This motorist maneuver is defined as positioning their vehicle in the intersection. Un-positioned left-turning vehicle is defined as a vehicle that remains behind the stop line until an acceptable gap is observed by the motorist to start and complete the entire turning maneuver in one movement. Past research (Tarawneh and McCoy, 1996) has reported as many as 40% of older motorists

are hesitant to advance into the intersection and remain un-positioned, i.e., stopped at the stop line in left-turn lanes, until an acceptable gap is identified. Therefore, in order to better accommodate older motorists, designing sight distance should be based on un-positioned vehicles for both left-turn lanes. Also, the left-turn design process should be based on the worst-case scenario which is a truck in the opposing left-turn lane. Figure 4.3 illustrates the concept of un-positioned and positioned left-turn vehicles and the influence the location has on available sight distance for each motorist.

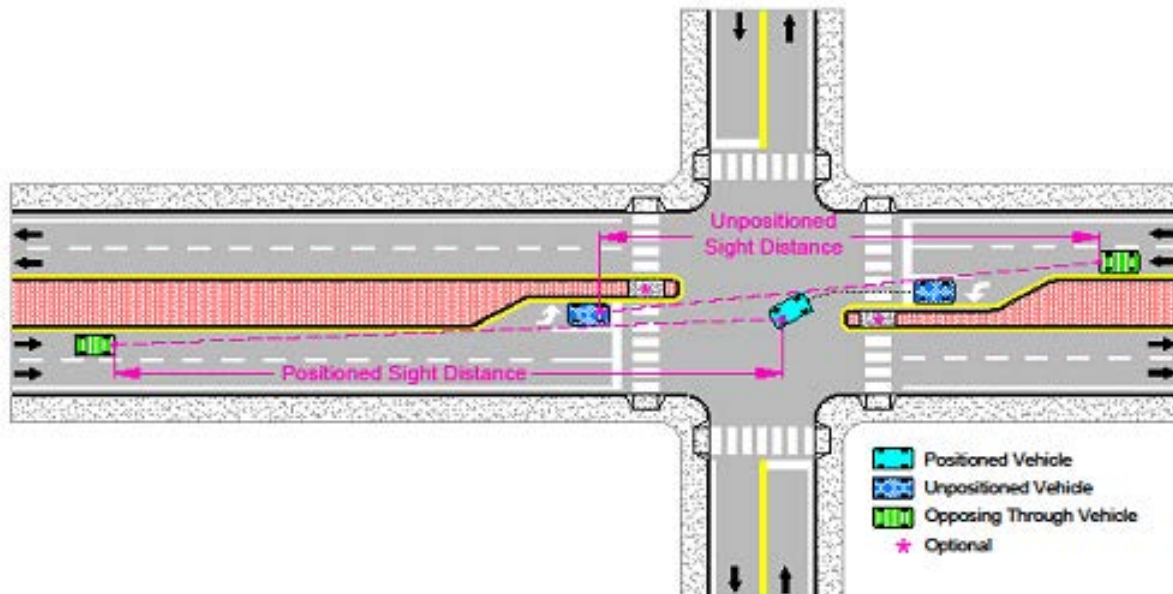


Figure 4.3 Sight distances for un-positioned and positioned vehicles making left-turn maneuver at negative offset turn lane intersection. Note: asterisk indicates the crosswalk cut through is an optional design.

Providing positive offset turning lanes can greatly enhance the ability for all motorists to see further up the opposing oncoming traffic lanes, whether un-positioned or positioned, as demonstrated in Figure 4. Figure 4.4 does illustrate the need to assure opposing left-turn lanes are designed with sufficient length to prevent spill back into through lanes. Not only can spill back potentially result in rear end crashes on the approach to the turn lane, but potentially cause a sight distance issue for the opposing left-turning motorist.

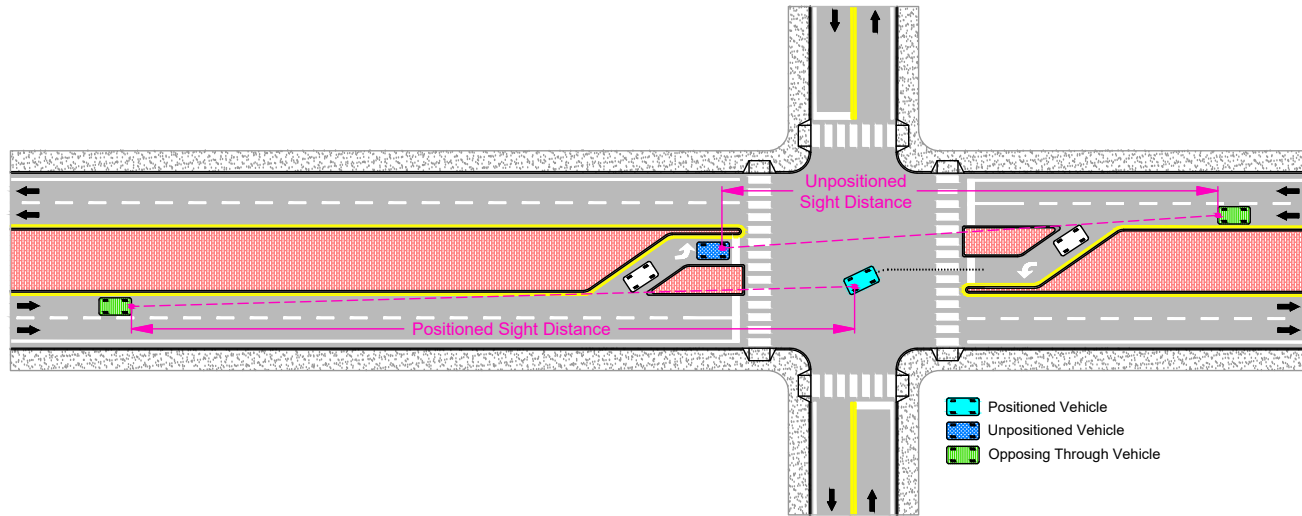


Figure 4.4 Sight distances for un-positioned and positioned vehicles making left-turn maneuver at positive offset turn lane intersection.

4.1.1.4 Discussion and definitions on types of improvement projects

Level or amount of improvement that is being designed into a project will influence the left-turn design process. The two basic MnDOT RDM improvement project levels are new construction/reconstruction and preservation projects.

New construction/reconstruction is an investment category that includes the most extensive types of work, typically cost the greatest amount of dollars per mile. This investment category includes projects that will result in a new roadway on new alignment, or reconstruction with replacement on existing alignment. These types of projects provide the highest degree of safety and traffic-carrying capability for each functional classification. The design of new construction or reconstruction projects should meet all current design standards as identified in MnDOT RDM Section 2-6.0.

Preservation is an investment category to extend the life of a highway, bridge, or other transportation facility. Preservation projects are intended to safely manage and operate existing systems efficiently while effectively addressing critical safety and operations needs through minor and moderate cost improvements to the existing facility. Preservation projects generally use the majority of the existing pavement but may entail minor widening or geometric improvements, and normally require little or no additional right of way. These projects should either retain the existing design features of the roadway or meet new construction/ reconstruction standards, whichever is less costly. Safety should also be considered in the design of all preservation projects, including cost-effective intersection improvements where warranted.

Regardless of project improvement type, the use of flashing yellow arrows as a permissive left-turn indication should be included in all project designs where left-turn lanes are present and permissive traffic signal operation is anticipated for even a portion of the day.

The left-turn lane offset design process is influenced by whether the project is preservation or new construction/reconstruction. On preservation projects with existing inadequate or less than desirable sight distance, crash history and level of investment involving left-turn vehicles will strongly influence the need to improve sight distance. Additionally, available sight distance will also determine what mode of signalization will be appropriate.

4.1.2 Lateral Offset Left-turn New Construction and Reconstruction projects

4.1.2.1 Design decision factors for lateral offset and sight distance

Lateral offset distances at median left-turn lanes are an important early intersection design consideration on new construction and reconstruction projects. With intersections that will require signalization based on turning and through traffic volumes, available sight distance for the left-turn movements often influences whether permissive, protected/permissive, or protected only signalization is an appropriate mode of operation for each signal cycle. As a rule of thumb, the more cycles during the day that intersections may operate with a permissive left-turn operation, the greater the overall intersection efficiency. It is common to operate intersections for at least a portion of the day or portion of a signal cycle in permissive mode to reduce unnecessary stops and delay during off peak travel periods. However, this mode of operation requires adequate sight distance for motorists to identify acceptable gaps in approaching through traffic. Besides sight distance, other factors for determining available time gaps for left-turning lanes are vehicle speed on the approaching through movements, number of opposing through lanes, and type of vehicles, i.e., large trucks or only passenger vehicles in the opposing left-turning lane.

Intersections not requiring signalization, or not requiring signalization for the foreseeable future, should also have sufficient sight distance for left-turning motorists to judge and identify appropriate traffic gaps in order to safely cross or make U-turns.

If desirable sight distances can't be provided due to factors such as insufficient right-of-way, cost or geometry, protected left-turn operations may be required during more periods or at all times of the day. However, providing as much positive offset as possible is still beneficial to improve intersection efficiencies, safely accommodate left-turn sneakers, and may allow permissive operations during off-peak time periods when there is no or little approaching through traffic, or during periods when there is significant split in directional volumes.

The MnDOT Traffic Control Signal Design Manual (Minnesota DOT, 2014b) has identified the following intersection design conditions, to operate signalized intersections in protected only mode of operation for all times of the day.

1. When railroad preemption is used and the movement is opposite the track clearance movement or turns across the tracks unless other measures are implemented to address this conflict.
2. Intersection geometrics will create a conflicting left-turn path with opposing left-turn movements.

MnDOT Traffic Control Signal Design Manual (Minnesota DOT, 2014b) has also identified additional conditions in the following paragraph for recommending protected only operation. These conditions warrant consideration on new construction and reconstruction projects to determine if protected only mode is not required.

If any of the following conditions exist, an engineering study is necessary to determine if permissive signal operation will be precluded at all times or just during certain times when high traffic volumes are present.

1. The left-turn motorist will face three or more opposing through lanes.
2. Dual left-turn lanes are required for mainline left-turn movement volumes.

The engineering study should include the planned mainline speed limit and opposing through lane hourly volumes and left-turning hourly volumes. If permissive signal operation will be precluded from use at any time period during the day, left-turn sight distance is not a critical design factor. Therefore, lateral positive offset distances may be reduced or eliminated. However, the ability to improve sight lines could allow reconsideration of allowing permissive movements for some time periods as applicable based on review.

4.1.2.2 Left-turn lane lateral offset dimensions for unobstructed sight distance

Discussion: Past research and application standards have developed several guidelines with different desirable positive offset distances. The lateral offset table shown below was developed based on research by Tarawneh and McCoy (1997), which is also the basis of values developed by Texas Transportation Institute in their Urban Intersection Design Guide (Fitzpatrick et al., 2005) for Texas DOT. It is recommended the positive offset values in the table shown below should be rounded to the nearest half foot to simplify field implementation, which is six feet, from the exact values developed by the researchers.

The researchers concluded that lesser values of positive offsets may accommodate sufficient sight distance, especially if the opposing left-turn traffic is not a large vehicle, i.e. trucks and busses. Since large vehicles usually block the entire view for left-turning motorists who are waiting to turn left, if opposing left-turn traffic is comprised of mostly passenger vehicles, some visibility may be possible by viewing through or over opposing left-turn traffic. This possibility is not a good basis for basing new construction or reconstruction standards, and thus sight distance should be based on the assumption that visibility will always be completely blocked by opposing left-turn traffic.

Guidelines for Left-turn Lane Positive Offset distances

<i>All vehicle types allowed in opposing left-turn lane</i>	<i>Design Speed (miles per hour) of Approaching Mainline Traffic</i>							
	<i>Desirable Positive Lateral Offset (feet)</i>							
	<i>30</i>	<i>40</i>	<i>45</i>	<i>50</i>	<i>55</i>	<i>60</i>	<i>70</i>	<i>Desirable Offset</i>
	<i>4.9</i>	<i>4.9</i>	<i>4.9</i>	<i>5.2</i>	<i>5.2</i>	<i>5.2</i>	<i>5.2</i>	<i>5.6</i>

Source: Urban Intersection Design Guide [Fitzpatrick et al., 2005]

Because the differences in the table values are minimal for a wide range of design speeds, a single uniform desirable offset distance of six feet is recommended for ease in designing new construction and reconstruction projects.

In order to obtain optimum safety and signal operational efficiency, unobstructed sight distance is desired. A desirable lateral positive offset of six feet will normally provide optimum safety and signal operation efficiencies and allow the use of permissive traffic signal operations, if desired, where other intersection conditions permit.

A six feet offset value is based on research roadways with opposing left-turn lanes at 90-degree intersections on level, tangent sections of divided roadways with 12 feet wide lanes and left-turning vehicles waiting to turn are stopped at the stop bar, i.e. un-positioned in the intersection.

The offset distance should provide adequate sight distances for all motorists, including inexperienced and older motorists who commonly remain at the stop bar until an acceptable gap is available. Designs with the desirable offset distance will allow the ability to use permissive traffic signal operation to the maximum extent possible during the day. Desirable offset values will also allow unrestricted sight distance for opposing motorists, regardless of position location, and therefore are independent of design speed of approaching mainline traffic and provide optimum left-turn lane safety and efficiency.

While positive lateral offset values are desirable on side road/street approaches, an engineering study should be conducted to determine if less than desirable positive offsets are sufficient. The engineering study should include cost and availability of right-of-way, and through and left-turning existing and projected volumes on the side road.

If sufficient right-of-way is not obtainable for environmental reasons, and/or right-of-way and construction costs are significant, less optimum offsets may be considered as a compromise (8). The following table may be used if justified by engineering study. The study should include the amount of trucks occupying the opposing turning lane. The table was developed with the assumption that opposing left-turn traffic includes a moderate to heavy volume of large trucks.

Recommended Minimum Positive Offset Distances for Left-turn Lanes

<i>All vehicle types allowed in opposing left-turn lane</i>	<i>Design Speed (miles per hour) of Approaching Mainline Traffic</i>						
	<i>Minimum Positive Lateral Offset (feet)</i>						
	<i>30</i>	<i>40</i>	<i>45</i>	<i>50</i>	<i>55</i>	<i>60</i>	<i>70</i>
	<i>3</i>	<i>3.5</i>	<i>4</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>5</i>

Source: Florida Design Manual [Florida DOT, 2017] Table 212.14.1

Lateral offset distance for each turning movement is the distance between the left edge of the turn lane and the right edge of the opposing turn lane. Figure 4.5 demonstrates that this distance is determined by subtracting the opposing channelization island width, shown as “d” distance, from the median island width, shown as “b” distance. In Figure 4.5, “a” distance is the total median width and “c” is the turning lane width.

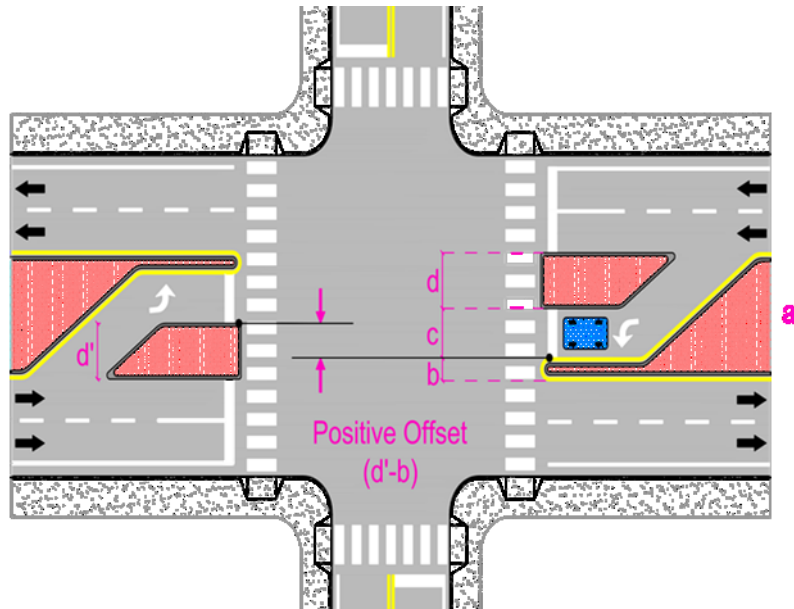


Figure 4.5 Schematic drawing illustrating positive offset distance and calculation to determine lateral offset dimension.

4.1.2.3 Urban multilane roadways and expressways

Discussion: Based on discussions with MnDOT, the use of parallel left-turn lane geometry at signalized urban intersections is preferred. Also, MnDOT prefers to design signalized intersections that permit single stage pedestrian crossings (i.e., pedestrians do not normally need to stop at a median island). A minimum median pedestrian storage width of 6 feet will always be recommended in the event a pedestrian does stop in the median requiring multiple stages to cross the street.

At urban signalized intersections with median left-turn lanes, the preferred geometry is for the lanes to be parallel to the through lanes at the left-turn lane stop bar. In addition to offsetting left-turning lanes as discussed in Section 2C, safely accommodating pedestrians also must be considered for urban multiple lane roadways and expressways.

At signalized intersections, the preferred traffic signal operation is for most pedestrians, if not for all pedestrians, to cross the entire roadway in a single signal interval without having to stop at an intermediate location. At some intersections, pedestrian median refuge islands are provided. Refuge areas should be 6 feet wide or more to be considered suitable as a pedestrian refuge. However, if the median width is reduced to less than 6 feet to move the left-turn lane closer to the opposite direction of travel, the storage location may be on a wide channelization island. An optional crosswalk design is to cut crosswalks through raised medians and channelization islands to improve crosswalk visibility for the benefit of pedestrians and motorists. On roadways with large pedestrian volumes, the refuge islands should be wider in the range of 8 to 10 feet. At unsignalized intersections, it is desirable for pedestrians to have an intermediate refuge location, preferably on medians. However, if the median is narrowed to

provide positive offset left-turn lanes, the refuge location may be located on a 6 feet wide or greater channelization island.

At unsignalized intersections, it is desirable for pedestrians to have an intermediate refuge location. Preferably the refuge is located on a median allowing the pedestrian to cross one direction of traffic at a time. However, if the median is narrowed to provide positive offset left-turn lanes, the refuge location may have to be located on a 6 feet wide or greater channelization island. This location will present a more complex crossing situation because the pedestrian will need to cross two directions of traffic without a refuge location during one of the crossing movements.

An example of parallel left-turn lanes with pedestrian crosswalk accommodation and an eighteen feet median is shown in Figure 4.6. If symmetrical left-turn lanes are provided on the mainline with an 18 feet wide median, a desirable positive offset of 6 feet for each left-turn can be achieved for both turn lanes, if the turn lane widths are 10 feet wide, the median is one foot wide and the left-turn channelization island is 7 feet wide. Typically, the pedestrian walk phase is set to allow the pedestrian to cross the entire roadway in one cycle. However, if the pedestrian selects not to cross the entire way across, pedestrian storage is accommodated on the channelization island and pedestrian push button pedestals should be considered to allow pedestrians to make a call request.

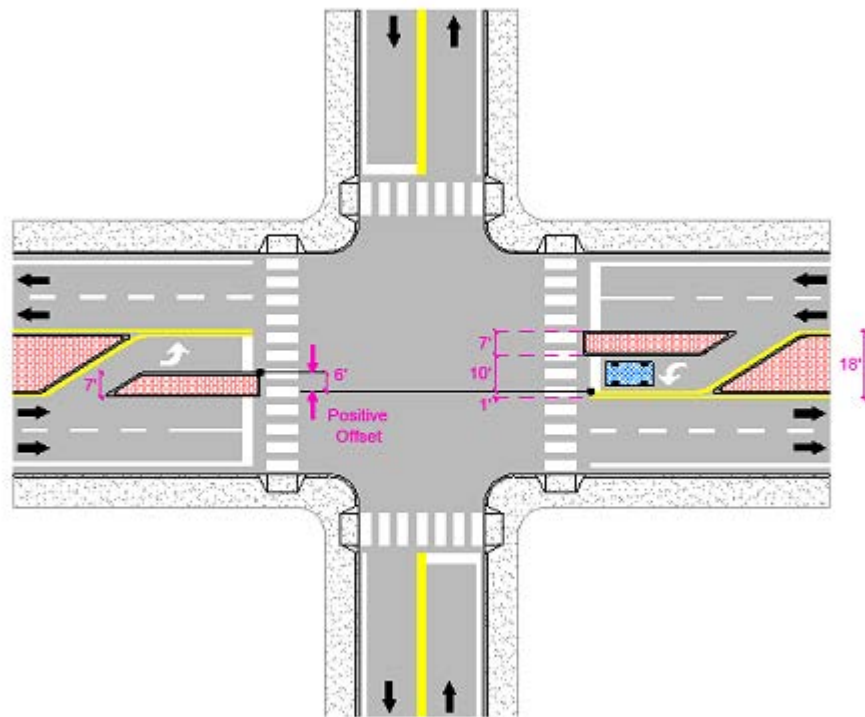


Figure 4.6 Eighteen feet wide median with six feet positive offset turn lanes.

On roadways with a 30-foot wide median, a positive offset of 6 feet for each left-turn can be developed, if the turn lane width is 12 feet wide, the median is 6 feet wide and the left-turn channelization island is 12 feet wide. Pedestrian storage can be accommodated in either the median or channelization island. However, anticipating the pedestrians desire to use the median as a midpoint stop, traffic signal push button pedestals are normally located at that location.

4.1.2.4 Rural multilane roadways and expressways

Left-turn lane design may use either parallel or tapered geometry. Use of tapered left-turn lanes may allow more speed reduction to occur in the turn lane without impeding through traffic since the lane separates from the through lane at a lesser angle, as shown in Figure 4.7. In rural areas, channelization islands may be created using curbs and edge line pavement markings to raise the island height to the height of the curb, or only using a crosshatching pattern on the pavement made with pavement marking materials.

There are maintenance advantages and disadvantages for using pavement markings to create left-turn channelization islands. An advantage is the ability for winter maintenance operations to clear snow more efficiently from the intersection pavement area without concern for curbed islands. Snow clearance operations are more difficult with curbed islands and snow pushed onto channelization islands could potentially block motorist's views, especially for minor movement roadway motorists. A disadvantage is snow on the pavement area will cover the lane assignment pavement markings until the snow is cleared by snow plowing operations.

Figure 4.8 shows a typical rural positive offset left-turn design with channelization islands created using crosshatched pavement markings. The use of cross hatching is optional in lieu of conventional curb and gutter. While Figure 4.8 does not illustrate the use of pedestrian cross walks the designer should consider the use of an urban intersection cross walk design, such as Figure 4.6. The designer should also consider providing a pedestrian safety storage area, either on the median or on the left-turn channelization island.

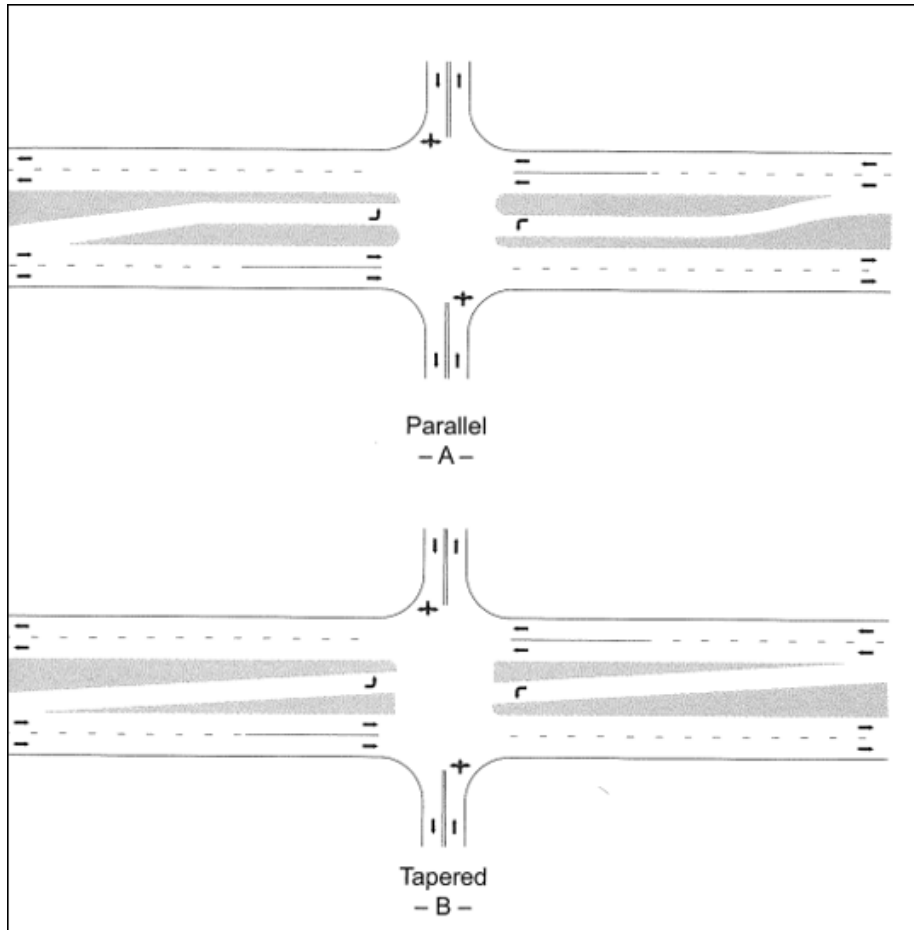


Figure 4.7 Parallel and tapered offset left-turn lane. [AASHTO, 2018]

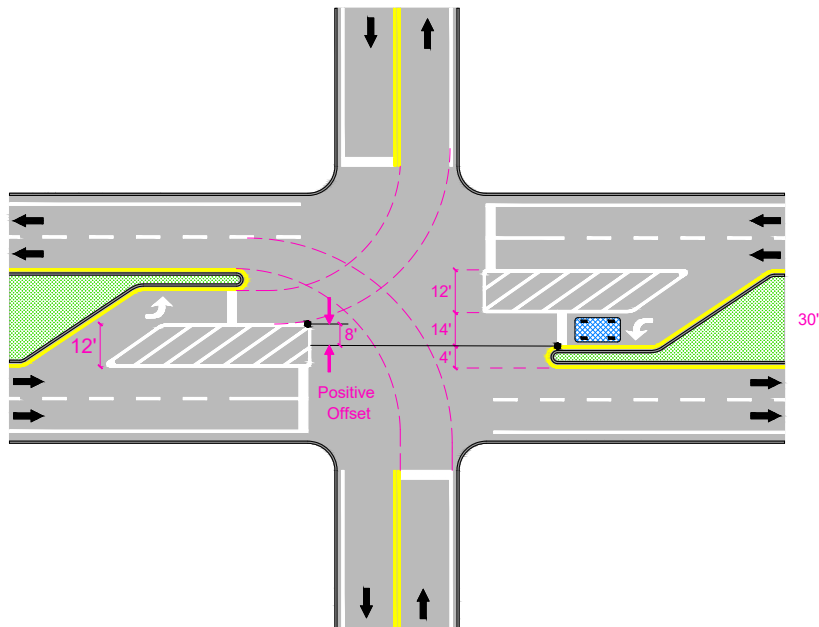


Figure 4.8 Example of rural four lane divided highway with 30 feet wide median and eight feet positive offset turning lanes and turning paths illustrated. The use of crosshatched channelization islands are illustrated.

In Figure 4.8, channelization islands are created with crosshatched pavement markings and also illustrates turning movement paths. Designs should always be checked to assure turning vehicles can turn into appropriate receiving roadway lane without interfering with median ends.

4.1.2.5 Accommodating U-turns at intersections and median openings

Multilane roadways with curbed medians prevent left-turns into driveways and other mid-block access points for each direction of travel. Therefore, U-turns at intersections or mid-block median openings are used as an access management feature to minimize travel inconvenience. AASHTO cautions about allowing U-turns from through lanes, which infers the desirability to consider installing auxiliary median left-turn /U-turn lanes for safer U-turn maneuvers. Two geometric design parameters needed at U-turn locations are adequate pavement area for turning vehicles to complete the U-turn in one uninterrupted movement and adequate sight distance along the approaching roadway for motorists to judge traffic gaps. Therefore, median left-turn lanes at locations where U-turns are desired need to be properly designed.

Depending on the number of lanes and lane widths on the receiving side, in order to accommodate the turning radius for U-turns, median widths typically need to be at least 18 feet for passenger vehicles. Figure 4.9 provides AASHTO's recommended minimum median widths for different types of vehicles. If 30 feet wide medians are designed, U-turn movements can usually be provided, including for trucks if special design treatments are applied. Special design treatments may include providing an extra lane or shoulder for a short distance created on the outside of the receiving roadway travel lane. Another design treatment at intersections is by widening the cross street right turn radius, as shown in Figure 4.10.

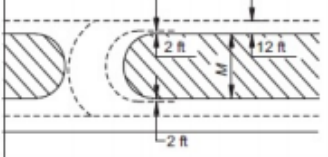
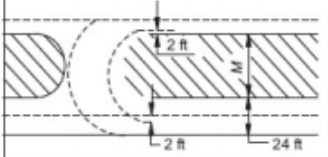
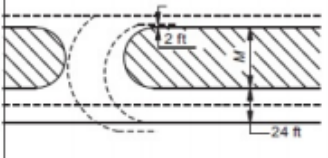
Type of Maneuver		U.S. Customary						
		M—Minimum Width of Median (m) for Design Vehicle						
		P	WB-40	SU-30	BUS	SU-40	WB-62	WB-67
		Length of Design Vehicle (ft)						
		19	50	30	40	40	63	68
Inner Lane to Inner Lane		30	61	63	63	76	69	69
Inner Lane to Outer Lane		18	49	51	51	64	57	57
Inner Lane to Shoulder		8	39	41	41	54	47	47

Figure 4.9 Minimum designs for U-Turns. [AASHTO, 2018]

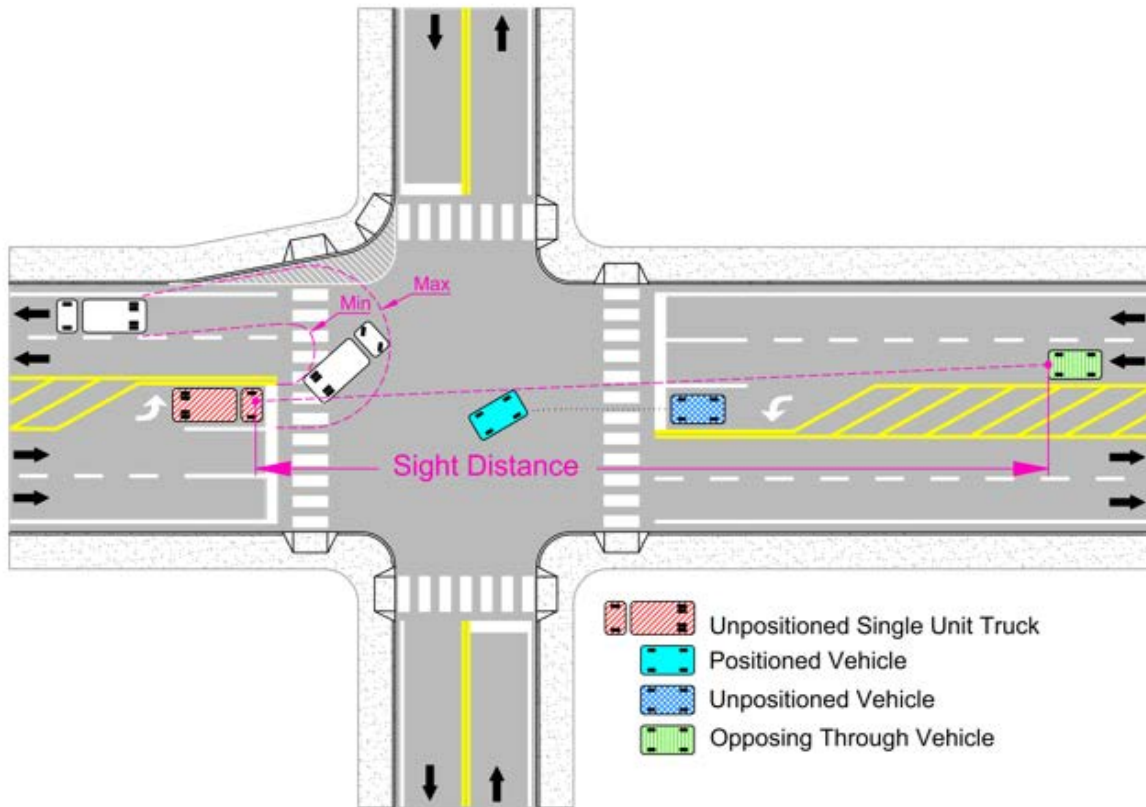


Figure 4.10 Accommodating U-turns at left-turn lanes on divided roadways can be accomplished by widening the cross street right turn radius. The drawing also shows the concept of measuring sight distance for U-turning vehicle.

At mid-block U-turn locations, a special design treatment to increase the pavement width required for turning movements to complete the U-turn maneuver is called a “loon”. The size of the loon should be designed by applying a turning vehicle template to accommodate the designated design vehicle and available median width. Signing to prohibit parking may be necessary to keep bump outs free of stopped or parked vehicles. Figure 4.11 shows the typical schematic drawing from the AASHTO Green Book. (6 pp. 9-140)

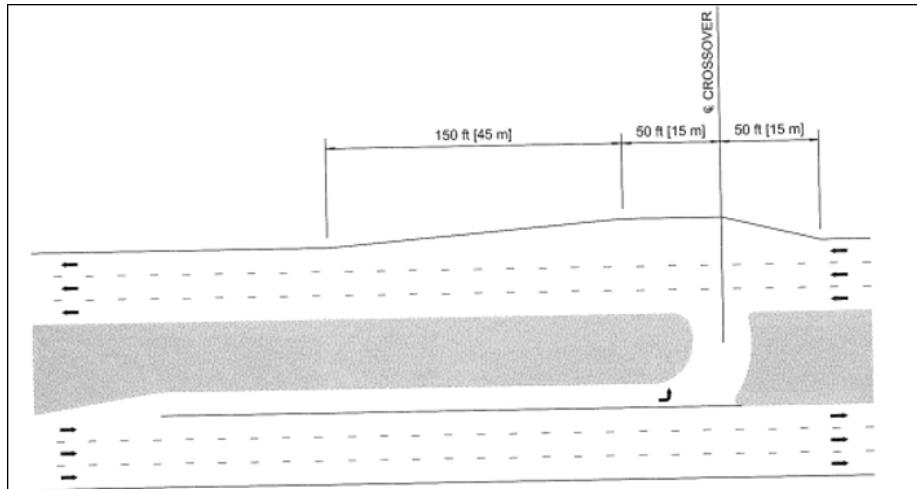


Figure 4.11 Typical loon design to facilitate U-turning traffic on arterials with restricted median widths. [AASHTO, 2018]

The second design feature for U-turn locations is assuring adequate sight distance is available for motorists to make the U-turn movement. Necessary sight distance along the mainline to safely accommodate U-turns is more involved than only calculating the distance traversed at the design speed on the mainline, either at an intersection or median opening. A sight distance chart for passenger vehicles has been developed by FDOT (2014) using the following assumptions, shown in Figure 4.12:

1. 2 seconds perception-reaction time,
2. additional time needed to perform the U-turn maneuver,
3. begin acceleration from 0 mph at the end of the U-turn movement,
4. speed/distance, and acceleration figures from AASHTO Green Book, and
5. 50 feet safety clearance.

Since trucks need more time to perform the U-turn movement and have slower acceleration, greater sight distance is desirable. Trucks can sometimes compensate for this longer distance since driver eye height is higher and may be able to see over the top of any opposing left-turning passenger vehicles.

<i>Speed (mph)</i>	<i>Sight Distance (ft)</i>
35	520
40	640
45	830
50	1,040
55	1,250
60	1,540

Figure 4.12 Optimum sight distance needed for U-turn at unsignalized median opening. [Florida DOT, 2014]

Measuring available sight distance for a vehicle desiring to make a U-turn is shown in Figure 4.10. A median opening for left-turns or U-turns within the physical length of a left-turn lane or lanes can create a conflict between a motorists stopping to turn at the opening and motorists continuing to the end of the turn lane. Such an opening is not recommended, particularly for higher volume turn movements.

4.1.2.6 Pavement markings and signing

The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2009) provides standards and guidance on placement of signs to direct motorists into their proper lanes for motorists making left-turns, and to keep motorist from entry into a left-turn lane used by opposing traffic. MUTCD regulatory signs Keep Right and Keep Left (R4-7 and R4-8) are the preferred signs on urban roadways without the need for One Way (R6-1, R6-2) signs, if medians are no wider than 30 feet and can be placed for optimum viewing by motorists making a left-turn onto to the mainline from the cross street. The preferred placement of Keep Right signs is shown in Figure 4.13, which is near the end of the raised median nose.

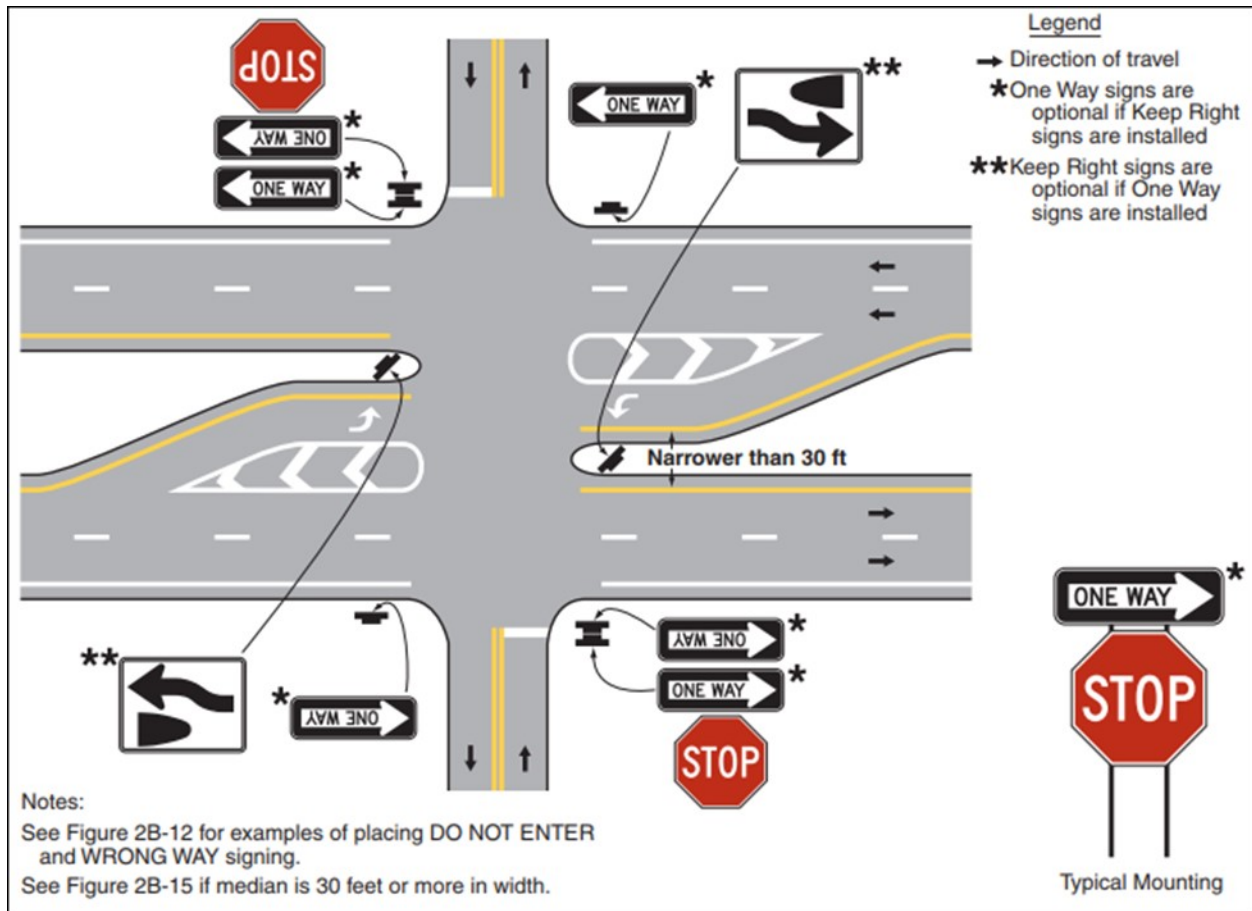


Figure 4.13 One Way and Keep Right signing for divided highways with medians widths narrower than 30 feet and separated left-turn lanes. [FHWA, 2009 Figure 2B-17]

When a Keep Right sign can't be accommodated near the nose because the sign width would be too close to vehicles passing on each side, the Keep Right sign should be placed further back to a point

where the median width is adequate, usually four feet wide. Yellow pavement markings should be placed on each side and around the nose of the island to emphasize the median presence. In addition, the MUTCD option of installing One Way signs on the far side of the receiving roadway should be considered, as shown in Figure 13. When median widths are very narrow and created only with pavement markings, the use of six-inch wide or wider double yellow centerline pavement markings should be considered.

There should be no signs on channelization islands visible to cross street motorists. At the approach end of the channelization island where the left-turn lane separates from the through lane, a Begin Left-turn Lane (R3-20L) regulatory sign should be installed and is the preferred sign. However, a double down arrow warning sign (W12-1) is acceptable.

See MUTCD sections 2B.32, 2B.38, and 2B.40 for additional guidance on signing for intersections with median left-turn lanes.

4.1.3 Preservation Projects

4.1.3.1 Lateral offset and sight distance for left-turns at intersections and median openings

Discussion: The current MnDOT RDM policy in Chapter 5-2.02 regarding sight distance at intersections emphasizes the importance of sight distance and is recommended to continue in this section. The first sentence of the existing MnDOT RDM has been included for left-turn lanes on preservation projects.

“A vehicle operator approaching or entering an intersection in left-turn lane needs adequate sight distance to safely conduct a turning maneuver, especially considering the speed of oncoming through traffic” (Minnesota DOT, 2019). Providing additional sight distance is beneficial, especially if permissive signal phase timing is desired and the cost to implement additional sight distance is justified. An engineering study should be done to determine if an improvement is warranted. Data examined should include left-turn volumes, past intersection crash experience, existing left-turn sight distances for all movements, percent of trucks and buses in opposing left-turn lanes, and mitigation costs for additional right-of-way and construction. The data and analysis can be used to evaluate various design alternatives. Calculating available left-turn sight distances should include horizontal and vertical curvature and assume that opposing left-turning vehicles block all or a portion of the left-turn lane.

If mitigation costs and/or environmental factors make upgrading to desirable positive 6 feet left-turn lane offset distances uneconomical or impractical, several low-cost alternatives should be examined for possible intersection improvement. Research has demonstrated that increasing the offset of the existing left-turn lane without significant or costly construction can sometimes be achieved, especially if the existing turn lane is wider than ten feet. Shifting left and right edge lines of all turn lanes closer to the median should encourage motorists to move as far left as possible in the turn lane and should improve motorist visibility as they move into the turn lane. Also, reducing the lane width between the edge lines, with using the extra width between the right edge line and channelization should improve motorist visibility to observe vehicles in the opposing through lanes.

Shifting motorists further to the left in the turn lane can be further increased, by increasing the distance of the right edge pavement marking in each turn lane from the edge of the adjacent through lane i.e. increasing the width of the channelization island using pavement marking edge lines (McCoy, 2001). A caution in the research notes this approach may affect the traffic capacity of the turn lane and lower the level of service since this treatment will result in narrowing the turn lane width.

Available sight distance for left-turning motorists can be determined using the procedure in Chapter 9, Section 5.3.6 in the 2018 AASHTO Green Book (AASHTO, 2018). This sight distance calculation can be stated as the distance traversed at the design speed on the major road in a certain amount of time. The amount of time is based on the time gap required for the left-turning vehicle to traverse safely across the approaching opposing through lanes. Figure 4.14 provides the time gaps for various left-turning design vehicles. Figure 4.15 is the formula for calculating a specific intersection sight distance for a left-turning vehicle. The sight distances for passenger cars turning left with vehicles approaching at different design speeds is shown in Figure 4.16 (AASHTO, 2018).

If the existing left-turn lane has negative, no offset, or minimal positive offset, implementing some or additional positive offset may still be useful. The designer should attempt to provide whatever positive offset is practical. If no improvements in left-turn sight distance are practical, permissive signal phasing with flashing yellow arrow may still be used for at least a portion of the day when volumes are reduced and/or minimal opposing left-turn vehicles are present. For a discussion on the need for protected left-turns, see section 2A.

If additional “more positive” left-turn offset can be obtained, the resulting increased sight distance should enhance safety and improve intersection efficiency in the final design. Even a slight negative offset, no offset, or slightly positive offset may still provide sufficient sight distance depending on vehicle placement in the turning lane (FDOT, 2017), to provide an opportunity to use permissive left-turn signal phasing.

Design Vehicle	Time Gap (t_g)(s) at Design Speed of Major Road
Passenger car	5.5
Single-unit truck	6.5
Combination truck	7.5

Note: Time gaps shown are for a stopped vehicle turning left from a two-lane highway with no median. For multi-lane and/or divided roadways – For left-turns on two-way roadways across more than one opposing lane, including turn lanes, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane to be crossed in the left-turn maneuver in excess of one lane.

Figure 4.14 Recommended time gap needed for left-turn motorists to safely cross oncoming major roadway traffic. [AASHTO, 2018]

$$ISD = 1.47 V_{\text{major}} t_g$$

where:

ISD = intersection sight distance (length of the leg of sight triangle along the major road) (ft)

V_{major} = design speed of major road (mph)

t_g = time gap for minor road vehicle to enter the major road (s)

Figure 4.15 Formula for calculating intersection sight distance. [AASHTO, 2018]

Design Speed (mph)	Stopping Sight Distance (ft)	Intersection Sight Distance	
		Passenger Cars	
		Calculated (ft)	Design (ft)
15	80	121.3	125
20	115	161.7	165
25	155	202.1	205
30	200	242.6	245
35	250	283.0	285
40	305	323.4	325
45	360	363.8	365
50	425	404.3	405
55	495	444.7	445
60	570	485.1	490
65	645	525.5	530
70	730	566.0	570
75	820	606.4	610
80	910	646.8	650

Figure 4.16 Desirable intersection sight distances calculated for left-turning passenger vehicles. [AASHTO, 2018]

4.2 OTHER MNDOT GUIDANCE DOCUMENTS AND MATERIALS THAT REFERENCE LEFT-

MnDOT currently has two traffic engineering guidance documents for engineers to use when designing left-turn lanes at intersections. MnDOT Geometric Design Support Unit uses a comprehensive design information checklist, and MnDOT Research Services produced a checklist for “Design of Turn Lane Guidelines”. Several recommendations are provided to increase the designer awareness for left-turn lane offsets and sight distances.

4.2.1 MnDOT Traffic Engineering Manual

Section 9-7.02, Intersection Geometry, identifies geometric elements that should be considered, but offset geometry is not mentioned. **Recommendation:** add a new item, after current item number 3: “4. Turn lanes should provide adequate sight distance for left-turning vehicles to determine safe gaps to turn left in front of approaching through traffic in opposing through lanes.”

Section 9-7.05, Signal Design Elements, currently item number 4 discusses pedestrians. However, there is no mention on the need for possible pedestrian storage in medians for pedestrians unable to cross the street in a single signal cycle, nor geometric requirements for pedestrians when left-turn lane and channelization are required to provide adequate sight lines which make a single crossing sometimes difficult. **Recommendation:** Add narrative to explain sight distance requirements and provide minimum standards for pedestrian refuge design.

Section 9-6.02, Notes on Traffic Control Signal Project Management Flowchart, Pencil Figure. Language in the list of design topics discussed by the designer should be revised and added to include sight lines and pedestrian activity at the intersection. **Recommendations:** Item #2, suggest adding following language, “left-turn lane geometry, i.e., whether left-turn lanes have positive, negative, or no offset.” Item #5, suggest revising item language to, “determine left-turn lane sight distances.” Add new item #25, “Estimate the amount of pedestrian activity at the crossing.”

4.2.2 MnDOT Traffic Control Signal Design Manual

Section 2.5.2 Left-turn Protected Phasing Selection Guidelines, in Protected Only Guidelines section. The manual currently recommends using protected only left-turn phasing for certain situations including when mainline left-turning motorist has limited sight distance (5th bullet in the list). A **recommendation** is to revise the sentence by adding, “consider improving the turn lane offset channelization geometry to increase sight distance to avoid use of protected only phasing due to left-turn lane viewing obstructions.”

Section 2.5.3 Terms, Definitions and additional Phasing Guidance Discussion, **Recommendations:** In Left-turn Lane Alignment section, revise first sentence to strike out “head on” and replace with “positive offset”. The revised sentence would read “Left-turn lanes that have positive offset from each other work best for permissive left-turns since the motorist can more easily see around the opposing left-turning vehicle and look for a safe gap in traffic.” In Conflicting Left-turn Paths section add new sentence at the end, “In this example, if geometric curb or pavement marking left-turn lane channelization improvements can be made to correct this problem and allow simultaneous opposing left-turn movements, lead-lag sequence or split phase sequence may be avoided.” In Limited Sight Distance section, make editorial change in third sentence by adding “and” between “acceleration and vehicle height.” In Left-turn Related Collisions section, in the first sentence following “corrected” add “or reduced,” and following protected only phasing, add “or improving the left-turn lane geometrics.”

Section 2.6 Left-turn Lateral Offset: The first two existing paragraphs in this section currently read as follows: “Sight distance is important for motorists to identify acceptable gaps in opposing traffic.

Opposing left-turn lanes are typically aligned directly across from one another and immediately adjacent to the through lanes. Thus, a left-turning vehicle in the left-turn lane can obstruct the view of oncoming vehicles, particularly those in the opposite left-turn lane.

To improve sight distance and safety for left-turning motorists at intersections, the use of offset left-turn lanes has been recommended, as discussed in the NCHRP Report 500 Series Volume 12, "A Guide for Reducing Collisions at Signalized Intersections." Sight distance for left-turning vehicles is diminished with a negative offset or, to a lesser degree, no offset. Sight distance can be improved by shifting left-turn lanes to the left to create a positive offset. **Recommendations:** In the first paragraph, second sentence, replace the word "typically" with "often found." In the second paragraph, first sentence, revise the wording from "has been recommended" to "is recommended." In the second paragraph, modify the sentence to read as follows, "Sight distance can sometimes be improved by shifting left-turn lanes to the left to create a positive offset" by the use of edge line pavement markings that guide motorist closer to the median. At end of this paragraph, **suggest** adding a new sentence to read, "(See xxxx in the Road Design Manual for more information on left-turn lateral offset.)"

In Exhibit 2-7, the first photo used is intended to show negative offset, however the photograph appears to show "no offset." **Recommendation:** For the "negative offset" photo, replace existing photograph with a better photo that actually shows "negative offset."

4.2.3 MnDOT Geometric Design Support Unit (GDSU) Layout Content Review Form-1954370-v2)

Recommend adding a new block "Offset Distances for Left-turn Lanes on Mainline" in the Profile section and located immediately below the "Intersection Sight Distance" block shown in Figure 4.17.

PROFILE				
Alignment/Profile & GPK Name				
Direction of Travel				
Elev & Sta Labels				
Begin/End Profile				
Existing Ground				
Grades				
Bridges				
Vertical Clearance				
Design Speed				
K Value				
Length of Curve				
PVC/PVT/PI Sta.				
Cross Streets				
Nose Locations				
Horizontal Curves				
Stopping Sight Distance				
Headlight Sight Distance				
Comfort Sight Distance				
Decision Sight Distance				
Passing Sight Distance				
Intersection Sight Distance				
Signal Head Sightline				

Figure 4.17 Existing GDSU Layout Content Review Form-1954370-v2 (Only Page 3 shown)

4.2.4 MnDOT Research Services Report, “Design of Turn Lane Guidelines”

Report focused on designing deceleration and storage lengths for left-turn lanes on mainline. However, a section in the report briefly discussed an “Innovative Intersection Design Concept – Positive Offset Turn Lanes.”

Recommendation: if material from this report, including the Turn Lane Design Checklist, is incorporated into the next MnDOT RDM for intersection upgrade projects, the checklist should be revised and expanded to include existing intersection inventory information, including crash history, available time gaps available for all left-turn vehicle movements, and available left-turning sight distances. The checklist form could also be used to document design decisions for left-turn lane offsets.

TURN LANE DESIGN CHECKLIST (PAGE 1 OF 2)

STEP 1 – DATA GATHERING

Location	State Roadway: _____ Intersection: _____ <input type="checkbox"/> Left Turn Lane Design for Approach: N / S / E / W <input type="checkbox"/> Right Turn Lane Design for Approach: N / S / E / W	
Vehicle Speed <i>Page B-2</i>	Choose one. Shown in order of preference. <input type="checkbox"/> Design Speed: _____ mph <input type="checkbox"/> 85 th Percentile Speed: _____ mph <input type="checkbox"/> Statewide Average Speed: _____ mph (<i>page B-2, Figure B-1</i>)	
Forecast Traffic Volumes <i>Page B-3</i>	Choose one. Shown in order of preference. <input type="checkbox"/> Design Year Volumes (provided by District/Central Office Planning Staff) <input type="checkbox"/> Historic Volumes (existing volumes extrapolated to estimate 20 year forecast volumes) <input type="checkbox"/> 20-Year Multiplier (documented by State Aid and found at the following website under County Reference Data: http://www.dot.state.mn.us/stateaid/sa_csah.html Turning Volumes: see graphic at right, also note the number of lanes for each movement. Daily Volumes Major Street Daily Traffic Volumes: _____ vehicles per day Minor Street Daily Traffic Volumes: _____ vehicles per day	
Heavy Commercial <i>Page B-5</i>	Percent Heavy Vehicle: _____% (If percentage of heavy commercial is high special consideration should be taken in Step 4 for deceleration and storage length of turn lane)	
Grade <i>Page B-5</i>	<input type="checkbox"/> Upgrade <input type="checkbox"/> Downgrade Grade of approach: _____% (If greater than 3%, apply deceleration adjustment in Step 4)	
Seasonal Variations <i>Page B-4</i>	Is there a large seasonal variation within the corridor (recreational routes, primary farm to market routes, etc)? If yes, consider the variation and potential increase in traffic volumes during peak periods. Is it enough of an increase to change the design? <input type="checkbox"/> Yes, adjust traffic volumes <input type="checkbox"/> No	
Roadway Geometry and Corridor Characteristics <i>Page B-6</i>	Is the intersection located on a horizontal curve? If yes, adjust taper in Step 4. (See <i>Page B-17</i> and <i>Table B-8</i>) <input type="checkbox"/> Yes, on horizontal curve <input type="checkbox"/> No Are there adjacent intersections that may influence the turn lane design? If yes, consider adjustments to the turn lane design to better accommodate the constrained conditions. (See <i>Pages B-23 and 24</i>) <input type="checkbox"/> Yes, constrained location <input type="checkbox"/> No	
STEP 2 – DETERMINE FACILITY TYPE		
Determine Facility Type <i>Page B-8</i>	Rural vs. Urban (based on Access Management Category Assignments: www.dot.state.mn.us/accessmanagement/index_categoryassignments.html) <input type="checkbox"/> Urban <input type="checkbox"/> Rural Expressway vs. Conventional (determined by Mn/DOT Office of Traffic, Safety and Technology) <input type="checkbox"/> Expressway <input type="checkbox"/> Conventional	
Intersection Control <i>Page B-9</i>	<input type="checkbox"/> Signalized: _____sec cycle length <input type="checkbox"/> Unsignalized <input type="checkbox"/> Future Signal? (see <i>Figure B-3</i>)	

Development of Turn Lane Design Guidelines

TURN LANE DESIGN CHECKLIST (PAGE 1 OF 2)

STEP 3 – CALCULATE TURN LANE DEMAND

Deceleration Length <i>Page B-11</i>	Based on speed and facility type determine deceleration length for turn lane. <ul style="list-style-type: none"> • Table B-1 for low speed (20 – 50 mph) Urban Conventional Roadway • Table B-2 for high speed (45 – 75 mph) Rural and Urban Roadways Interpolation between values in the tables may be necessary based on speed data.	Deceleration Distance _____ feet
Storage Length <i>Page B-12</i>	<u>Unsignalized Intersections</u> Left Turn Lane – see <i>Table B-3</i> , based on Left-Turning Volume and Heavy Commercial %, or equation on <i>Page B-12</i> . Right Turn Lane – assumed to be 0 feet since in virtually all cases these vehicles would have the right-of-way entering the intersection and would incur no delay <u>Signalized Intersections</u> <input type="checkbox"/> Synchro Output Available: 95 th percentile queue length. <input type="checkbox"/> Method 1 – Basic Equation: equation on <i>Page B-13</i> . <input type="checkbox"/> Method 2 – Look Up Tables: <i>Tables B-4</i> through <i>B-6</i> on <i>Page B-14</i> using Sum of Critical Movement Calculations (see <i>Page 4</i> of checklist)	Storage Distance _____ feet
Turn Lane Demand	Add the Deceleration Distance and the Storage Distance	Turn Lane Demand = _____ feet

STEP 4 – CALCULATE TURN LANE DESIGN

Determine Taper <i>Page B-17</i>	Determine Taper based on Facility Type <ul style="list-style-type: none"> <input type="checkbox"/> Unconstrained Conventional/Expressway = 180 feet (1:15 taper) <input type="checkbox"/> Constrained Expressway = 100 feet (1:8 taper) <input type="checkbox"/> Constrained Conventional = 60 feet (1:5 taper) 	Taper Length _____ feet
Full Turn Lane Length (before adjustments)	Take the Turn Lane Demand minus Taper Length	Full Width Turn Lane Length (no adjustments) _____ feet

ADJUSTMENTS AND FINAL TURN LANE DESIGN

Adjust Taper <i>Page B-21</i>	If the intersection is located on a horizontal curve, use a 1:8 taper (100 feet)	Adjusted Taper Length _____ feet
Adjust Full turn Lane Length	If grade is greater than 3% adjust based on <i>Table B-9</i> (multiply the Deceleration Distance by adjustment in table and document the difference in deceleration to the right. <i>Page B-19</i>)	+ / - _____ ft
	If heavy commercial is greater than averages shown in <i>Table B-10</i> , increase Deceleration Distance by 30% and document the difference in length to the right. <i>Page B-20</i>	+ _____ ft
	Are there more than 300 vehicles per hour? May consider <i>dual lefts</i> . The storage length required would be half of the calculated Storage Distance . Document the difference in distance to the right. <i>Page B-22</i>	- _____ ft
	Are there <i>constraints</i> with the adjacent intersections or driveways? Does the <i>through lane queue</i> extend further than the turn lane length? Document a review of the potential impact to the desired turn lane length and adjust accordingly. <i>Page B-23 & B-24</i>	+ / - _____ ft
	Total Adjustments	+ / - _____ ft
		Full Width Turn Lane Length (with adjustments) _____ feet

Development of Turn Lane Design Guidelines

CHAPTER 5: CONCLUSIONS

Studies as far back as the 1970s as well as recent studies have clearly demonstrated that obstructed sight lines at intersections (signalized and unsignalized) could cause higher possibilities of collisions between left-turning vehicles and oncoming vehicles from the opposing direction. Evaluations of the effects of left-turn lane offsets, with data from multiple states in the United States, reported results indicating that positive left-turn lane offsets were more effective in reducing intersection left-turn crashes than zero and negative left-turn offsets. In terms of the effects on intersection traffic operations, providing positive left-turn offsets decreases the critical gap of motorists and leads to higher capacities for left-turn movements. Several researchers have developed guidelines for geometric design elements of left-turn offsets, based on different sight distance models and considering different vehicle types and vehicle positioning situations. These studies served as valuable references for the development of left-turn lane offset guidelines to satisfy the needs of Minnesota.

Based on a review of the largest states' road design manuals and intersection design guides, Florida DOT provides the most comprehensive policies and guidance on design standards and guidance for assuring unobstructed sight lines at left-turn lanes. Several states, including North Dakota, South Dakota, Iowa, North Carolina, Michigan, Florida, Wisconsin, and Nebraska, have policies and/or guidance promoting the use of positive offsets at left-turns, at least under certain conditions. The majority of states provide only a limited discussion on this topic and when guidance is offered it is typically only on one or two aspects of left-turn lane design, such as briefly mentioning safety consideration when sight lines are restricted from opposing left-turn lanes, optimum median widths, protected versus protected/permitted traffic signal phasing, and optimum sight distance and gap acceptance.

Recommendations developed in this project center on general policies and guidance for designing offset left-turn lanes for a new edition of MnDOT's *Road Design Manual*. The primary goal is for designers to have a better understanding of the concern and need for providing optimum sight lines at left-turn lanes on mainline highways. Recommendations are organized to provide recommended standards, policies, and guidance for new and reconstruction projects and for preservation projects. Topics covered include definition of left-turn lane offset, impact of the type of improvement project, various design factors impacting the offset, suggested designs for urban and rural multilane roadways and expressways, accommodating U-turns, pedestrian and bicyclist considerations as well as winter maintenance considerations. Besides the changes to MnDOT's *Road Design Manual*, other recommendations are included for changes to MnDOT's *Traffic Engineering Manual* and its *Traffic Control Signal Design Manual*. These suggested recommendations are offered to improve consistency among all MnDOT manuals and guides used for intersection design and operations of left-turn lanes on mainline streets and highways.

REFERENCES

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- AASHTO. (2018). *A Policy on Geometric Design of Highways and Streets*, 7th Edition. American Association of State Highway and Transportation Officials, Washington, D.C.
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APPENDIX A
STATE PRACTICE SUMMARY

State	Title of Document	Location in Manual, i.e. section or page number	Standard Policy (Y/N)	Type of Project Used On or Limitations	Standard Drawings/ Layout	Safety Discussion	Geometrics Discussion	Operational Discussions-sight distance & critical gap	Discuss Median Width	Discuss U-Turns	Discuss Effect on Peds	Discuss Winter Maintenance	Comments
CA	Highway Design Manual	Section 403.6	Design Policy & Guide	CA State highway system	No		Min	Recommends offset left-turn lanes at signalized & unsignalized					Minimal discussion, makes reference to AASHTO Green Book for further guidance.
FL	FDOT Design Manual	Section 212	Policy	FDOT projects			Yes 212.11.3 & 4	Yes 212.14 Table with Min Offset Distances for Left-Turn Lanes.4	Yes 21 2.9	Yes 21 2.9			212.14.1 Good explanation for offset left-turn lanes. Reference to AASHTO Green Book Figure 9-52 for parallel & tapered left-turn lanes.
FL	FDOT Plans Preparation Manual	Chap 2 2.13.2	Policy	FDOT State Highway System	No	Min	Yes	Yes, offset distances (guidelines)	No	No	No	No	Uses offset chart from FHWA Older Driver Highway Design Handbook
FL	Manual Uniform Min Stds Design, Const & Maint. For Streets & Hwys.	3-75 & 77	Manual	All projects <u>not</u> on the state & national highways				Intersection Sight Distance Min time gap for design vehicles based on sight distances.					Referred to as Florida Green Book
FL	FL Intersection Design Guide 2015	Section 4.6.4 on page 4-16	Design Guide	State Hwy New construct & reconstruct intersections		Yes					Yes		Provides conditions which require protected-only phasing.
FL	FDOT 2014 Median Handbook	Offset 3.0.5 U-Turn 5.0-5.1	No- Guide Only				Yes		Yes	Yes			Overview & discussion of offset intersections
GA	Georgia DOT Design Policy Manual												Nothing relevant found.
IL	Bureau of Design & Environmental Manual	Section 36-1.05(c)	Design Guide Manual	All IDOT projects	No	Min	Yes						Does not discuss concept of positive offset, only no or negative offset. Uses concept of desirable intersection width taper based on speed.
IN	Indiana Design Manual for 2013	Chapter 46-4.02(4)	Design Guide Manual	All INDOT projects	Typical. 46-4N	Min	Min	No	Yes Where median is $\geq 24'$	No	No	No	Positive offset dimension shown on typical drawings (only signalized intersections), but does not mention offset terms.

IA	IA Design Manual	Chapter 6C-5; 6A-1	Design Guide Manual	Four-Lane Expressway Turn; Rural Two-Lane	Typical	No	Yes	Minimal	Yes	No	No	No	Use Offset only if traffic signals installed or opposing left-turn vehicles create significant sight distance problem.
MD	Maryland DOT Policy Manual												Nothing relevant found.
MI	MDOT Michigan Intersection Guide	Sig- 2.1.d Unsig- 2.3	Guide	All	No	Yes	No	No	No	No	No	No	Good discussion on topic as a safety countermeasure. Divides topic into signalized & unsignalized intersections.
MN	Design of Turn Lane Guidelines-Final Report #2010-25.	Part C	Guide	All	Example only	No	No	No	No	No	No	No	Calls Offset Turn Lane as an "innovative Intersection design concept." Guide is a comprehensive intersection guide but does not include offset guidance.
MN	Development of Guidelines for Permitted Left-Turn Phasing Using Flashing Yellow Arrows.	p.27, 28,45, 46, & 47.	Guide	All	No	Yes	Yes	No gap analysis	No	No	No	No	Guide for using flashing yellow arrows. Synthesis for McCoy's calculations for required left-turn sight distance. Sign distance calculated at 328 intersections.
MN	Mn DOT Road Design Manual	Chap 5, 5-2.05	Guide Manual	All, but left-turn lanes only for urban road.	Typical	No	Yes	No	No	No	No	No	Only shows undivided roadway, painted centerline – no median.
NE	Neb DOT Roadway Design Manual	Chap. 4-1.D (Pages 21-24)	Guide Manual	All	Typical	No	No	No	No	No	No	No	When 18' medians exist, provide +1' offset & wide striping to encourage traffic to move closer to median. Exhibit provided.
NV	Nev Strategic Highway Safety Plan	Offset Left-turn Lanes	Plan	All	No	No	No	No	No	No	No	No	References research studies
NY	New York Highway Design Manual	Chap. 5 (5.9.8.2,5.9.10) App. 5C Table 5C-8	Guide Manual	Divided Highway w/Medians Urban	diagrams	Min	Min	Yes, Appendix 5C, Table 5C-8 based on GDHS 9.5.3, 2011	Yes	No	No	No	Ref AASHTO GDHS

NC	NC DOT Roadway Design Manual	Chap. 9	Guide Manual	Divided highways; Undivided highways	Typicals	No	No	No	Yes , 20' , 30' , 36' & 40'	Yes , typical	No	No	Provides criteria for applying typical drawings.
ND	ND DOT Guidelines Turn Lanes State Highways		Guide	All ND hwys.	No	No	No	No	No	No	No	No	+ offset recommended when: there are crash trends; sight distance issues; unsig. where mainline left-turn lanes each have 300 PCE; signal w/permissive only or protected-permissive phasing.
OH	Ohio DOT Roadway Design Manual	Section 401.6.1 Figure 401-8	Guide Manual	All Ohio hwys.	Yes	No	No	No	No	No	No	No	Offset mentioned and typical drawing provided, but nothing relevant found for developing warrants or guidance.
OR	Oregon Highway Design Manual	Section 8.3.9	Guide Manual	All ODOT projects	No	No	No	None	Yes	No	No	No	Ref. to GDHS. Nothing relevant found for developing warrant or guidance. The Oregon DOT Analysis Procedures Manual also examined and relevant identified.
PA	PennDOT Design Manual	Chap. 3	Guide Manual	All PennDOT projects	No	No	No	None	No	No	No	No	Ref. 2011 AASHTO Green Book, Chapter 9. Nothing relevant found.
SC	SCDOT Access & Roadside Management Standards	Page 51	Stds. & Guide	All	Typical	No	No	No	Yes	No	No	No	>17' medians
SD	SD Road Design Manual	Page 12-40	Guide Manual	All	Diagram	No	No	No	Yes	No	No	No	>20' medians are desirable, but 16' to 18' ok
TX	Texas Roadway Design Manual												Nothing relevant found. Note: TTI Research report, Urban Intersection Design Guide, FHWA/TX-05/0 excellent source.
VA	VDOT Road Design Manual		Guide Manual	All DOT projects	No	No	No	No	No	No	No	No	Nothing relevant found.

WA	Washington State DOT Design Manual	1310.04 (1), 1310.02, 02(5),03(2) 1310.03 (2), 1330.03 & .06.	Guide Manual	All DOT projects & optional for others	**	Min	Min	*(limited)	Min	No	Yes, general discussion	No	*Ref. to GDHS for calculating sight distance for determining whether protected/permissive or permissive signal phasing is acceptable. Limited use of positive offset for left-turn lanes. **Diagram of using offset left-turn lane to provide clearance of opposing vehicle paths at signalized intersection.
WI	WisDOT FDM	11-10 5.1.4.2.6 & 11-25 5.4.1	Guide Manual	All WisDOT projects	Diagrams	No	No	* & **	No	No	**	No	*Ref. to GDHS 2004, page 674-676, w/ state specific time gaps and Intersection Sight Distances. ** FHWA-RD-01-051 Guidelines & Recommendations to Accommodate Older Drivers & Peds