# Guidelines for Offsetting Opposing Left-Turn Lanes on Four-Lane Divided Roadways

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Vehicles turning left at intersections from opposing left-turn lanes often restrict each other's sight distance. Previous research has indicated that collisions between left-turn and opposing through vehicles may result from such sight-distance restrictions. However, this problem can be eliminated simply if the opposing lanes are offset so that opposing left-turn vehicles do not interfere with each other's line of sight. Existing design guides do not specify the amount of offset needed. Although they acknowledge the potential problem when medians exceed 18 ft, they do not seem to recognize that it can also occur when medians are narrower than 18 ft. Therefore, a study was conducted to develop guidelines for offsetting opposing left-turn lanes to eliminate the left-turn sight-distance problem. The guidelines presented in this paper specify the offsets required between opposing left-turn lanes at 90-degree intersections on level, tangent sections of four-lane divided roadways with 12-ft lanes. The guidelines provide adequate sight distances for passenger cars opposed by left-turning passenger cars and trucks. A 2.0-ft offset provides unrestricted sight distance when the opposing left-turn vehicle is a passenger car, and a 3.5-ft offset provides unrestricted sight distance when the opposing left-turn vehicle is a truck. All the minimum offsets specified in the guidelines are positive, indicating that the negative offsets typically found at these locations do not provide adequate sight distances for opposing left-turn vehicles.

Vehicles in opposing left-turn lanes can obstruct each other's view of the oncoming traffic streams through which they must turn. Sometimes the sight distances available to opposing left-turn vehicles are too short to enable them to turn safely. Previous research has found that some intersections with opposing left-turn lanes have higher left-turn accident rates than similar ones without opposing left-turn lanes. A study of accidents on 363 signalized and unsignalized intersection approaches in Ohio concluded that left-turn lanes could not be expected to reduce left-turn accident rates (*1*). In California, signalized intersections with opposing left-turn lanes were found to have significantly more accidents than intersections without opposing left-turn lanes (*2*). Likewise, a study of uncontrolled approaches to intersections on rural two-lane highways in Nebraska found that approaches with opposing left-turn lanes had higher left-turn accident rates than approaches without left-turn lanes (*3*). The findings of these studies were attributed primarily to sight-distance obstructions caused by opposing left-turn vehicles. In the Nebraska study, the most frequently observed traffic conflict on approaches with opposing left-turn lanes was between left-turn and opposing through vehicles when the sight distance between the vehicles was restricted by vehicles in the opposing left-turn lane.

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This sight-distance problem has been recognized by others as well, particularly at signalized intersections. Reilly et al. recommended the use of protected-only left-turn phases at signalized intersections with medians more than 18 ft wide because of the sight-distance obstruction caused by vehicles in the opposing left-turn lanes (*4*). In an evaluation of left-turn signal phasing, Rocciola noted that permitted left-turn phasing might result in operational difficulties when there is not enough sight distance for drivers making left turns to see adequate gaps in the opposing traffic stream, particularly when medians are wider than 20 ft or when the traffic in the opposing left-turn lane has more than 20 percent trucks large enough to obstruct the view of oncoming traffic (*5*). In addition, the Florida Section of ITE has recommended that protected-only left-turn phasing might be appropriate when the view of opposing traffic is limited by roadway curvature or opposing left-turn vehicles (*6*).

The sight-distance problem associated with opposing left-turn lanes can be eliminated simply if the lanes are offset so that opposing left-turn vehicles do not obstruct each other's view of adequate gaps in the opposing traffic stream. Reilly et al. presented sight distance requirements for left turns and recommended that opposing left-turn lanes should be offset on medians 18 ft or wider (*4*). Although they did not specify the amount of offset required, neither do existing design guides. The AASHTO design guide (*7*) and the ITE design criteria for left-turn channelization (*8*) merely caution the designer about the potential problem when median widths exceed 18 ft. However, the problem can also occur with medians narrower than 18 ft.

## OBJECTIVE

The University of Nebraska–Lincoln, in cooperation with the Nebraska Department of Roads, conducted a study of the left-turn sight-distance problem at signalized intersections with opposing left-turn lanes (*9*). The objective of the research was to develop guidelines for offsetting the lanes to eliminate the problem. The guidelines were to account for the effects of roadway alignment and traffic conditions. The guidelines developed for offsetting opposing left-turn lanes at 90-degree intersections on level, tangent sections of four-lane divided roadways are presented in this paper.

## METHODOLOGY

The problem occurs when the sight distance *available* to drivers making left turns is less than the sight distance *required* to turn left safely. The available sight distance depends on the degree to which the driver's line of sight is obstructed by opposing left-turn vehicles and the extent to which it is limited by the alignment of the roadway. The degree of obstruction caused by an opposing left-turn vehicle is determined by its size and position in the field of view. Where drivers of opposing left-turn vehicles position their vehicles with respect to one another in the intersection determines the extent to which they restrict each other's line of sight. Often they position themselves in the intersection in a way that minimizes the amount of sight-distance obstruction they cause each other and reduces the distance required to complete their turns. In this way, they attempt to overcome the sight-distance problems created by the placement of opposing left-turn lanes at many intersections. A knowledge of this behavior is essential to the development of meaningful guidelines for offsetting opposing left-turn lanes. Unfortunately, previous research has not provided this knowledge. Therefore, the development of the guidelines involved a study of the positioning of left-turn vehicles. The results of the study were then used to express available sight distance as a function of vehicle positioning and the offset between opposing left-turn lanes.

The required sight distance is the length of roadway ahead needed to see opposing through traffic that is too close to enable safe left turns. Thus, the time needed to turn left and the speed of the opposing traffic determine the required sight distance. The method used to compute the required sight distance was based on the method of computing the intersection sight distance required for a crossing maneuver presented in the AASHTO design guide (*7*).

The guidelines were developed by comparing the available and required sight distances. The minimum offsets between opposing left-turn lanes were determined by setting the expression derived for available sight distance equal to the required sight distance and solving for the offsets needed to provide the required sight distances.

## VEHICLE POSITIONING

### Data Collection

The data for the vehicle positioning study were collected by filming the left-turn movements on 12 approaches at six intersections on four-lane divided arterial streets. The left turns studied on these approaches were made from 12-ft left-turn lanes in 16-ft curbed medians with 4-ft medial separators. The criteria for selecting the study sites included the requirement that they have sufficiently high left-turn volumes to provide adequate sample sizes within reasonable amounts of time. In addition, the sites had to have suitable vantage points from which to film. Consequently, because of the left-turn volume requirement, all of the sites were at signalized intersections in Lincoln and Omaha, Nebraska.

Traffic was filmed at the study sites to record the vehicle-positioning behavior of drivers making left-turns at these locations. A 16-mm Automax Model 16010 Cine-Pulse camera was used. The camera was operated at the film speed of two frames per second. The filming was conducted primarily during periods of peak traffic flow in order to obtain adequate sample sizes. The camera was set up so that the left-turn movements from the study approach and the opposing left-turn and through traffic could be filmed simultaneously. The filming was done from an elevated vantage point on the roof of a nearby building or on a platform truck parked near the intersection.

### Data Reduction

The COGO/TOPO/ROADS software (*10*) was used in conjunction with a Lafayette 16-mm Analyzer Model 300 projector and a Numonics digitizer pad connected to a Stride computer to determine the film coordinates of the left-turn vehicles filmed at the study sites. The film was projected on to the digitizer pad. The locations of the following points were digitized in each frame of the film: (a) the left front wheel of the left-turn vehicle, (b) the right front wheel of the opposing left-turn vehicle, and (c) one of four reference points of known location. In addition, the types of the left-turn and opposing left-turn vehicles were also recorded. The location of the reference point was digitized to provide a way to check the accuracy of the digitizing.

The film data provided a record of the path of each left-turn vehicle so that its position within the intersection could be determined. However, the film coordinates were in perspective view. Therefore, it was necessary to convert the film coordinates to actual roadway coordinates. The locations of the four reference points were digitized at the beginning of each digitizing session and periodically during the session to provide the frame of reference needed for this conversion. The Huber and Tracy algorithm was used to translate film coordinates to roadway coordinates (*10*).

### Findings

Vehicle positioning refers to the location within an intersection at which a left-turn vehicle waits for an acceptable gap in the opposing through traffic stream. The vehicle positioning of the left-turn vehicles observed at the study sites was defined in terms of their longitudinal and lateral position in the intersection: the longitudinal position was the longitudinal distance of the vehicle's front left corner from the extension of the lane on the cross street into which it was turning, and the lateral position was the lateral distance of the vehicle's front left corner from the extension of the left edge of the lane from which it was turning. These distances are illustrated in Figure 1.

The longitudinal and lateral positions of the left-turn vehicles were computed from the roadway coordinates of their positions in the intersections. The positioning of a total of 1,090 opposed and 561 unopposed left-turn vehicles was ob-

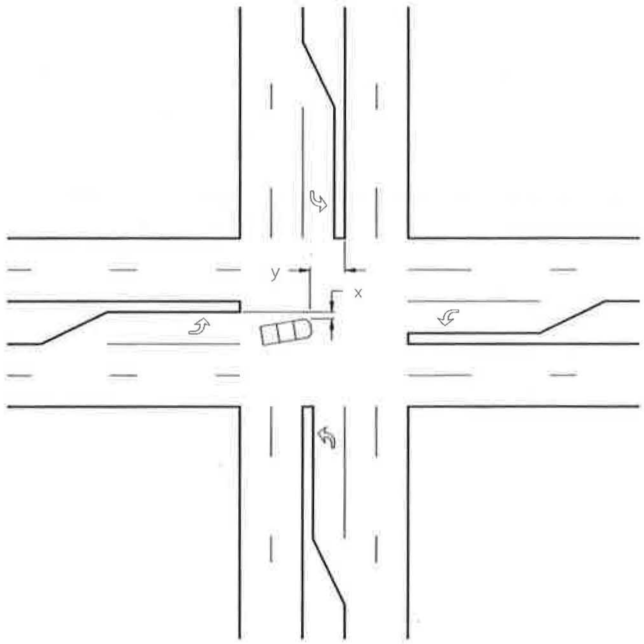


**FIGURE 1 Longitudinal and lateral distances used to define vehicle positioning.**

served. As expected, the positioning of opposed left-turn vehicles was found to be closer to the middle of the intersection than that of unopposed left-turn vehicles. However, there was no significant difference in the positioning of opposed left-turn passenger cars and trucks. The longitudinal and lateral position distributions of the opposed left-turn vehicles were the same at all of the study sites. Therefore, the opposed left-turn vehicle positioning data collected at the study sites were pooled to obtain the distributions of longitudinal and lateral distances used to develop the guidelines. These distributions were found to be normally distributed; the means and standard deviations are given in Table 1. Two of the distributions shown in Table 1 are the longitudinal and lateral position distributions for opposed left-turn vehicles that move into the intersection while waiting for an acceptable gap. The third distribution shown is the lateral position distribution for opposed left-turn vehicles that remain at the stop line in the left-turn lane while waiting for an acceptable gap. In developing the guidelines, the first two distributions were used to determine the location of the opposing left-turn vehicle and the third distribution was used to determine the location of the left-turn vehicle.

### Design Values

The critical condition for the sight distance of a left-turn vehicle occurs when there is an opposing left-turn vehicle. The positioning of the left-turn and opposing left-turn vehicles affects the amount of sight distance available to the left-turn vehicle. When the left-turn vehicle positions itself farther into the intersection, its sight distance is increased. Conversely, when the opposing left-turn vehicle moves farther into the intersection, the sight distance of the left-turn vehicle is reduced. The guidelines were developed for the 95th-percentile

**TABLE 1 Normal Distributions of Vehicle Positioning**

| Distribution | Mean (feet) | Standard Deviation (feet) | Design Value (feet) |
|---|---|---|---|
| Longitudinal Position of Opposed, Positioned Left-Turn Vehicles | 28.5 | 13.1 | 7.0[a] |
| Lateral Position of Opposed, Positioned Left-Turn Vehicles | 0.2 | 1.1 | 2.0[b] |
| Lateral Position of Opposed, Unpositioned Left-Turn Vehicles | 2.2 | 0.79 | 3.5[b] |

[a] 5th-percentile value.

[b] 95th-percentile value.

positioning of the left-turn and opposing left-turn vehicles. This means that 95 percent of the left-turn vehicles locate themselves in a position that would give them more sight distance and 95 percent of the opposing left-turn vehicles locate themselves in a position that would also give the left-turn vehicle more sight distance. Thus, if the locations of the left-turn and opposing left-turn vehicles are independent, the guidelines would be expected to accommodate about 90 percent of the left-turn vehicles.

The position of the left-turn vehicle was the 95th-percentile position of a nonaggressive left-turn driver who does not move into the intersection while waiting for an acceptable gap but instead remains in the left-turn lane. This position corresponds to the 95th-percentile value of the lateral position distribution for opposed, unpositioned left-turn vehicles in Table 1. Thus, the 95th-percentile position of the left-turn vehicle was at the stop line in the left-turn lane, 3.5 ft from the left edge of the lane.

The position of the opposing left-turn vehicle was the 95th-percentile position of an aggressive left-turn driver who moves into the intersection to wait for an acceptable gap. The longitudinal distance of this position corresponds to the 5th-percentile value of the longitudinal position distribution for opposed, positioned left-turn vehicles in Table 1, and the lateral position corresponds to the 95th-percentile value of the lateral position distribution for opposed, positioned left-turn vehicles in Table 1. Thus, the 95th-percentile position of the opposing left-turn vehicle was a longitudinal distance of 7.0 ft and a lateral distance of 2.0 ft.

## AVAILABLE SIGHT DISTANCE

The available sight distance was expressed as a function of the offset between opposing left-turn lanes. The offset is the lateral distance between the left edge of a left-turn lane and the right edge of the opposing left-turn lane. If the right edge of the opposing left-turn lane is to the left of the left edge of the left-turn lane, the offset is a negative offset. If it is to the

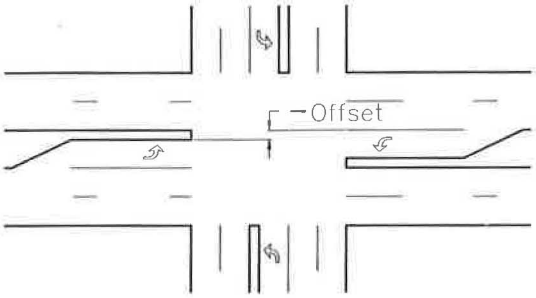


**FIGURE 2 Negative offset between opposing left-turn lanes.**

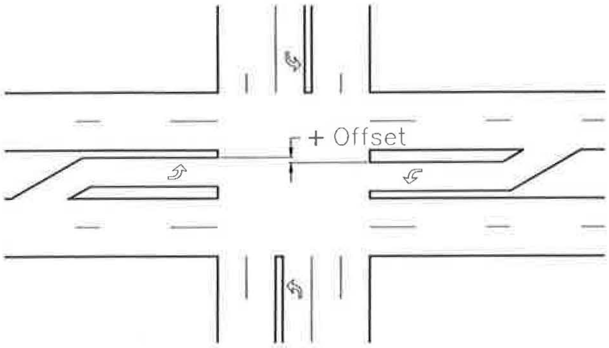


**FIGURE 3 Positive offset between opposing left-turn lanes.**

right, it is a positive offset. Examples of negative and positive offsets are shown in Figures 2 and 3. According to this definition, the offsets at the study sites were −4.0 ft, because they had opposing 12-ft left-turn lanes in 16-ft medians with 4-ft medial separators.

The available sight distance was defined as the distance from the left-turn vehicle to the point at which the driver's line of sight intersects the centerline of the inside opposing through lane. As illustrated in Figure 4, the available sight distance is

$$SD_a = Y_a + Y_b \tag{1}$$

where

$SD_a$ = available sight distance (ft),
$Y_a$ = sight distance in advance of the opposing left-turn vehicle (ft), and
$Y_b$ = sight distance beyond the opposing left-turn vehicle (ft).

The sight distance in advance of the opposing left-turn vehicle, $Y_a$, is equal to the width of the median opening at the intersection between the cross-street medial separator and the left-turn vehicle plus the longitudinal distance of the opposing left-turn vehicle. According to the AASHTO design guide (*7*), the median-opening distance for a 50-ft control radius and a 4-ft medial separator is 44 ft. From Table 1, the 95th-percentile longitudinal distance of the opposing left-turn vehicle is 7.0 ft. Therefore, the value used for $Y_a$ was 51 ft.

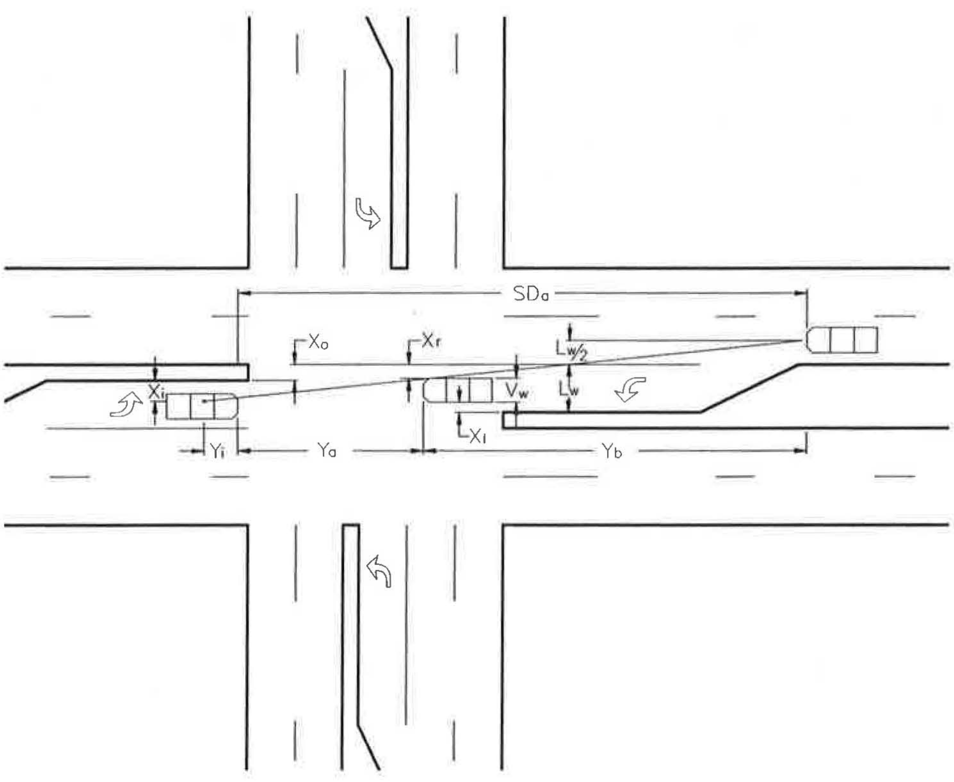


**FIGURE 4 Available sight distance.**

From Figure 4, it can be shown that the sight distance beyond the opposing left-turn vehicle, $Y_b$, is

$$Y_b = \frac{(Y_a + Y_i)\left(X_r + \frac{L_w}{2}\right)}{X_i - (X_r - X_o)} \tag{2}$$

where

$Y_i$ = longitudinal distance from the front of left-turn vehicle to driver's eye (ft),
$X_i$ = lateral distance of driver's eye from left edge of left-turn lane (ft),
$X_r$ = lateral distance of right front corner of opposing left-turn vehicle from the ridge edge of opposing left-turn lane (ft),
$X_o$ = offset between left-turn lanes (ft), and
$L_w$ = lane width (ft).

According to the AASHTO design guide (7), the value used for $Y_i$ in computing intersection sight distance is 10 ft. The distance $X_i$ is the sum of the 95th-percentile lateral position of an opposed, unpositioned left-turn vehicle in Table 1, which is 3.5 ft and the lateral distance of the driver's eye from the left side of the vehicle, which was assumed to be 1.5 ft. Therefore, a value of 5.0 ft was used for $X_i$ in Equation 2.

The lateral distance of the right side of the opposing left-turn vehicle from the right side of the opposing left-turn lane, $X_r$, is

$$X_r = L_w - V_w - X_l \tag{3}$$

where $V_w$ is the vehicle width (in feet), and $X_l$ = 95th-percentile lateral position of an opposed, positioned left-turn vehicle (in feet).

In the AASHTO design guide (7), the design vehicle width, $V_w$, is 7.0 ft for a passenger car and 8.5 ft for a truck. From Table 1, the 95th-percentile lateral position of an opposed, positioned left-turn vehicle is 2.0 ft. Therefore, for 12-ft lanes, the values used for $X_r$ were 3.0 ft for opposing left-turn passenger cars and 1.5 ft for opposing left-turn trucks.

Substituting those values into Equation 2, $Y_b$, when the opposing left-turn vehicle is a passenger car, is

$$Y_b = \frac{549}{2.0 - X_o} \tag{4}$$

And, when the opposing left-turn vehicle is a truck, $Y_b$ is

$$Y_b = \frac{457.5}{3.5 - X_o} \tag{5}$$

It is obvious from Equations 4 and 5 that unrestricted sight distance is provided at offsets of 2.0 and 3.5 ft, respectively. In these cases, the driver's eye is even with the right side of the opposing left-turn vehicle, and therefore, the opposing left-turn vehicle no longer obstructs the driver's view of the opposing through lanes.

## REQUIRED LEFT-TURN SIGHT DISTANCE

The sight distance required by left-turn vehicles is the length of roadway ahead needed to see opposing through traffic that is too close to enable left turns to be made safely. The required sight distance depends on the size of the acceptable gap and the speed of the opposing traffic. The AASHTO design guide (7) does not give explicit design values of the sight distance for left turns *from* a major roadway, which is the problem addressed by this research. Instead, it recommends the use of the AASHTO method of computing the sight distance for a crossing maneuver. According to this method, the sight distance required is based on the time it takes the stopped vehicle to clear the intersection and the design speed of the roadway being crossed as follows:

$$SD_r = 1.47V(J + t_a) \tag{6}$$

where

$SD_r$ = sight distance needed (ft),
$V$ = design speed of roadway being crossed (mph),
$J$ = perception-reaction time (sec), and
$t_a$ = time required to travel across the roadway (sec).

A value of 2.0 sec is assumed for the perception-reaction time. The time required to cross the roadway is determined from an empirical time-distance relationship for various vehicle types. The distance that must be traveled by the left-turn vehicle in order to clear the intersection depends on the size of the intersection and the length of the left-turn vehicle. For left turns made from a left-turn lane on a four-lane divided roadway, this distance plus 19 ft for the length of a passenger car is typically about 100 ft. According to the AASHTO time-distance relationship, it would take a passenger car 6.5 sec to accelerate through a distance of 100 ft. Therefore, application of the AASHTO method of computing sight distance for a crossing maneuver suggests that the time needed to turn left is 8.5 sec.

## MINIMUM OFFSETS

The minimum offsets needed between opposing left-turn lanes to provide adequate sight distance were determined by setting the available sight-distance equations equal to the required sight-distance equation and solving for the offset. When the opposing left-turn vehicle is a passenger car, the minimum offset is

$$X_o = 2.0 - \frac{549}{12.5V - 51} \tag{7}$$

This relationship is shown in Figure 5 for design speeds from 40 to 70 mph. The minimum offset is always positive. It increases with design speed and approaches a value of 2.0 ft, which is the offset that provides unrestricted sight distance when the opposing left-turn vehicle is a passenger car. An offset of 1.0 ft would accommodate design speeds 45 mph and below, and an offset of 1.5 ft would accommodate design speeds up to 70 mph.

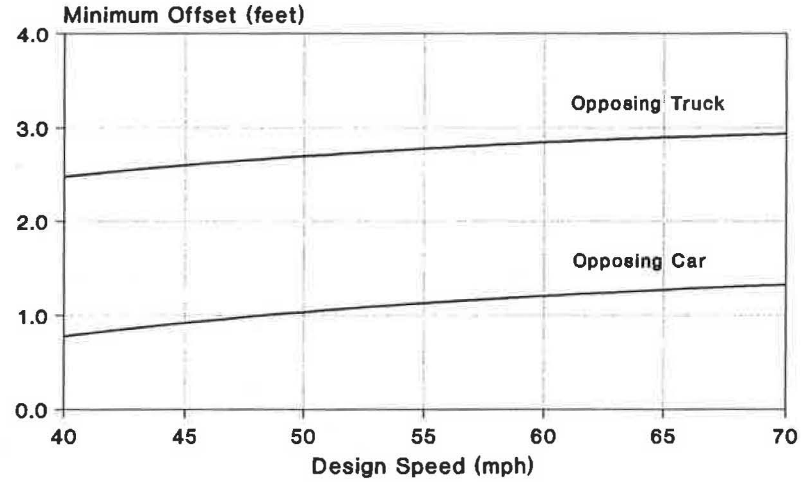


**FIGURE 5 Minimum offsets.**

When the opposing left-turn vehicle is a truck, the minimum offset is

$$X_o = 3.5 - \frac{457.5}{12.5V - 51} \quad (8)$$

This relationship is also shown in Figure 5. The minimum offset is always positive. In this case, unrestricted left-turn sight distance is provided by a 3.5-ft offset. A 2.5-ft offset would accommodate design speeds of 40 mph and lower, and a 3.0-ft offset would provide adequate sight distance for design speeds up to 70 mph.

## LEFT-TURN LANE LENGTH

When a left-turn lane is too short, traffic in the adjacent through lane may be blocked by left-turn vehicles stopped at the entrance to the left-turn lane. These left-turn vehicles waiting to enter the left-turn lane may obstruct the opposing left-turn vehicle's view of traffic in the other through lanes as illustrated in Figure 6. Therefore, at intersections where the storage capacity of the left-turn lanes may be exceeded, the sight distance between the left-turn vehicles and the traffic in the other through lanes must be adequate. The minimum offsets for opposing left-turn lanes in Equations 7 and 8 are based on the presumption that the left-turn lanes are long enough to prevent this situation from occurring.

When the storage capacity of a left-turn lane is exceeded and left-turn vehicles block the adjacent through lane, the sight distance available to a left-turn vehicle on the opposite approach depends on (a) the length of the left-turn lane, (b) the width of the intersection, and (c) the relative positioning of the left-turn vehicle and the vehicle blocking the opposing through lane. As illustrated in Figure 6, the left-turn sight distance available is

$$SD_a = W + L + Y \quad (9)$$

where

$W$ = width of intersection between opposing left-turn lanes (ft),
$L$ = length of left-turn lane plus taper (ft), and
$Y$ = sight distance beyond obstruction vehicle (ft).

The sight distance beyond the obstructing vehicle depends on the positioning of the obstructing vehicle relative to that of the left-turn vehicle. The distance between the left-turn vehicle and the obstructing vehicle is the sum of the intersection width between the opposing left-turn lanes and the length of the opposing left-turn lane, including its taper length.

Setting $SD_a$ equal to $SD_r$, it can be shown from Figure 6 that the minimum length of left-turn lane plus taper ($L$) to ensure adequate left-turn sight distance is

$$L = \frac{X_i - X_o + L_w - 2}{X_i - X_o + 1.5L_w}(SD_r + Y_i) - W - Y_i \quad (10)$$

Values of $L$ were computed for design speeds from 40 to 70 mph using the same values of $X_i$, $L_w$, $Y_i$, and $W$ that were used to derive the minimum offset equations. The obstructing vehicle was located at the end of the taper of the opposing left-turn lane in the inside through lane, 2 ft from the adjacent through lane. The results of these calculations are shown in Figure 7. It should be noted that these lengths need to be provided only at locations where the left-turn lanes are too short to prevent left-turn vehicles from blocking the through lanes.

## GUIDELINES

The guidelines developed for offsetting opposing left-turn lanes at 90-degree intersections on level, tangent sections of four-lane divided roadways with 12-ft lanes are shown in Table 2. The minimum offsets are those required to provide the opposing left-turn vehicles with the required sight distances. The desirable offsets are those that provide the opposing left-turn

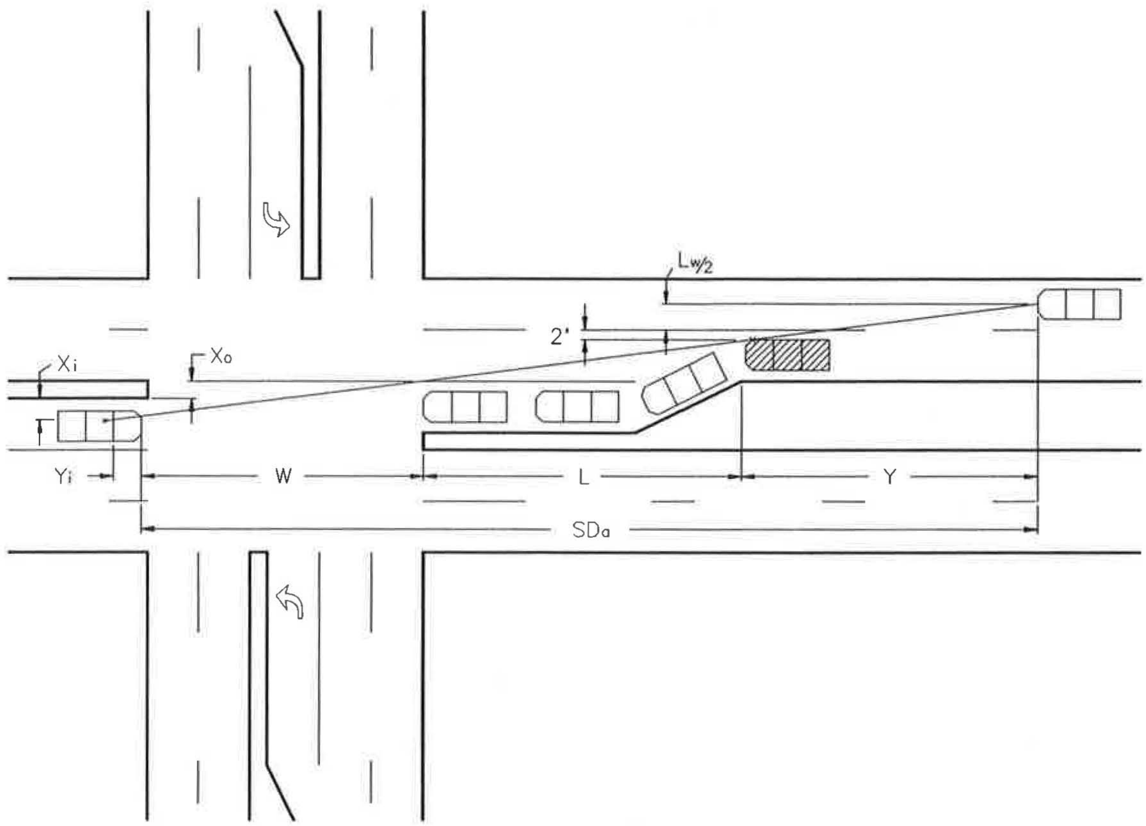


**FIGURE 6 Effect of insufficient left-turn lane storage capacity.**

vehicles with unrestricted sight distances. The desirable offsets are independent of required sight distance and are therefore more applicable than the minimum offsets. The offsets provide the required sight distance for left-turn vehicles that are passenger cars, and they are specified for two types of opposing left-turn vehicles, passenger cars and trucks. The guidelines for the opposing left-turn passenger car should be used at locations where the volumes of trucks turning left are low. Otherwise, the guidelines for the opposing left-turn truck should be used.

## LIMITATIONS

Application of the guidelines is limited to opposing left-turn lanes at 90-degree intersections on level, tangent sections of four-lane divided roadways with 12-ft lanes. They should not

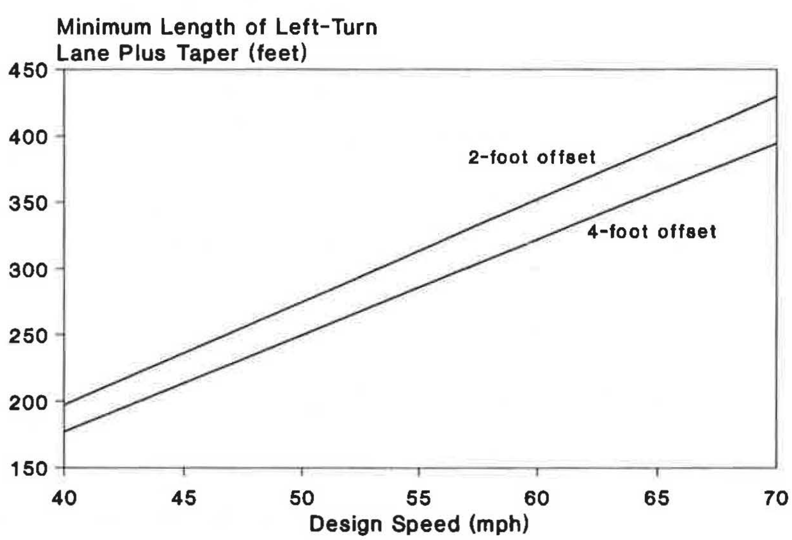


**FIGURE 7 Minimum left-turn lane lengths.**

**TABLE 2 Guidelines**

| Design Speed (mph) | Minimum Offsets (feet) | | Desirable Offsets (feet) | |
|---|---|---|---|---|
| | Passenger Car[a] | Truck[b] | Passenger Car[a] | Truck[b] |
| 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 |

[a] Opposing left-turn vehicle is a passenger car.

[b] Opposing left-turn vehicle is a truck.

be applied to situations outside the scope of these limitations. The guidelines are not applicable at skewed intersections or intersections on horizontal curves, because the geometric relationships used to derive the guidelines do not account for skew or horizontal curvature. However, they do apply at intersections on vertical curves on tangent sections that are long enough to provide adequate sight distance.

The extent to which opposing left-turn vehicles obstruct each other's sight distance depends on where they locate themselves while waiting for an acceptable gap. The vehicle positioning used to develop the guidelines was determined from the observations of vehicles making left turns from 12-ft left-turn lanes in 16-ft curbed medians with 4-ft medial separators at signalized intersections on four-lane divided roadways. The positioning of opposing left-turn vehicles at unsignalized intersections and intersections with other geometrics may not be the same. For example, vehicles may position themselves differently in 10-foot left-turn turns or in left-turn lanes with painted medians instead of curbed medians. Consequently, the offsets required in such cases may not be the same as those specified in the guidelines.

The guidelines were developed on the presumption that the storage capacities of the opposing left-turn lanes would be adequate. However, if the left-turn lanes are too short to prevent left-turn vehicles from blocking the through lanes, the effectiveness of the guidelines is compromised. In cases in which the storage capacities of the left-turn lanes are inadequate, the minimum left-turn lane lengths shown in Figure 7 must exist in order to provide the required left-turn sight distance.

Finally, it should be noted that the minimum offsets in Table 2 are dependent on the required sight distance, whereas the desirable offsets are not because they provide unrestricted sight distances. The required sight distances used to determine the minimum offsets were computed using 8.5 sec as the time needed to complete a left turn. This time was computed using the procedure in the AASHTO design guide (7) for computing the required intersection sight distances for crossing maneuvers. Thus, the development of the guidelines was consistent with the AASHTO intersection sight-distance methodology. However, required sight distances computed using times shorter than 8.5 sec would result in minimum offsets less than those shown in Table 2. Conversely, required sight distances computed using times longer than 8.5 sec would result in minimum offsets greater than those shown in Table 2. But, in either case, the desirable offsets would still be the same as those shown in Table 2.

## CONCLUSION

Vehicles turning left from opposing left-turn lanes at intersections on four-lane divided roadways restrict each other's sight distance unless the lanes are sufficiently offset. This problem can exist even on roadways with medians of only 16 ft. The guidelines presented in this paper specify the minimum and desirable offsets required between opposing left-turn lanes to provide opposing left-turn vehicles with adequate sight distance at 90-degree intersections on level, tangent sections of four-lane divided roadways with 12-ft lanes. The offsets specified are all positive indicating that the negative offsets that typically exist between opposing left-turn lanes at these locations do not provide adequate sight distances for opposing left-turn vehicles.

The vehicle positioning data used to develop the guidelines were collected at 90-degree intersections on level, tangent sections of four-lane divided roadways with 12-ft left-turn lanes in 16-ft curbed medians with 4-ft medial separators. Additional research is needed to determine the extent of any differences in positioning at other intersections such as skewed intersections, intersections on horizontal curves, and intersections with narrower lanes or painted medians. Guidelines for offsetting opposing left-turn lanes could then be developed for these types of intersections.

## ACKNOWLEDGMENT

This paper was based on research sponsored by the Nebraska Department of Roads.

## REFERENCES

1. T. J. Foody and W. C. Richardson. *Evaluation of Left-Turn Lanes as a Traffic Control Device*. Project 148210. Bureau of Traffic Control, Columbus, Ohio, Nov. 1973.
2. N. A. David and J. R. Norman. *Motor Vehicle Accidents in Relation to Geometric and Traffic Features of Highway Intersections, Volume II*. Research Report FHWA-RD-76-129. FHWA, U.S. Department of Transportation, July 1975.
3. P. T. McCoy, W. J. Hoppe, and D. V. Dvorak. *Cost-Effectiveness of Turning Lanes on Uncontrolled Approaches of Rural Intersections*. Final Report HPR Study 79-3. Nebraska Department of Roads, Lincoln, Oct. 1984.
4. W. R. Reilly, J. H. Kell, and I. J. Fullerton. *Design of Urban Streets*. Technology Sharing Report 80-204. FHWA, U.S. Department of Transportation, Jan. 1980.
5. J. Rocciola. *An Evaluation of Exclusive and Exclusive-Permissive Left Turn Signal Phasing*. Maryland Department of Transportation, Baltimore, April 1981.
6. Florida Section of ITE. Left-Turn Phase Design in Florida. *ITE Journal*, Sept. 1982, pp. 28–35.

7. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 1990.
8. ITE Technical Council Committee 5-S. Design Criteria for Left-Turn Channelization. *ITE Journal*, Feb. 1981, pp. 38–43.
9. P. T. McCoy and U. R. Navarro. *Positioning of Left-Turn Lanes*. Research Report TRP-02-24-90. Department of Civil Engineering, University of Nebraska, Lincoln, June 1991.
10. *COGO/TOPO/ROADS User's Manual*. CLM Systems, Tampa, Fl., 1986.
11. M. J. Huber and J. L. Tracy. *NCHRP Report 60: Effects of Illumination on Operating Characteristics of Freeways*. HRB, National Research Council, Washington, D.C., 1968, Appendix B.

*Publication of this paper sponsored by Committee on Operational Effects of Geometrics.*