Comparison of Left-Turn Accident Rates for Different Types of Left-Turn Phasing

JONATHAN UPCHURCH

Left-turn accident rates are compared for five types of left-turn phasing: permissive; leading exclusive/permissive; lagging exclusive/permissive; leading exclusive; and lagging exclusive. Two different study designs were used to compare left-turn accident rates; both a simple comparison design and a simple before-and-after design were used. Left-turn accident rate (number of left-turn accidents per million left-turning vehicles) is used to compare the relative safety of the different types of left-turn phasing. Left-turn accident rates are shown for each type of left-turn phasing and are further subdivided by whether there are two or three lanes of opposing traffic, by left-turn volume, and by opposing volume. The before-and-after data are categorized according to the types of left-turn phasing in the before and after periods. Observations and conclusions are made about the effect of volume, number of lanes of opposing traffic, and type of left-turn phasing on the accident rate.

During the past several years there has been a substantial interest in different types of left-turn signal phasing. Research has centered on both the operational and safety characteristics associated with different types of left-turn phasing. Agent (*1–3*), Beaudry (*4*), Mohle and Rorabaugh (*5*), the Florida Section of ITE (*6*), Cottrell and Allen (*7*), Machemehl and Mechler (*8*), the Colorado-Wyoming Section of ITE (*9*), Warren (*10*), and Upchurch (*11*) each conducted research that looked at various operational and safety aspects of left-turn phasing.

The research project described here compared the accident rates associated with different types of left-turn phasing.

PREVIOUS WORK COMPARING ACCIDENT EXPERIENCE

None of the previous studies compared the accident experience of all five types of left-turn phasing, namely: permissive; leading exclusive/permissive; lagging exclusive/permissive; leading exclusive; and lagging exclusive. Seldom are all five of these types of phasing used in one jurisdiction. Generally speaking, many of the previous research efforts have been before-and-after types of studies that compared a change from one type of phasing to another. Warren (*10*), for example, compared intersections that were changed from leading exclusive to leading exclusive/permissive and intersections that were changed from permissive to leading exclusive/permissive. Little research has compared the accident experience of leading phasing versus lagging phasing.

Department of Civil Engineering, Arizona State University, Tempe, Ariz. 85287-5306.

RESEARCH APPROACH

This study compares the relative safety of different types of left-turn phasing by comparing the accident rate for left-turn accidents. Left-turn accidents are those in which the manner of collision reported on an accident report form involves a vehicle turning left. The accident rate is based on the number of left-turn accidents and the associated left-turn volume. The rate is expressed in terms of number of left-turn accidents per 1 million left-turning vehicles.

ACCIDENT STATISTICS FOR A SIMPLE COMPARISON

One method of comparing the relative safety of different types of left-turn phasing is to compare accident rates on approaches with one type of left-turn phasing with accident rates on approaches with a second type of left-turn phasing. This is called a simple comparison design.

Two large data bases were created for this project. The data bases included information, by approach, for 495 signalized intersections on roadways maintained by the Arizona Department of Transportation (ADOT) and 132 signalized intersections in six local jurisdictions in Arizona. The data provided the opportunity to develop accident statistics and enabled a comparison. Statistics were developed for different types of left-turn phasing, varying numbers of opposing lanes (two or three), varying ranges of left-turn volume, and varying ranges of opposing volume.

Each sample used in developing the accident statistics represents a single approach at an intersection. A total of 523 samples (intersection approaches) were included in developing the accident statistics. Approaches with two opposing lanes had 329 samples; approaches with three opposing lanes had 194 samples. All approaches used for this analysis had a separate left-turn lane.

For intersections on the state highway system, most samples represent a 4-year accident history (1983 through 1986). For intersections in local jurisdictions, samples range from a minimum of 7 months to a maximum of 48 months (all in the period from 1981 to 1989). The "mean" accident rate is a

weighted average which is weighted in proportion to the time period sampled on an approach.

Gross accident statistics are shown in Table 1. Statistics are shown for five types of left-turn phasing: permissive; leading exclusive/permissive; lagging exclusive/permissive; leading exclusive; and lagging exclusive. Separate statistics are presented for locations having two opposing lanes of traffic and locations having three opposing lanes of traffic. The mean left-turn accident rate is shown along with the sample size (*N*) on which that mean rate is based.

The sample size for lagging exclusive phasing is too small to rely on the average accident rates for comparison purposes. For the four remaining types of phasing, the following observations and conclusions can be made about the statistics that are not stratified by volume:

- Leading exclusive phasing has the lowest left-turn accident rate.
- When there are two opposing lanes, lagging exclusive/permissive has the worst accident rate.
- When there are three opposing lanes, leading exclusive/permissive has the worst accident rate.
- For two opposing lanes, the order of safety (from best to worst) is leading exclusive, permissive, leading exclusive/permissive, and lagging exclusive/permissive. However, there is a small difference in the accident rate among the last three types of phasing.
- For three opposing lanes, the order of safety (from best to worst) is leading exclusive, lagging exclusive/permissive, permissive, and leading exclusive/permissive.
- In three out of four cases, accident rates are higher with three opposing lanes. The exception is for lagging exclusive/permissive phasing (although the difference in rates is small).

Tables 2 and 3 show similar accident statistics for various ranges of left-turn volume (vehicles per day) and various ranges of opposing volume (vehicles per day).

Opposing volume is defined as the through and right-turn volume on the approach opposite the left-turn movement. Again, the sample size for lagging exclusive phasing is too small to rely on the average accident rates for comparison purposes. For the four remaining types of phasing, the following observations and conclusions can be made about the statistics that are stratified by volume:

- Several cases have a sample size of five or less. No interpretations are made for these cases because it would be risky to make comparisons with mean accident rates based on such a small sample size.
- Leading exclusive phasing has the lowest left-turn accident rate in almost every case. This is true in every left-turn volume range and every opposing volume range except one (19 out of 20 cases).
- When there are two lanes of opposing traffic, lagging exclusive/permissive tends to have the worst accident rate.
- When there are three lanes of opposing traffic, leading exclusive/permissive tends to have the worst accident rate.
- When there are two lanes of opposing traffic, the order of safety (from best to worst) tends to be leading exclusive, permissive, leading exclusive/permissive, and lagging exclusive/permissive. However, there is a small difference in the accident rate among the last three types of phasing.
- When there are three lanes of opposing traffic, the order of safety (from best to worst) tends to be leading exclusive, lagging exclusive/permissive, permissive, and leading exclusive/permissive.
- Generally, accident rates are higher for three opposing lanes of traffic than for two opposing lanes of traffic. This is true in 30 out of 40 cases (combinations of phasing and volume). Lagging exclusive/permissive tends to be an exception to this rule.
- Some trends are apparent in the accident rate as a function of volume:
  - —For all four types of phasing (permissive, leading exclusive/permissive, lagging exclusive/permissive, and leading exclusive), with *two* opposing lanes of traffic, the accident rate *decreases* as left-turn volume *increases*. Figures 1 to 3 plot left-turn accident rate as a function of left-turn volume for three of these conditions (permissive phasing, lagging exclusive/permissive, and leading exclusive). Note that the vertical scale is different on each of these three figures.
  - —For all four types of phasing (permissive, leading exclusive/permissive, lagging exclusive/permissive, and leading exclusive), with *two* opposing lanes of traffic, the accident rate *increases* as opposing volume *increases*.
  - —For *three* opposing lanes of traffic, only one trend is apparent in left-turn accident rate as a function of volume.

TABLE 1 STATISTICS ON LEFT-TURN ACCIDENT RATE

		Permissive	Leading Exclusive/ Permissive	Lagging Exclusive/ Permissive	Leading Exclusive	Lagging Exclusive
2 opposing lanes	M	2.62	2.71	3.02	1.02	2.09
	N	162	62	44	57	4
3 opposing lanes	M	3.83	4.54	2.65	1.33	0.55
	N	25	52	35	80	2

M = Mean Left Turn Accident Rate

N = Number of approaches in the sample

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

TABLE 2 STATISTICS ON LEFT-TURN ACCIDENT RATE STRATIFIED BY LEFT-TURN VOLUME

Left Turn Vol.	Permissive		Leading Exclusive/ Permissive		Lagging Exclusive/ Permissive		Leading Exclusive		Lagging Exclusive	
	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N
2 Opposing Lanes										
0-1000	3.07	93	4	16	4.71	10	1.24	14	6.3	1
1000-2000	2.38	51	2.44	25	2.89	13	1.42	22	1.43	1
2000-3000	.87	13	2.43	16	2.66	9	.51	13	.62	1
3000-4000	1.62	3	2.87	3	2.19	7	.52	2	N.A.	0
>4000	.45	2	.84	2	1.21	5	.24	6	0	1
Cumu-lative	2.62	162	2.71	62	3.02	44	1.02	57	2.09	4
3 Opposing Lanes										
0-1000	4.21	8	4.33	17	1.11	7	1.37	12	1.66	1
1000-2000	3.51	12	5.94	8	4.34	12	1.09	23	0	1
2000-3000	4.06	5	3.98	11	2.87	6	1.26	26	N.A.	0
3000-4000	N.A.	0	3.98	11	2.03	6	.84	12	N.A.	0
>4000	N.A.	0	5.27	5	1.67	4	.92	7	N.A.	0
Cumu-lative	3.83	25	4.54	52	2.65	35	1.33	80	.55	2

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

Left Turn Volume is the 24 hour left turn volume.
MEAN is the mean accident rate for the approaches in the sample.
N is the sample size.
Cumulative is the weighted average mean for all volumes.

TABLE 3 STATISTICS ON LEFT-TURN ACCIDENT RATE STRATIFIED BY OPPOSING VOLUME

Opposing Volume	Permissive		Leading Exclusive/ Permissive		Lagging Exclusive/ Permissive		Leading Exclusive		Lagging Exclusive	
	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N
2 Opposing Lanes										
0-5000	1.4	71	1.97	15	1.43	5	.23	9	0	1
5000-10000	1.98	58	2.92	21	3.26	15	.49	17	1.43	1
10000-15000	3.54	17	2.89	19	3.47	18	2.07	19	3.46	2
15000-20000	6.08	8	2.33	5	3.54	2	.64	6	N.A.	0
>20000	4.99	8	4.54	2	2.37	2	.69	6	N.A.	0
Cumu-lative	2.62	162	2.71	62	3.02	42	1.02	57	2.09	4
3 Opposing Lanes										
0-5000	3.28	5	3.91	2	N.A.	0	.25	3	1.66	1
5000-10000	2.05	7	4.78	10	2.57	8	1.01	12	N.A.	0
10000-15000	4.83	5	4.32	12	3.3	11	.98	22	.0	1
15000-20000	6.61	4	4.98	16	2.51	10	1.15	17	N.A.	0
>20000	2.78	4	4.07	12	1.88	6	1.45	26	N.A.	0
Cumu-lative	3.83	25	4.54	52	2.65	35	1.33	80	.55	2

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume.Rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

Opposing Volume is the 24 hour opposing volume (through and right turning vehicles on the opposite approach).
MEAN is the mean accident rate for the approaches in the sample.
N is the sample size.
Cumulative is the weighted average mean for all volumes.

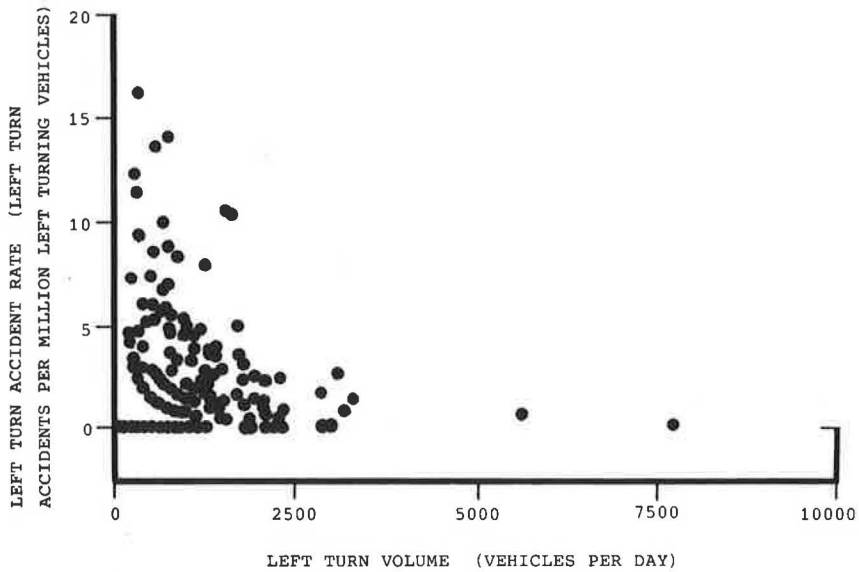

FIGURE 1 Left-turn accident rate plotted for permissive phasing.

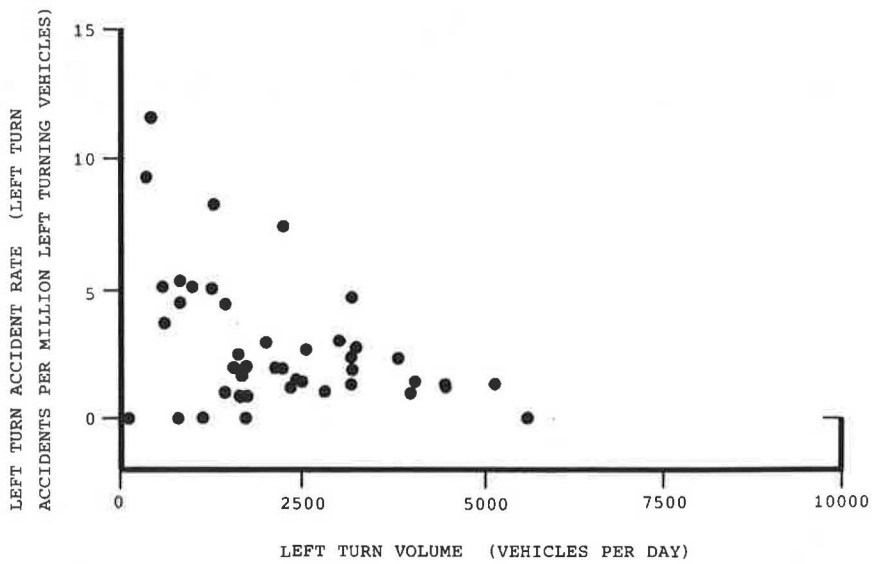

FIGURE 2 Left-turn accident rate plotted for lagging exclusive/permissive phasing.

For permissive left-turn phasing the accident rate *increases* as opposing volume *increases*.

The study team also looked at accident statistics for conditions that were stratified by both left-turn volume and opposing volume at the same time. This stratification would allow a traffic engineer to pick a range of left-turn volume, a range of opposing volume, a number of opposing lanes, and a type of phasing and determine the accident rate for those conditions. For example, the condition of left-turn volumes between 0 and 1,000 per day, opposing volume between 0 and 5,000 per day, two opposing lanes, and permissive left-turn phasing had a left-turn accident rate of 1.53 (based on a sample size of 44).

The availability of accident rate information of this form would be a tremendous asset to the traffic engineer. Unfortunately, stratifying conditions to this level of detail resulted in very small sample sizes for most cases. Eighty-eight percent of the cases had a sample size of five or less. Forty-two percent of the cases had a sample size of zero.

ACCIDENT STATISTICS FOR CONVERSIONS

A second means of comparing the relative safety of different types of left-turn phasing is to compare the accident experience before and after a location had been converted from one type of phasing to another. This is the simple before-and-after design. To make this type of comparison, additional information was obtained on conversions from one type of phasing to another for both ADOT roadway intersections and local jurisdiction intersections.

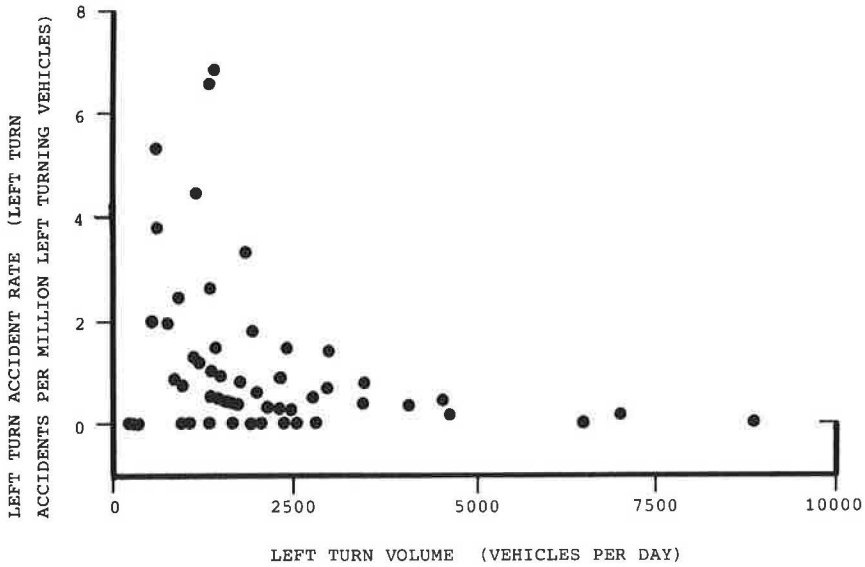

FIGURE 3 Left-turn accident rate plotted for leading exclusive phasing.

Six local jurisdictions provided information. The number of intersection approaches in each jurisdiction that were usable for the analysis were as follows:

Jurisdiction	*No. of Usable Approaches*
ADOT	15
Glendale	12
Maricopa County	0
Mesa	0
Pima County	3
Scottsdale	157
Tempe	7
Total	194

The local jurisdiction conversions used for a before-and-after analysis included some conversions that were made in 1984 and several that were made in late 1988 and early 1989. For each conversion, 4 years of before accident data and 4 years of after accident data were used where available. In many cases, such as the conversions done in late 1988 and early 1989, a shorter after period was available. In most of these cases, accident data through the end of 1989 were acquired.

With five different types of left-turn phasing, 20 different conversions could take place. The different types of conversions are not equally popular. For example, it is rare to convert from some more restrictive type of phasing to permissive phasing. Among the 194 approaches used in the statistical evaluation, the more popular types of conversion and their frequency are noted below:

Conversion	*Frequency*
Permissive to leading exclusive/permissive	20
Permissive to lagging exclusive/permissive	17
Leading exclusive/permissive to permissive	17
Leading exclusive/permissive to lagging exclusive/permissive	73
Leading exclusive to leading exclusive/permissive	25
Leading exclusive to lagging exclusive/permissive	15
Leading exclusive to lagging exclusive	22

These seven types of conversion accounted for 189 of the 194 intersection approaches. Eleven of the 20 possible types of conversions were never done.

Tables 4 and 5 show before and after accident statistics for the 194 approaches that were converted from one type of left-turn phasing to another. The left-turn accident rate is based on the number of left-turn accidents (manner of collision) and the associated left-turn volume. The rate is in terms of accidents per million left-turning vehicles. Each sample represents a single approach at an intersection. Data are shown for the before and after accident rates, the total number of months of data in the before period and in the after period, and the number of intersection approaches on which the statistics are based. Table 4 shows statistics for intersections with two opposing lanes of traffic; Table 5 shows statistics for intersections with three opposing lanes of traffic.

The following observations and conclusions can be made for the conversions made at approaches having two opposing lanes of traffic.

- Each before case and after case has at least 5½ approach years of data on which the statistics are based.
- The following conversions resulted in decreases in the left-turn accident rate:
  - —From permissive to leading exclusive/permissive,
  - —From permissive to lagging exclusive/permissive, and
  - —From leading exclusive/permissive to lagging exclusive/permissive.
- The following conversions resulted in increases in the left-turn accident rate:
  - —From leading exclusive/permissive to permissive,
  - —From leading exclusive to leading exclusive/permissive,
  - —From leading exclusive to lagging exclusive/permissive, and
  - —From leading exclusive to lagging exclusive.

TABLE 4 BEFORE AND AFTER LEFT-TURN ACCIDENT RATES FOR APPROACHES CONVERTED FROM ONE TYPE OF PHASING TO ANOTHER—TWO OPPOSING LANES

	AFTER TYPE OF PHASING				
BEFORE TYPE OF PHASING	Permissive	Leading E/P	Lagging E/P	Leading Exclusive	Lagging Exclusive
Permissive	x x x x x x x x x x x x	4.77 3.49 608 425 17	5.44 4.16 359 131 9		
Leading E/P	2.07 2.66 462 340 14	x x x x x x x x x x x x	3.10 2.25 1170 622 35		
Lagging E/P			x x x x x x x x x x x x		
Leading Exclusive		0.93 3.11 144 70 3	0.38 1.57 220 67 6	x x x x x x x x x x x x	1.46 1.91 346 144 10
Lagging Exclusive					x x x x x x x x x x x x

KEY

A	B
C	D
E	

A = Before left turn accident rate
B = After left turn accident rate
C = Total number of months of before data
D = Total number of months of after data
E = Number of intersection approaches

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

TABLE 5 BEFORE AND AFTER LEFT-TURN ACCIDENT RATES FOR APPROACHES CONVERTED FROM ONE TYPE OF PHASING TO ANOTHER—THREE OPPOSING LANES

	AFTER TYPE OF PHASING				
BEFORE TYPE OF PHASING	Permissive	Leading E/P	Lagging E/P	Leading Exclusive	Lagging Exclusive
Permissive	x x x x x x x x x x x x	4.64 5.55 144 77 3	8.75 1.37 194 59 8	18.96 0.36 87 67 3	
Leading E/P	2.25 5.85 82 73 3	x x x x x x x x x x x x	4.54 2.74 1181 831 38	7.08 0.75 12 68 2	
Lagging E/P			x x x x x x x x x x x x		
Leading Exclusive		1.40 4.72 998 594 22	2.13 1.03 329 84 9	x x x x x x x x x x x x	0.35 0.35 390 114 12
Lagging Exclusive					x x x x x x x x x x x x

KEY

A	B
C	D
E	

A = Before left turn accident rate
B = After left turn accident rate
C = Total number of months of before data
D = Total number of months of after data
E = Number of intersection approaches

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

- The statistics for conversions from permissive to leading exclusive/permissive and from leading exclusive/permissive to permissive reinforce each other. Both statistics suggest that leading exclusive/permissive is safer than permissive.

The following observations and conclusions can be made for the conversions made at approaches having three opposing lanes of traffic.

- Each before case or after case has at least 5 approach years of data on which the statistics are based.
- The following conversions resulted in decreases in the left-turn accident rate:
  - —From permissive to lagging exclusive/permissive,
  - —From permissive to leading exclusive,
  - —From leading exclusive/permissive to lagging exclusive/permissive,
  - —From leading exclusive/permissive to leading exclusive, and
  - —From leading exclusive to lagging exclusive/permissive.
- The following conversions resulted in increases in the left-turn accident rate:
  - —From permissive to leading exclusive/permissive,
  - —From leading exclusive/permissive to permissive, and
  - —From leading exclusive to leading exclusive/permissive.
- The statistics for conversions from permissive to leading exclusive/permissive, and from leading exclusive/permissive to permissive contradict each other. The former statistic suggests that permissive phasing is safer. The latter statistic suggests that exclusive/permissive phasing is safer. It is possible that conditions at these two sets of intersections are different (traffic volumes, for example) and that these differences may account for the contradiction.
- The statistics for conversions from leading exclusive to leading exclusive/permissive, and from leading exclusive/permissive to leading exclusive reinforce each other. Both statistics suggest that leading exclusive is safer than leading exclusive/permissive.

The cases with two opposing lanes of traffic can be compared to those with three opposing lanes of traffic. In most cases the trends are the same. For example, a conversion from leading exclusive/permissive to permissive will result in an increased accident rate for approaches with two opposing lanes of traffic *and* for approaches with three opposing lanes of traffic.

In two cases, however, the trends are opposite. For two opposing lanes of traffic, a conversion from permissive to leading exclusive/permissive results in a decrease in accident rate. The opposite is true for three opposing lanes. This finding for three opposing lanes supports the view of some traffic engineers who are reluctant to use exclusive/permissive phasing with three opposing lanes because a larger gap is required, because it is more difficult for the driver to judge an acceptable gap, and because there is a greater chance that an oncoming vehicle in one lane will be masked out by a vehicle in another lane.

The other case in which trends are opposite is conversion from leading exclusive to lagging exclusive/permissive. For two opposing lanes, this conversion results in an increase in accidents. For three opposing lanes, it results in a decrease.

INTERPRETATION OF STUDY DESIGNS

It is important to understand some of the limitations of the accident rate information presented here. Both designs—the simple comparison and the before-and-after design—are simple. The intersections used to develop these accident statistics were *not* randomly selected. They are simply the intersections for which jurisdictions were able to provide all of the necessary data. Although efforts were made to make intersections as alike as possible (in type of phasing, number of opposing lanes, left-turn volume, opposing volume, and the existence of a separate left-turn lane), there may still be differences in intersection characteristics among the different groups.

Although these limitations are shortcomings of the study design, the strength of this study is that a very large sample size was involved in both designs. The simple comparison design included 523 intersection approaches, and the before-and-after design included 194 intersection approaches. The fact that all the necessary data, including turning-movement counts, were available at such a large number of intersections is an achievement, in comparison to other studies of left-turn signal phasing.

CONCLUSIONS

The choice of left-turn phasing type at a signalized intersection affects the left-turn accident rate. The accident rate is also influenced by the number of opposing lanes of traffic, left-turn volume, and the volume of opposing traffic. The traffic engineer should consider each of these factors when selecting the type of left-turn phasing to be installed at an intersection.

This information on relative safety will assist the traffic engineer in selecting the type of left-turn phasing to be used at a signalized intersection.

ACKNOWLEDGMENT

This research was sponsored by the Arizona Department of Transportation.

REFERENCES

1. K. R. Agent and R. C. Deen. *Warrants for Left-Turn Signal Phasing*. Division of Research, Bureau of Highways, Kentucky Department of Transportation, Lexington, Oct. 1978.
2. K. R. Agent and R. C. Deen. Warrants for Left Turn Signal Phasing. In *Transportation Research Record 737*, TRB, National Research Council, Washington, D.C. 1979, pp. 1–10.
3. K. R. Agent. *An Evaluation of Permissive Left Turn Phasing*. Division of Research, Bureau of Highways, Kentucky Department of Transportation, Lexington, April 1979.
4. P. M. Beaudry. *Guidelines for the Installation of Separate Left-Turn Signal Phasing*. Northwestern University Traffic Institute, Evanston, Ill., Aug. 1979.
5. R. M. Mohle and T. Rorabaugh. *Left Turn Phasing, Volume 4: A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals*. Report FHWA-RD-78-49. FHWA, U.S. Department of Transportation, May 1980.
6. Florida Section, ITE. Left Turn Phase Design in Florida. *ITE Journal*, Sept. 1982, pp. 28–35.
7. B. H. Cottrell and G. R. Allen. *Guidelines for Exclusive/Per-*

missive Left-Turn Signal Phasing. Virginia Highway and Transportation Research Council, Charlottesville, July 1982.
8. R. B. Machemehl and A. M. Mechler, *Procedural Guide for Left Turn Analysis*. Center for Transportation Research, University of Texas, Austin, Nov. 1983.
9. Colorado-Wyoming Section, ITE. A Study of Use of Warrants for the Installation of Left-Turn Phasing at Signalized Intersections. ITE, Washington, D.C., March 1985.
10. D. L. Warren. Accident Analysis of Left-Turn Phasing. *Public Roads*, Vol. 48, No. 4, March 1985, pp. 121–127.
11. J. E. Upchurch. Guidelines for Selecting Type of Left Turn Phasing. In *Transportation Research Record 1069*, TRB, National Research Council, Washington, D.C., 1986, pp. 30–38.

The contents of this paper reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arizona Department of Transportation.

Publication of this paper sponsored by Committee on Traffic Control Devices.