Safety Effects of Left-Turn Lanes on Urban Four-Lane Roadways

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As part of research conducted to develop a more definitive guide for the selection of divided and undivided sections on urban four-lane roadways in Nebraska, accident experience at signalized and unsignalized intersections on urban four-lane roadways was analyzed to assess the safety effects of left-turn lanes. Results of this analysis are presented. Multivehicle accidents on intersection approaches with left-turn lanes were compared with those on similar approaches without left-turn lanes. The degree to which left-turn lanes on signalized and on uncontrolled approaches reduced acccidents was computed. The statistical significance of the percent reductions was determined using the chi-squared test. Left-turn lanes at intersections on urban four-lane roadways were found to significantly reduce rear-end, sideswipe, and left-turn accidents. However, on the uncontrolled approaches of intersections on urban undivided roadways, left-turn lanes were found to significantly increase right-angle accidents, as well as reduce rear-end, sideswipe, and left-turn accidents.

The Nebraska roadway design manual (*1*) contains a guide for the selection of typical sections on urban roadways. According to the guide, four-lane undivided sections should be selected for roadways with projected design hourly volumes (DHVs) between 400 and 600 vehicles per hour (vph), and four-lane divided sections should be selected for roadways with projected DHVs between 1,800 and 3,200 vph. For roadways with projected DHVs between 600 and 1,800 vph, the guide suggests using either a four-lane undivided or divided section, depending on the character of the roadway, traffic, and surrounding area.

The experience of the Nebraska Department of Roads (NDOR) with the guide indicates that it is too ambiguous to use for urban roadways with projected DHVs between 600 and 1,800 vph. Frequently, four-lane undivided sections have been selected and later found to be inadequate well in advance of their design years because they do not provide for left-turn lanes at the intersections. Therefore, research was undertaken to develop a more definitive guide to consider the need for left-turn lanes at intersections on urban roadways with projected DHVs between 600 and 1,800 vph.

The need for left-turn lanes was determined on the basis of intersection capacity and the safety effects of left-turn lanes. Intersection capacities were evaluated to determine the traffic volumes at which left-turn lanes would be required in order to provide design levels of service. Accident experience at intersections on urban four-lane roadways was analyzed to assess the safety effects of left-turn lanes. The accident analysis is presented in this paper. The capacity analysis and the section selection guide developed are presented elsewhere (*2*).

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PREVIOUS RESEARCH

Several studies have been conducted of the safety effects of left-turn lanes. Only a few of those conducted at intersections on four-lane roadways, however, have been reported in the literature.

A before-and-after study of 53 left-turn channelization projects at urban and rural intersections in California found that the installation of left-turn lanes resulted in significant reductions in accidents (*3*). Rear-end, left-turn, and total accidents at unsignalized intersections were reduced by 85 percent, 37 percent, and 48 percent, respectively. However, right-angle accidents increased significantly by 153 percent. At signalized intersections, left-turn and total accidents were reduced by 54 percent and 17 percent, respectively. No significant changes in right-angle and rear-end accidents were reported.

Accident experience over a 2-year period on 363 intersection approaches on rural state highways in Ohio was analyzed to evaluate the safety effects of left-turn lanes (*4*). Approaches were classified with respect to signalization, number of lanes, presence of a left-turn lane, and intersection type. Approaches with left-turn lanes were found to have lower accident rates than approaches without left-turn lanes.

On four-lane roadways at unsignalized approaches with left-turn lanes, left-turn and total accident rates were 27 percent and 32 percent lower, respectively, and at signalized approaches with left-turn lanes, left-turn and total accident rates were 39 percent and 9 percent lower, respectively. None of these differences was found to be statistically significant at the 5 percent level of significance. However, the results of the study showed that the number of approach lanes and the type of intersection control must be considered in the evaluation of the safety effects of left-turn lanes.

A study of the relationships between accidents and roadway conditions revealed that there were significantly higher accident rates at intersections with opposing left-turn lanes than at intersections without left-turn lanes (*5*). The addition of left-turn lanes at signalized intersections without left-turn phases was found to increase accident rates, a situation that led to the recommendation that left-turn lanes be used as a means to increase intersection capacity and not as an accident-reduction measure. However, these findings were confounded by the failure to differentiate between one-lane and two-lane approaches.

Five years of accident data for intersections in Lexington, Kentucky, were used to investigate the relationship between left-turn accidents and left-turn lanes (*6*). The study definition of left-turn accidents included three types of collisions: (a) a vehicle turning left into the path of an oncoming vehicle; (b) a left-turning vehicle that is struck from behind while waiting to turn left; and (c) a vehicle that weaves around a vehicle stopped to turn left and is struck by a third vehicle. The left-turn accident rates for intersections with left-turn lanes were found to be substantially lower than those for intersections without left-turn lanes. The left-turn accident rate was 77 percent lower at unsignalized intersections and 54 percent lower at signalized intersections without protected left-turn phases.

The accident reduction factors from the literature cited previously are summarized in Table 1. Except for right-angle accidents at unsignalized intersections and rear-end accidents at signalized intersections, left-turn lanes were consistently found to be associated with fewer accidents. However, only the accident reductions found in the California study (*3*) were reported as statistically significant. None of the accident-reduction factors was reported as being computed exclusively from accident experience at intersections on urban four-lane roadways.

PROCEDURE

Accident experience at intersections on urban four-lane roadways in Nebraska was analyzed to determine the safety effects of left-turn lanes at these locations. The first step was to select the intersections for the study from among urban four-lane roadways with DHVs between 600 and 1,800 vph, the focus of the research. According to NDOR traffic count data (*7*), the DHV on an urban roadway is about 10 percent of the annual average daily traffic (AADT). Therefore, the (NDOR) computerized state highway system inventory was searched to identify all urban four-lane segments with AADTs between 6,000 and 18,000 vpd. The NDOR traffic signal inventory and photolog data were then used to locate and classify the intersection approaches on these segments.

Intersection approaches were classified according to type of control and presence of left-turn lane:

1. Signalized approach without a left-turn lane,
2. Signalized approach with a left-turn lane,
3. Uncontrolled approach without a left-turn lane, and
4. Uncontrolled approach with a left-turn lane.

Signalized approaches with protected left-turn phases, stop-sign controlled approaches, and yield-sign controlled approaches were not included in the study. Only approaches at intersections with AADTs on the crossroads of at least 1,000 vpd were classified.

TABLE 1 ACCIDENT REDUCTION FACTORS FOR LEFT-TURN LANES FROM PREVIOUS RESEARCH

Accident Type	Unsignalized Intersections (%)	Signalized[a] Intersections (%)
Right angle	−153[b] (*3*)	None reported
Rear-end	85[b] (*3*)	−15 (*3*)
Left turn	37[b] (*3*), 27 (*4*) 77[c] (*6*)	54[b] (*3*), 39 (*4*) 54[c] (*6*)
All	48[b] (*3*), 32 (*4*)	17[b] (*3*), 9 (*4*)

[a]Without protected left-turn phases.
[b]Statistically significant at the 5 percent level of significance.
[c]Includes left-turn related rear-end and sideswipe accidents.

A minimum of 10 intersection approaches in each of the four approach categories were to be used in the accident study. Ten intersections from each category were selected initially at random. Photologs, construction records, and traffic volume data were examined to determine if the roadway and traffic conditions had remained the same since 1984 at each of the intersections selected. Approaches at intersections where the conditions had changed were not used as study sites.

The approaches in the two signalized approach categories were compared to ensure that they had similar roadway and traffic conditions and that the only major distinction between them was the presence of left-turn lanes. Likewise, the approaches in the two uncontrolled approach categories were compared. Approaches with conditions that differed from the majority were not used as study sites. If the elimination of some intersections reduced the total number of study sites in any category to fewer than 10, additional intersections were selected at random to increase the number to at least 10.

Current 8-hour turning movement counts and copies of all accident reports for 1984, 1985, and 1988 for the study sites were obtained from NDOR. The turning movement counts were expanded to AADTs, which were used to compute mean accident rates for each approach category.

Accident rates for the approach categories with left-turn lanes were compared with those for the corresponding approach categories without left-turn lanes to compute the reductions in accident rate attributed to left-turn lanes. The statistical significance of the percent reductions was determined using the chi-square test (*8*), which has also been referred to as the Poisson comparison of means test (*9*).

STUDY SITES

A total of 63 intersections were found to have approaches that met site selection criteria. See Table 2 for the number of intersections in each approach category. Ten intersections were initially selected at random from each category. Four of the 40 were eliminated because the roadway and traffic conditions had not remained the same since 1984. These were not replaced, however, because the remaining intersections provided more than 10 study sites in each category. A total of 46 study sites were used. Table 3 presents the number of study sites in approach categories.

All of the study sites were on tangent sections of urban four-lane roadways in outlying commercial areas with streetlights. All were approaches to four-leg, right-angle intersections. Most were on level grades, and the rest were on slight to moderate grades. None was on a hillcrest or had sight distance restrictions caused by the alignment of the roadway.

TABLE 2 TOTAL NUMBER OF INTERSECTIONS IN EACH APPROACH CATEGORY

Approach Category	Number of Intersections
Signalized[a] without left-turn lane	20
Signalized[a] with left-turn lane	15
Uncontrolled without left-turn lane	14
Uncontrolled with left-turn lane	14
Total	63

[a]Without protected left-turn phases.

Posted speed limits of 30 and 35 mph were found at sites in the signalized approach categories; at sites in the uncontrolled approach categories, they were between 35 and 45 mph. Table 4 gives the distribution of study site speed limits.

Sites without left-turn lanes were on four-lane undivided roadways and had two 12-foot lanes—one through/left-turn lane and one through/right-turn lane. Sites with left-turn lanes were on four-lane divided roadways with 16-ft raised curb medians and had three 12-ft lanes—one left-turn lane, one through lane, and one through/right-turn lane. The opposing approach at each site also had a left-turn lane.

ACCIDENT ANALYSIS

Left-turn lanes are intended to reduce multivehicle accidents on intersection approaches, particularly those accidents related to left-turning traffic. Therefore, accident rates were computed for each approach category for the following types of multivehicle accidents: (a) right-angle, (b) rear-end, (c) sideswipe (same direction), (d) sideswipe (opposite direciton), (e) head-on, (f) left-turn, and (g) right-turn. The volumes used to compute each rate were the volumes of the turning movements involved in the particular type of accident. The turning-movement combinations involved in each accident category and the turning-movement volumes used to compute each accident rate are presented in Table 5.

For example, the turning-movement combinations involved in accidents defined as rear-end accidents were:

1. Two left-turn movements on the study approach (movements 1 and 1);
2. A left-turn and a through movement on the study approach (movements 1 and 2);
3. A left-turn and a right-turn movement on the study approach (movements 1 and 3);
4. Two through movements on the study approach (movements 2 and 2);
5. A through and a right-turn movement on the study approach (movements 2 and 3); and
6. Two right-turn movements on the study approach (movements 3 and 3).

Therefore, the volume used to compute the rear-end accident rate was the sum of the left-turn, through, and right-turn volumes on the study approach.

However, only three movement combinations were defined for the left-turn accident:

1. A left-turn movement on the study approach and a left-turn movement on the opposing approach (movements 1 and 7);
2. A left-turn movement on the study approach and a through movement on the opposing approach (movements 1 and 8); and
3. A left-turn movement on the study approach and a right-turn movement on the opposing approach (movements 1 and 9).

Therefore, the volume used to compute the left-turn accident rate was the sum of the left-turn volume on the study approach and the total volume on the opposing approach.

The accident rates were computed using the accidents that occurred on the study approaches during 1984, 1985, and 1986. For each of the four approach categories, each accident rate was computed using the total number of accidents and the total turning-movement volumes on all study approaches in the approach category.

The percent reductions in the accidents associated with the presence of left-turn lanes were computed as follows:

$$R = [(B - A)/B] \cdot 100\% \quad (1)$$

where

R = percent reduction in accidents (%),
B = number of accidents on approaches without left-turn lanes, and
A = number of accidents on approaches with left-turn lanes.

Percent reductions were computed for the signalized and the uncontrolled approach categories. The statistical significance of the percent reductions was checked using the chi-squared test. In Equation 1, the numbers of accidents on approaches with left-turn lanes were computed by applying the accident rates for these approaches to the turning-movement volumes for the approaches without left-turn lanes. Thus the number of accidents, with and without left-turn lanes, were for the same volumes.

TABLE 3 NUMBER OF STUDY SITES IN EACH APPROACH CATEGORY

Approach Category	Number of Study Sites
Signalized[a] without left-turn lane	11
Signalized[a] with left-turn lane	10
Uncontrolled without left-turn lane	12
Uncontrolled with left-turn lane	13
Total	46

[a]Without protected left-turn phases.

TABLE 4 SPEED LIMITS ON STUDY SITES

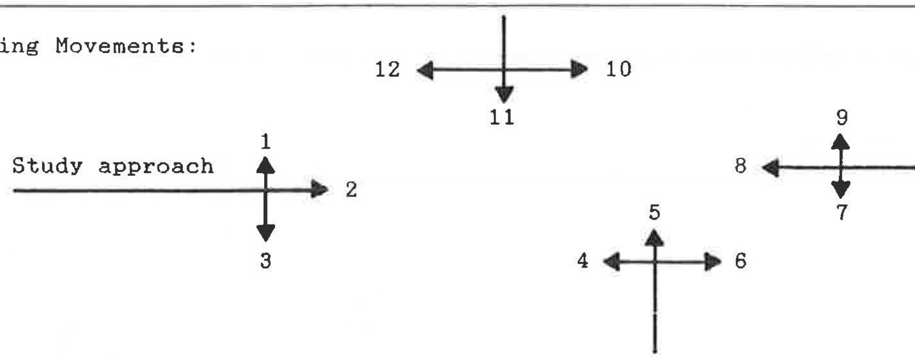
	Signalized Approach[a]		Uncontrolled Approach	
Speed Limit	Without LT Lane	With LT Lane	Without LT Lane	With LT Lane
30	5	3	0	0
35	6	7	6	4
40	0	0	1	2
45	0	0	5	7
Total Study Sites	11	10	12	13

[a]Without protected left-turn phases.

TABLE 5 ACCIDENT TURNING MOVEMENTS[a]

Accident Type	Turning Movement Combinations Involved	Turning Movement Volumes Used to Compute Accident Rates
right-angle	1-4,1-5,1-6,1-10,1-11, 2-4,2-5,2-6,2-10,2-11, 3-10,3-11	1,2,3,4,5,6,10,11
rearend	1-1,1-2,1-3,2-2,2-3,3-3	1,2,3
sideswipe (same direction)	1-1,1-2,1-3,2-2,2-3,3-3	1,2,3
sideswipe (opposite direction)	2-8,2-9,3-8,3-9	2,3,8,9
head-on	2-8,2-9,3-8,3-9	2,3,8,9
left-turn	1-7,1-8,1-9	1,7,8,9
right-turn	3-4,3-5,3-6	3,4,5,6

[a]Turning Movements:



FINDINGS

The accident rates computed for each category are given in Table 6, as well as the number of accidents and turning-movement AADTs used to compute the accident rates. The percent reductions in the accident rates associated with the presence of left-turn lanes are presented in Table 7.

The presence of left turn lanes was never associated with statistically significant reductions in sideswipe (opposite direction), head-on, or right-turn accident rates. This finding was expected because these types of accidents seldom occurred on the study approaches. It is consistent with previous research, which has not reported any relationships between the occurrence of these types of accidents and the presence of left-turn lanes (*3,4,5,6,10*).

The presence of left-turn lanes on the signalized intersection approaches was not associated with any statistically significant change in the right-angle accident rate. However, the presence of left-turn lanes on the uncontrolled approaches was associated with a statistically significant 68 percent increase in the right-angle accident rate. This finding is consistent with the California study (*3*) cited previously, which also found a significant increase in right-angle accidents after left-turn lanes were installed at unsignalized intersections in urban areas. It should be noted, however, that the increase in the right-angle accident rate was determined through a comparison of approaches on four-lane undivided roadways without left-turn lanes and on approaches on four-lane divided roadways with left-turn lanes. The increase in the right-angle accident rate probably reflects the greater degree of difficulty cross-street drivers have determining adequate gaps to accept (when crossing a four-lane divided street with a 16-ft median), as well as the longer distances that cross-street drivers must travel. Therefore, although the installation of left-turn lanes on

TABLE 6 NUMBER ACCIDENTS, TURNING MOVEMENT AADTS, AND ACCIDENT RATES

Accident Type	Signalized Approach[a] Without LTL[b]	Signalized Approach[a] With LTL	Uncontrolled Approach Without LTL	Uncontrolled Approach With LTL
Number of Accidents:[c]				
right-angle	37	25	23	48
rearend	61	26	27	4
sideswipe (same dir.)	14	4	5	3
sideswipe (opp.dir)	2	0	0	0
head-on	0	0	0	0
left-turn	31	11	40	7
right-turn	0	1	0	0
Turning Movement AADTs:				
right-angle	128,550	138,550	95,443	118,620
rearend	94,720	99,287	82,350	103,900
sideswipe (same dir.)	94,720	99,287	82,350	103,900
sideswipe (opp. dir.)	178,870	187,440	154,700	187,380
head-on	178,870	187,440	154,700	187,380
left-turn	100,960	104,860	87,340	109,980
right-turn	28,510	31,712	12,730	13,810
Accident Rates (accidents/million entering vehicles):				
right-angle	.26	.16	.22	.37
rearend	.59	.24	.30	.035
sideswipe (same dir.)	.14	.037	.055	.026
sideswipe (opp. dir.)	.010	0	0	0
head-on	0	0	0	0
left-turn	.28	.096	.42	.058
right-angle	0	.029	0	0

[a]Without protected left-turn phases.

[b]LTL - left-turn lane.

[c]Number of accidents during three-year period.

uncontrolled intersection approaches on four-lane undivided roadways would be expected to increase right-angle accidents, their installation on uncontrolled intersection approaches on four-lane divided roadways would not necessarily be expected to increase right-angle accidents.

Left-turn lanes are intended to reduce conflicts between through and left-turning traffic. As expected, the presence of left-turn lanes on signalized and uncontrolled approaches was associated with statistically significant reductions in rear-end, sideswipe (same direction), and left-turn accident rates. This finding is consistent with the results of previous studies (*3,4,6*) and indicates that left-turn lanes are effective in reducing these types of accidents at intersections on urban four-lane roadways.

CONCLUSION

The results of this research are consistent with those of previous studies. Left-turn lanes are demonstrated to be effective in reducing rear-end, sideswipe (same direction), and left-turn accidents at intersections on urban four-lane roadways with DHVs between 600 and 1,800 vph and cross-traffic AADTs above 1,000 vpd. Contrary to accident experience reported on two-lane roadways (*5,11*), the results of this study show that opposing left-turn lanes on four-lane roadways do not increase left-turn accidents.

However, the results of this research also indicate that left-turn lanes on the uncontrolled approaches of intersections on urban four-lane undivided roadways increase right-angle acci-

TABLE 7 PERCENT REDUCTION IN NUMBERS OF ACCIDENTS

Accident Type	Signalized Approach[a] (%)	Uncontrolled Approach (%)
Right-angle	37	−68[b]
Rear-end	59[b]	88[b]
Sideswipe (same direction)	73[b]	52
Sideswipe (opposite direction)	100	0
Head-on	0	0
Left-turn	66[b]	86[b]
Right-turn	---[c]	0

NOTE: Percent reductios in numbers of accidents associated with the presence of left-turn lanes. Negative percent reductions indicate higher numbers of accidents when left-turn lanes are present.
[a]Without protected left-turn phases.
[b]Percent reduction is statistically significant at the 5 percent level of significance.
[c]Undefined percent reduction, because there were no accidents without left-turn lanes, but a non-zero number of accidents with left-turn lanes.

dents. Consequently, the trade-off between the reductions in rear-end, sideswipe, and left-turn accidents and the increase in right-angle accidents should be considered when evaluating the cost-effectiveness of installing left-turn lanes at these locations.

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