Left-Turn Lane Offset: Research Synthesis and Review of Existing Guidelines

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ABSTRACT

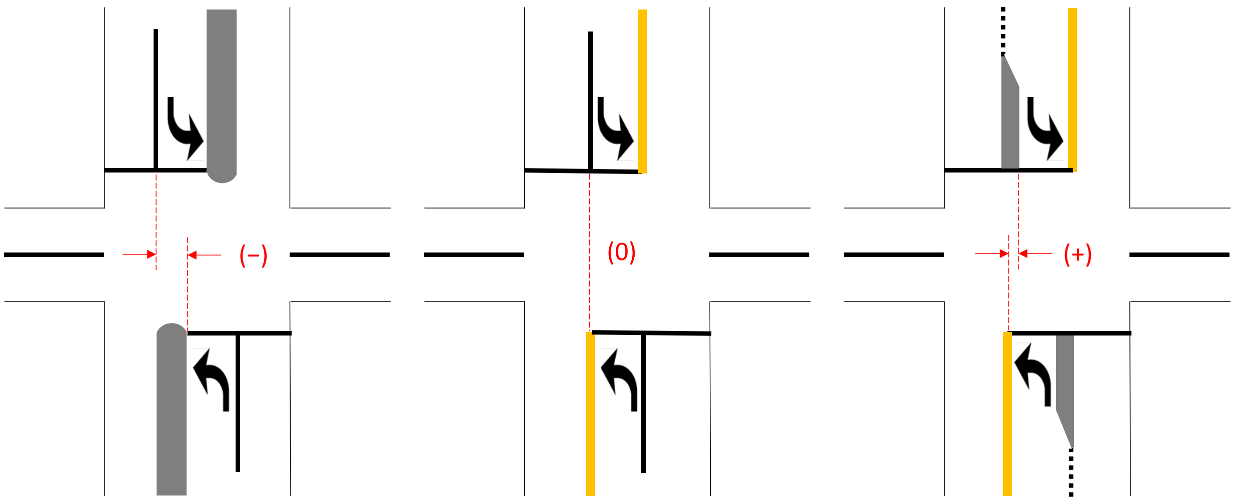
Syntheses of research studies and existing guidelines on left-turn lane offset are presented in this paper to better understand the impact of left-turn offset on drivers' sight distance, intersection left-turn safety, operations, and relevant design elements. Studies showed that at left-turn lanes, of both signalized and unsignalized intersections, obstructed sight line could cause higher possibilities of collisions between left-turning vehicles and oncoming vehicles from the opposing direction. Existing evaluations of left-turn lane offset, 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 left-turn traffic operations, providing positive offsets could help reduce the sight line obstruction situations and thus increase left-turn capacity. Existing recommendations in research publications for left-turn lane offset are based on different sight distance models, and consider different vehicle types and vehicle positioning situations. Most agency guides provide very limited discussion about left-turn lane offset and typically only on one or two aspects of left-turn lane offset are covered. This review serves as a valuable reference for transportation agencies in making decisions on left-turn lane offset design. Recommendations are also provided for developing relevant guidelines.

Keywords: left-turn lane offset, safety, operations, design, literature review

INTRODUCTION

At signalized intersections with permissive left-turn phases and at unsignalized intersections, left turning vehicles in the opposing lane may block the view of a left-turning driver. Blocked sight line can increase crash risk since drivers may not see vehicles approaching in the opposing through lanes and misjudge the gap. If the drivers decide not to proceed because of the obstructed sight line, delays for left-turning vehicles will increase and intersection capacity may decrease.

Transportation agencies apply various treatments to improve left-turning drivers' visibility of opposing through and right-turning traffic. These treatments may include positive offset, lateral separation with no offset, and lateral separation with improvements to negative offset, as shown in Figure 1. 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. The safety performance, operational efficiency, and costs of these treatments vary depending on the intersection configuration and environment. This literature review summarizes research studies relevant to these left-turn lane treatments, 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.



(a) Negative offset (b) Zero offset (c) Positive offset

Figure 1 Illustration of negative, zero, and positive offset left-turn lanes

The purpose of carrying out this review of left-turn lane offset relevant research studies is to obtain a better understanding of the connections and interactions among the impacts of this geometric feature on driver behavior, intersection left-turn safety, operations, and the development of guidelines on left-turn lane offset design elements. Existing academic studies, federal guidelines, and state guidelines, about left-turn lane offset, were reviewed. Recommendations are provided with this review to help state transportation agencies develop design standards for left-turn lane offset, to provide unobstructed sight lines at left-turn lanes considering safety, operational efficiency, and other needs.

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 (*1-3*). 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 (*4-7*). 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 (*8*).

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. Crash data from 1994 to 2002 was evaluated. A before-after analysis was conducted 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 showed a 0.285% reduction in crash frequency with the left-turn lane treatments, but was not statistically significant (*9*). Naik et al. investigated the safety effects of the same type of left-turn lane treatments at 3 signalized intersections, with a total of 12 approaches, in Nebraska (*10*). 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 in number of crashes after the treatments were applied.

The Federal Highway Administration (FHWA) sponsored a study in 2009, exploring the safety effectiveness of left-turn lane offset improvements in Florida, Nebraska, and Wisconsin (*11,12*). 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 Type I offset. Many of the Florida and Nebraska implementations resulted in Type II and III offsets. EB before-after study method was used. The study results are listed in Table 1. 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. 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. 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 was cost-effective.

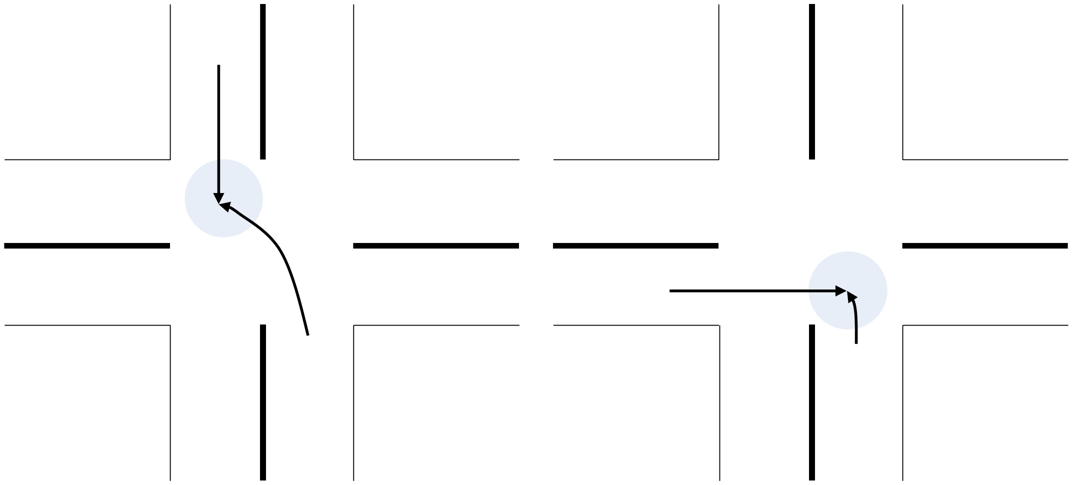
Table 1 Results for Florida, Nebraska, and Wisconsin Sites (*12*)

State / Crash Type	Estimated Crash Number	Observed Crash Number	Reduction (%)	s.d.
Florida				
Total	970	938	3.4	4.7
Injury	472	472	0.2	6.6
Left-turn opposing	119	106	11.4	11.2
Rear-end	258	273	-5.3	9.9
Nebraska				
Total	2,796	2,811	-0.5	2.4
Injury	1,536	1,441	**6.2**	3.0
Left-turn opposing	479	695	**-45.0**	6.7
Rear-end	1,249	1,335	**-6.9**	3.6
Wisconsin				
Total	234	155	**33.8**	6.0
Injury	96	62	**35.6**	9.0
Left-turn opposing	95	59	**38.0**	8.9
Rear-end	73	50	**31.7**	10.9

Note: A negative sign (-) indicates an increase in crashes. s.d. = standard deviation. Boldface denotes those safety effects that are significant at the 95% 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.

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 (*13*). Two types of left-turn crashes, which were referred in the paper as Pattern 5 and Pattern 8 (see Figure 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 levels 1 to 5 to represent no injury to fatal injury. The models estimated the effects of multiple variables, including left-turn lane offset (positive, zero, or negative), on Pattern 5 and 8 left-turn crash severity. 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.

There are several studies investigating the effects of blocked sight line at left-turn lanes on the left-turning driver 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 → driver behavior change → risks increase (more near-misses) → crash number increases". Tarawneh and McCoy studied left-turn lane offset's effects on driver performance in 1996 (*14*). The research evaluated 100 drivers' performance on three test circuits, with critical gap, clearance time, left-turn conflict, longitudinal and lateral positioning, and percentage positioned left-turns as measures of effectiveness (MOEs). The study results showed that driver performance could be adversely affected by negative left-turn offsets less than -0.9 m (-3 ft). 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.



(a) Crash pattern 5 (b) Crash pattern 8

Figure 2 Collision diagrams of left-turn crash pattern 5 and 8 (*13*)

Yan and Radwan further studied the effects of obstructed sight line on driver behavior during unprotected left-turn phase at signalized intersections using video data (*15*). Left-turning driver's gap acceptance behavior was specifically evaluated in the research. The results confirmed once again that blocked sight line 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, comparing with situations without the obstruction issue. Left-turning and U-turning drivers 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 driver behavior with surrogate safety measures including critical gaps, post-encroachment time, near crashes, and crash avoidance maneuvers (*16*). The SHRP 2 Naturalistic Driving Study (NDS) data were used in the study, with 3,350 gaps at 44 signalized intersections and 14 two-way stop-controlled (TWSC) intersections. The 3,350 left-turn events were grouped according to the intersection left-turn lane offset. There were 7 categories for signalized intersections, ranging from a negative offset of -16 ft or less to a positive offset of 4 ft to 6 ft. There were 4 categories for TWSC intersections, ranging from a negative offset of -16 ft or less to a zero offset. The length of each time gap and whether the driver accepted the gap were extracted from the videos. Logistic regression analysis was performed to estimate whether a gap was accepted by the drivers 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 drivers 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 analysis of the relationship between short gap lengths (1-4 s) and PET showed that although, on average, the critical gaps were longer at left-turn lanes with negative offsets than at left-turn lanes with positive or zero offsets, drivers 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 drivers' behavior to difficulties in accessing risk and hesitation when left-turning drivers' sight line was obstructed.

OPERATIONS

Apart from the effects on intersection safety, obstructed sight line's operational effects were also investigated by several studies (*16-18*). Yan and Radwan, in their 2008 study, evaluated the impact of restricted sight distance on the left-turn capacity (*17*). Videos were collected at a selected signalized intersection, where the major road approaches had 20-ft wide medians. A median wider than 18 ft causes sight distance problems. Logistic regression models used in the study estimated the probabilities of drivers accepting a gap and make left turn with sight line obstructed and not obstructed. The left-turn critical gap without sight obstruction was 5.6 s, and the critical gap with sight obstruction was 7.7 s. The average follow-up time without sight obstruction was found to be 2.2 s, and the average follow-up time with sight obstruction was 2.9 s. The results showed that restricted sight line can significantly affect critical gap and follow-up times. 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. A sensitivity analysis was carried out under conditions of different opposing through traffic volumes. Left-turn capacities were estimated using an example data set of an isolated signalized intersection. The results are illustrated in Figure 3. When opposing through traffic volume increases up to 1,800 vehicles per hour (vph), the left-turn capacity would drop by 70% with sight obstruction, comparing to without sight obstruction.

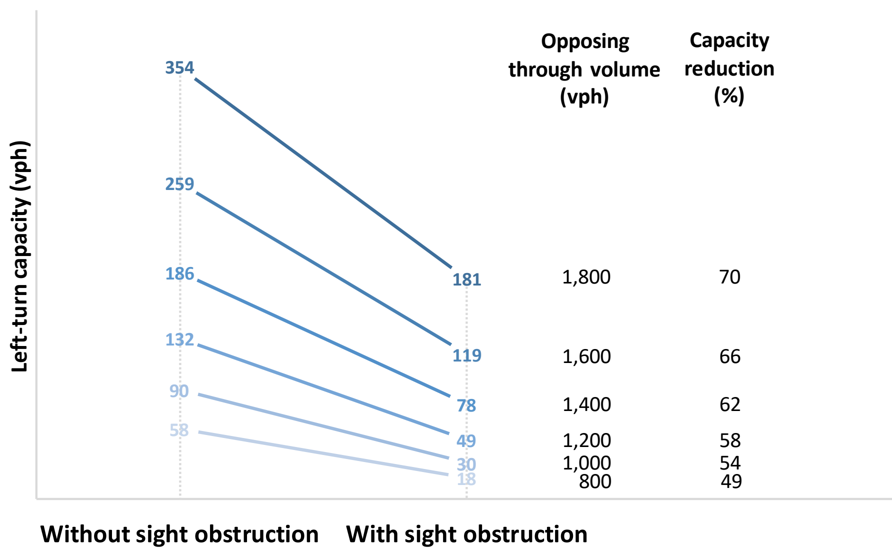
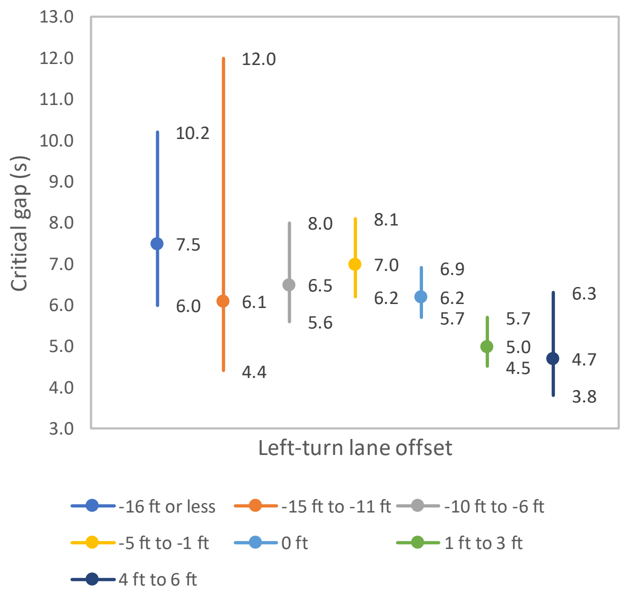
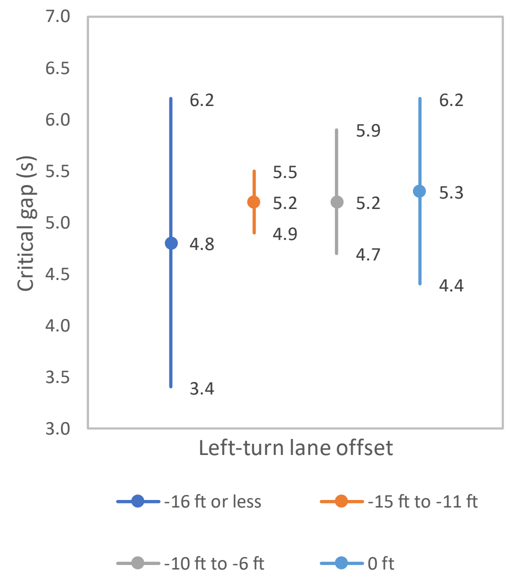


Figure 3 Left-turn capacity reduction due to sight obstruction

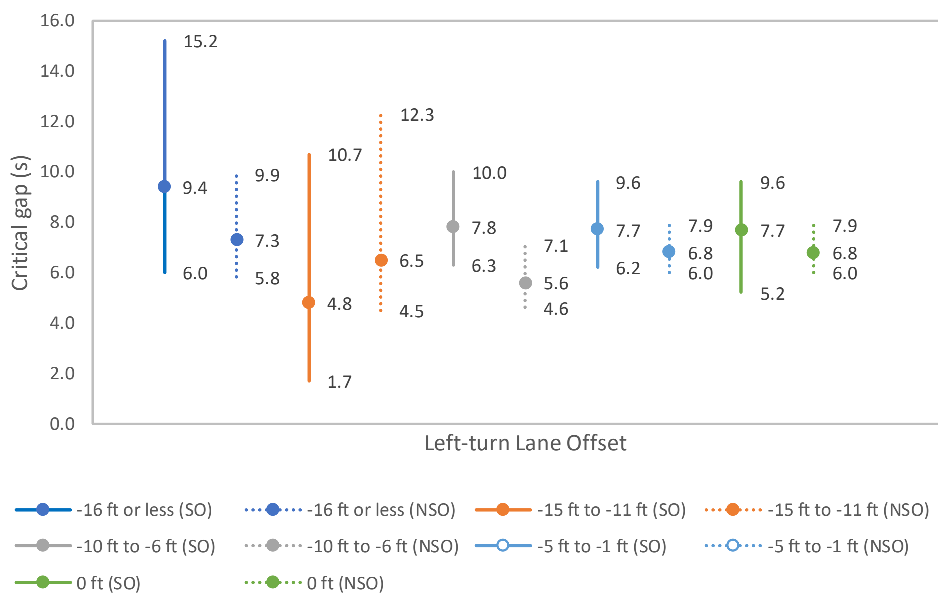
Ogallo and Jha proposed a methodology for critical gap analysis at signalized intersections with permissive opposing left-turn movements (*18*). Video data of left-turning movements from Baltimore and Annapolis, Maryland were collected. The study found that when sight lines were obstructed, the average critical gap was 1 second longer and the average follow-up time was also 1 second longer than when sight line was unobstructed. The critical gaps, for left-turning situations with and without sight obstruction, respectively, were 6 s and 5 s. The follow-up time, for left-turning situations with and without sight obstruction, respectively, were 3 s and 2 s. In terms of the sight obstruction's effect on left-turning capacity, Ogallo and Jha evaluated one of their ten study intersections using the HCM equations for left-turn capacity calculation. The results showed a 33.5% reduction in capacity when there is a sight line obstruction issue, compared with when no sight line obstruction exists.



(a) Signalized intersections



(b) TWSC intersections



(c) Signalized intersections with or without sight obstruction

Note: SO = sight obstruction; NSO = no sight obstruction.

Figure 4 Critical gap estimations (*16*)

In Yan and Radwan's and Ogallo and Jha's studies, the critical gap and follow-up time analysis did not differentiate intersections with different left-turn lane offsets. Hutton et al., in their SHRP2 study, conducted analysis of left-turn critical gap in addition to their safety analysis of left-turn offset and sight line obstruction issues (*16*). In Hutton et al.'s study, critical gaps and their associated 95% confidence intervals (CIs) were estimated for each left-turn lane offset category. The estimated critical gaps and 95% CIs for signalized intersections are shown in Figure 4(a). The estimated critical gaps and 95% CIs for TWSC intersections are shown in Figure 4(b). For signalized intersections, when the left-turn offset goes from positive 4 to 6 ft to negative 16 ft or less, the critical gap increased by 60%, from 4.7 s to 7.5 s. For TWSC intersections, the change was not statistically significant from a zero offset to a negative 16 ft or less offset. The results indicate that at signalized intersections, as the left-turn lane offset reduced, the critical gap increased. The increased critical gap thus consequently decreased the operational efficiency.

Estimations of the critical gaps with and without sight obstruction, for different left-turn lane offset categories at signalized intersections, are illustrated in Figure 4(c). Sight obstruction is noted as "SO", and no sight obstruction is noted as "NSO". Only in the -10 ft to -6 ft category, the difference of critical gaps with and without sight obstruction was statistically significant. With all offset categories combined, the critical gaps and 95% confidence intervals at left-turn lanes with and without sight obstruction were estimated. For signalized intersections, the critical gap with sight obstruction was 7.5 s, and the critical gap without sight obstruction was 6.4 s. For TWSC intersections, the critical gap with sight obstruction was 6.4 s, and the critical gap without sight obstruction was 5.1 s.

DESIGN ELEMENTS

With the understanding of left-turn lane offset's effects on driver sight distance, intersection safety, and operations, many transportation agencies would like to improve intersection performances by implementing left-turn lane offset treatments. The design elements of left-turn lane offset treatments have been studied since the 1990s, with sight-distance-based models developed. Left-turn lane offset design models are not a uniform set of models, because for different intersection geometric characteristics, the demands for sight distance are different, thus the requirements of left-turn lane offset are different. The existing studies covered such models to accommodate several different intersection geometric situations.

Two of the earliest studies on left-turn lane offset design were carried out by McCoy et al., and Tarawneh and McCoy (*4,5*). These two studies provided some guidelines for offsetting opposing left-turn lanes on divided roadways. 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 study, vehicle positioning was measured with a longitudinal distance and a lateral distance as shown in Figure 5. Vehicle positioning affects left-turn drivers' 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 driver reduces.

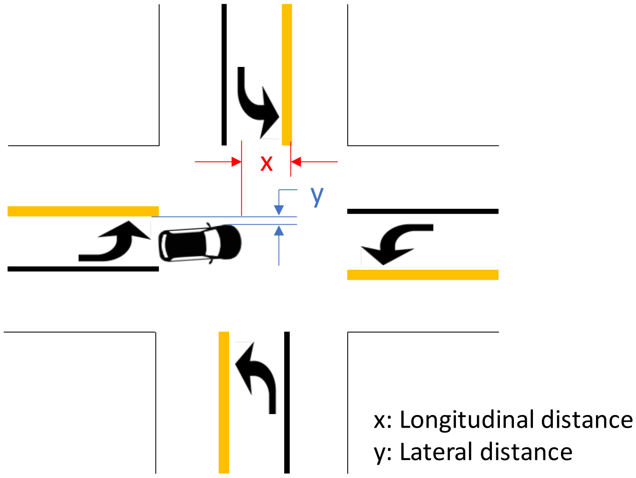


Figure 5 Longitudinal and lateral distances to measure vehicle positioning (*5*)

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 McCoy et al. study and Tarawneh and McCoy study, respectively, are as follows.

- Longitudinal position of positioned left-turn vehicle: 7.0 ft and 16.4 ft
- Lateral position of positioned left-turn vehicle: 2.0 ft and 1.6 ft
- Lateral position of positioned left-turn vehicle: 3.5 ft and 3.9 ft
- Maneuver time of positioned left-turn vehicle: 6.5 s and 3.8 s
- Maneuver time of unpositioned left-turn vehicle: 6.5 s and 6.7 s
- Perception-reaction time: 2.0 s and 2.0 s

Table 2 Left-turn lane offset values suggested by Tarawneh and McCoy (*5*)

Design speed (mph)	**Minimum offset (ft)**			
	Unpositioned passenger car	Positioned passenger car	Unpositioned truck	Positioned truck
35	3.3	0.7	5.0	2.6
40	3.3	1.0	5.0	2.6
45	3.6	1.0	5.0	3.0
50	3.6	1.3	5.3	3.0
55	3.6	1.3	5.3	3.0
60	4.0	1.3	5.3	3.3
65	4.0	1.3	5.3	3.3
Desirable offset (ft)	4.3	2.0	5.6	3.6

In addition to vehicle positing 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 driver behaviors.

Tarawneh and McCoy, in their 1997 study, expanded the equation for minimum left-turn offset to multiple equations to accommodate different positioning situations of the left-turning vehicle and its opposing direction left-turning vehicle. The suggested minimum and desirable left-turn lane offsets for divided roadways are listed in Table 2.

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 as the suggested guidelines to the National Association of City Transportation Officials (NACTO) (*19*). 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 drivers' sight distance. The TTI guide also proposed two types of commonly used offset left-turn lanes are, parallel and tapered. The parallel type is suitable for both signalized and unsignalized intersections, and the tapered type is typically only for signalized intersections.

McCoy et al., in a 2001 study, investigated an alternative for left-turn lane offsetting without involving reconstruction (*20*). The alternative was widening the left-turn lane line. McCoy et al. 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.

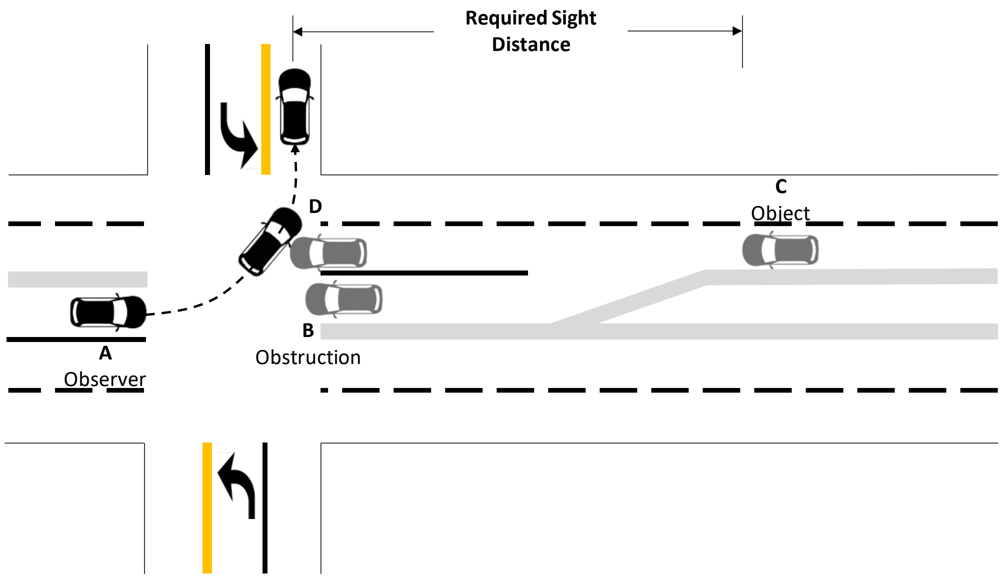


Figure 6 Measure of sight distance from conflict point D (*21*)

Easa and Ali developed modified analytical models and guidelines for left-turn lane offsets (*21*). Left-turn sight distance was measured from the conflict point "D" between left-turning vehicle and oncoming through vehicle, rather than from the point where the left-turn driver initiates the left-turn maneuver, point "A", which was used to develop guidelines by the McCoy studies (*4,5,20*). The proposed measure by Easa and Ali is shown in Figure 6, where the sight distance measure starts from the conflict point D. The modified guidelines for left-turn lane offset by Easa and Ali are summarized in Table 3, with previous offset values suggested by McCoy et al. for comparison.

Table 3 Modified and previous guidelines for minimum left-turn lane offset (*21*)

Major road Design speed (mph)	Minimum required offset (ft)				Desirable offset (ft)	
	OV: passenger car		***OV: truck***		***OV: passenger car***	***OV: 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: OV = "opposing vehicle". Boldface indicates that the modified and previous guidelines are different.

Easa et al. also investigated left-turn lane offsetting at intersections on horizontal curves (*22*). 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. The results indicated that with the increase in horizontal curve radius, the required minimum left-turn lane offset is reduced.

There are extensive studies on geometric models for left-turn lane sight distance calculation (*23-26*). Yan and Radwan developed sight distance model for unprotected left-turning traffic at linear intersections in 2004 (*23*). Later in 2006, Yan et al. 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 (*24,25*). Hussain and Easa conducted a reliability analysis of left-turn sight distance, developed a probabilistic approach for sight distance calculation (*26*). Hussain and Easa 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 (*27*). Cost of both offset left-turn lane and conventional left-turn lane designs, in terms of construction, maintenance, traffic operations, and safety, were analyzed. 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 Report 375; beginning using 20:1 taper; and using gradual widened separation line between left-turn lane and through lane on revised traditional left-turn lanes (*27*,*28*).

EXISTING GUIDELINES

Information and discussions about left-turn lanes and left-turn offset design treatments in the AASHTO Policy on Geometric Design of Highways and Streets (Green Book) are contained in two sections (*29*). The first offset reference deals with left-turn lanes in medians on divided arterials. In Chapter 7 Section 2.11 Divided Arterials, it is stated that "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." 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. The Green Book does not include guidelines regarding specific offset distances for different design speeds, which are provided by some state guidelines. However, the Green Book does emphasize the importance of left turn sight distance at intersections, which is covered in Chapter 9 Section 5.1 and 5.3.

The South Dakota Road Design Manual guidance states that "typically a 2 feet positive offset will provide improved sight distance to motorists; however, intersections should be evaluated on a case by case basis" (*30*). In Nebraska, a one-foot offset is considered adequate in 18 feet wide medians (*31*). The Wisconsin Department of Transportation (WisDOT) Facilities Development Manual (FDM) does not provide a positive offset value but does specifically recommend providing a positive offset for opposing left-turn lanes, if possible (*32*). The 2019 Florida DOT (FDOT) Design Manual provides clear guidance for minimum left-turn lane offset in the form of a table, as shown in Table 4 (*33*).

The Iowa DOT Design Manual provides discussion on offsets as part of the warrant for establishing turn lanes on rural two-lane highways (*34*). When left-turn lanes are justified, the centerlines of the left-turn lanes can be offset by the median width. 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."

Table 4 Guidelines for left-turn lane offset in 2019 FDOT Design Manual (*33*)

Design speed (mph)	**Minimum offset (ft)**	
	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

The North Dakota Guidelines for the installation of turn lanes along state Highways 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 of 300 or more; and signalized intersections with permissive-only or protected-permissive left turn phasing (*35*).

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 (*36*). 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.

Contrary to other states, the State of Washington believes that left-turning traffic at signalized intersections can operate more efficiently when the opposing left-turn lanes are directly opposite each other (*37*). The rational 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.”

SUMMARY AND RECOMMENDATIONS

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 data from multiple states in the United States, indicate 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 offsets decreases the critical gap of motorists and leads to higher capacities for left-turn movements. Several researchers have developed recommendations for geometric design elements of left-turn offsets, based on different sight distance models and considering different vehicle types and vehicle positioning situations.

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.

From the existing studies, it can be concluded that positive left-turn lane offsets are beneficial to intersection safety and operations. However, when designing left-turn lane offset for new or retrofitted facilities, local geometric and traffic features should be specifically considered and models that fit those local features should be used. It is also recommended for state transportation agencies to develop their own standards, policies, and guidance for new and reconstruction projects and for preservation projects involving left-turn lane offset design to accommodate local needs and conditions. Topics for these standards, policies, and guidance can cover definition of left-turn lane offset, impact on 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 for some states.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: DN, MC, and AB; literature collection: YS, MC, and WB; review and synthesizing: YS and WB; draft manuscript preparation: YS and MC. All authors reviewed the results and approved the final version of the manuscript.

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