2. J.W. Hall and P.L. Zador. Survey of Single-Vehicle Fatal Rollover Crash Sites in New Mexico. TRB, Transportation Research Record 819, 1981, pp. 1-8.
3. P.H. Wright and P.L. Zador. Study of Fatal Rollover Crashes in Georgia. TRB, Transportation Research Record 819, 1981, pp. 8-17.
4. Science Applications, Inc. Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments for Rural Two-Lane Highways. FHWA, FHWA-RD-78-50, 51, 1978.
5. F.M. Council and others. Accident Research Manual. FHWA, FHWA-RD-80-016, 1980.
6. Highway Safety Improvement Programs. U.S. Department of Transportation, Annual Rept. 1978.
7. H. Lunenfeld. Evaluation of Traffic Operations, Safety and Positive Guidance Projects. FHWA, FHWA-TO-80-1, 1980.
8. Annual Evaluation Report, Pavement Marking Demonstration Program. West Virginia Department of Highways, Charleston, 1981.
9. Progress Report. Planning and Research Bureau, Montana Department of Highways, Helena, Jan. 1981.
10. W.C. Taylor and T.J. Foody. Ohio's Curve Delineation Program--An Analysis. Traffic Engineering, June 1966.
11. J.I. Taylor and others. Roadway Delineation Systems. NCHRP, Rept. 130, 1972.
12. G. Bezkorovainy and C.C. Ku. The Influence of Horizontal Curve Advisory Speed Limits on Spot Speeds. Traffic Engineering, Sept. 1966, pp. 24-28.
13. R.W. Lyles. An Evaluation of Warning and Regulatory Signs for Curves on Rural Roads. FHWA, FHWA-RD-80-009, 1980.
14. J.S. Koziol and P.H. Mengert. Evaluation of Speed Control Signs for Small Rural Towns. Public Roads, June 1977.
15. C.G. Hamner. Evaluation of Minor Improvements. California Division of Highways, Part 6, May 1968.
16. C.W. Niessner. Construction Zone Delineation (Raised Pavement Markers). FHWA, 1978.
17. Field Evaluation of Selected Delineation Treatments on Two-Lane Rural Highways. Alan M. Voorhees and Associates, Inc., FHWA-RD-77-118, 119, 1977.
18. Annual Report, Title II Safety Improvement Program. Office of Highway Safety, Florida Department of Transportation, Gainesville, Sept. 1981.
19. N. Enustun. Three Experiments With Transverse Pavement Stripes and Rumble Bars. Michigan Department of State Highways, Lansing, Final Rept., Oct. 1972.
20. R.D. Helliar-Symons. Yellow Bar Experimental Carriageway Markings-Accident Study. Transport and Road Research Laboratory, Crownthorne, Berkshire, England, TRRL Laboratory Rept. 1010, 1981.
21. An Evaluation of the Effectiveness of Rumble Strips. Virginia Department of Highways and Transportation, Richmond, April 1981.
22. F.R. Hanscom. Evaluation of Signing to Warn of Wet Weather Skidding Hazard. TRB, Transportation Research Record 600, 1976, pp. 20-27.

Notice: This paper was supported by the Insurance Institute for Highway Safety. The opinions, findings, and conclusions expressed are ours and do not necessarily reflect the views of the Insurance Institute for Highway Safety.

Motorists' Reaction to Exclusive/Permissive Left-Turn Signal Phasing

MICHAEL A. PERFATER

The findings of a study of motorists' perceptions of exclusive/permissive (E/P) signal phasing at 10 intersections in Virginia are presented. Traffic volumes and conflict rates were counted at each site and accident files were investigated. In addition, 1,252 residences and small businesses in the vicinity of the sites were sent questionnaires to determine motorists' opinions and perceptions of E/P phasing. A total of 460 completed questionnaires were received and analyzed. Roughly one-third of those queried were confused by the E/P signal the first time they encountered it, but the confusion dissipated over time. Advance publicity of an E/P signal modification or installation and an explanatory sign placed adjacent to the signal head will do much to reduce motorists' confusion. More than 70 percent of those surveyed were in favor of E/P signal phasing and 77 percent thought that it reduced intersection delay. On-site observations revealed that vehicular conflicts at E/P intersections are most frequent at locations that have high volumes of turning vehicles and various movements of traffic. The conflict rate could not be attributed to any one characteristic of an intersection, however. The same was true for the accident rate.

Several means can be used to accommodate left-turn movements at signalized intersections. One of these is the recently introduced exclusive/permissive (E/P) left-turn signal phase, which permits left turns during the display of both the green arrow and the green ball. During the green-arrow phase the motorist is unopposed in making a left turn; during the green-ball phase he or she must yield to opposing vehicular traffic. The left-turn arrow may either follow or precede the green ball.

Several studies have been conducted nationwide to determine the best method for signalizing left-turn movements and as many as two dozen signal indications are available for use. One recent study conducted in Kentucky determined that E/P left-turn phasing is efficient because it results in fewer delays than other types of left-turn phasing; however, it was found to lead to an increase in accidents compared with exclusive phasing. The number of these mostly minor accidents decreased as drivers became familiar with the intersection. More than 90 percent of the drivers queried in that study were in favor of this type of signal, but many indicated that they had not understood the signal the first time they encountered it. They indicated that more advance publicity on the E/P signal was necessary (1).

The Virginia Department of Highways and Transpor-

tation has numerous E/P signal-phasing installations throughout the state and more are planned. To date, public reaction to this type of phasing has been favorable, except where accidents have occurred. The research council was asked to document the performance of these signals from the standpoint of public interpretation and understanding. Only the five-ball cluster system that features the exclusive left-turn phase before the green-ball phase was studied. The study included both surveys and on-site data analyses at 10 signalized intersections at various locations within the commonwealth.

METHODOLOGY

Four types of data were gathered for each of the sites. Traffic counters were installed on the roadway to determine the volume of through traffic. Then, on 2 successive days, observers were placed at opposite ends of the intersection for 10 hr to record conflicts. Five types of conflicts were recorded and the conflict volumes for the 2 days were averaged, as were the volumes of through traffic, which were also recorded for the 2 days. A procedure developed for a previous study was used to determine the left-turn conflicts (2). Observed conflicts were categorized as follows:

Type 1--The basic left-turn conflict caused by the turning vehicle crossing in front of or blocking the lane of an opposing through vehicle; a conflict was recorded when the driver of the through vehicle applied the brakes or weaved to evade the encroaching vehicle;

Type 2--A continuation of the first type in which the driver of a through vehicle that was following the first one also had to brake;

Type 3--The conflict caused by the vehicle entering the intersection after the E/P signal has turned red;

Type 4--The rear-end conflict in the left-turn lane occurring when the driver of the vehicle about to make the turn did not and the driver of the following vehicle had to brake or weave; and

Type 5--The conflict when left-turning vehicles overflowed the storage lane and blocked the through lanes.

The number of left turns made on the green arrow at each intersection was also recorded.

Once these data were collected residences and some small businesses located near each E/P intersection were mailed questionnaires that contained questions concerning the newly installed E/P signal.

Finally, accidents reported at each intersection both before and after installation of the E/P signal were tabulated. The after data included accidents reported during the period between the installation date and the date of the on-site evaluation, and the before data included accidents reported over a similar period of time before the installation.

Of the approximately 1,252 questionnaires distributed, 460 were returned, for a response rate of 36.7 percent.

RESULTS OF INTERSECTION ANALYSIS

Intersection Characteristics

The intersections evaluated are described in Table 1. Observations were made over a 2-day period and the volumes presented are averages. The average approach volume at the 10 intersections was about 5,780 vehicles/day. The highest count was 10,711 vehicles/day and the lowest was 3,134 vehicles/day. The intersections had an average turn volume of 908 vehicles/day, of which 401, or 44 percent, were made during the green-ball or permissive phase. This illustrates the additional number of left turns that can be made with permissive phasing. The reduction in delay and fuel use as a result of the permissive phase, although not measured in this study, is apparent.

Vehicle Conflicts

Types 1, 2, and 3 conflicts constituted almost 98 percent of the total conflicts counted. For this reason, types 4 and 5 conflicts were not considered to cause serious problems and thus will not be discussed. Type-3 conflicts were the most frequent--47 percent of those counted. Instances of high type-3 conflicts could not be attributed to any one characteristic of an intersection. This type of conflict tended to occur at intersections that have high approach volumes and are located away from shopping centers. Type-3 conflicts seem to result more from drivers being in a hurry than from a misunderstanding of the signal indications. Type-3 conflicts were relatively infrequent at high-volume shopping center intersections.

Type-1 conflicts (43 percent of those counted) were more frequent at intersections that have high volumes of turning traffic. Three of the four intersections that had the highest such volumes (green arrow and green ball) also had the highest rate of type-1 conflicts. Type-2 conflicts were generally rare (8 percent of those counted); the majority of them occurred at one intersection. That intersection allowed the greatest variety of traffic movements of all intersections studied.

Neither speed limits nor the length of time an E/P signal had been in place appeared to have any effect on conflict rates. At intersections that had high turn volumes an explanatory sign was important. One of the intersections that had the highest left-turn volumes and no explanatory sign had high ratios of type-1 and type-3 conflicts (Figure 1). Evidence also showed that the modification of an existing signal to one that contained an E/P phase may result in more conflicts than will the installation of a new E/P signal where no signal previously existed. In the latter case the intersections all exhibited relatively low conflict rates. On-site observers pointed out that intersections that have multiple right-turn-on-red alternatives appeared to create driver confusion and accompanying conflicts.

No single intersection characteristic that was responsible for vehicle conflicts could be found. Many possible culprits have been mentioned and, although a common denominator was not found, the observations revealed that the more movements that occur in an intersection the more likely that conflicts will occur.

RESULTS OF ACCIDENT ANALYSES

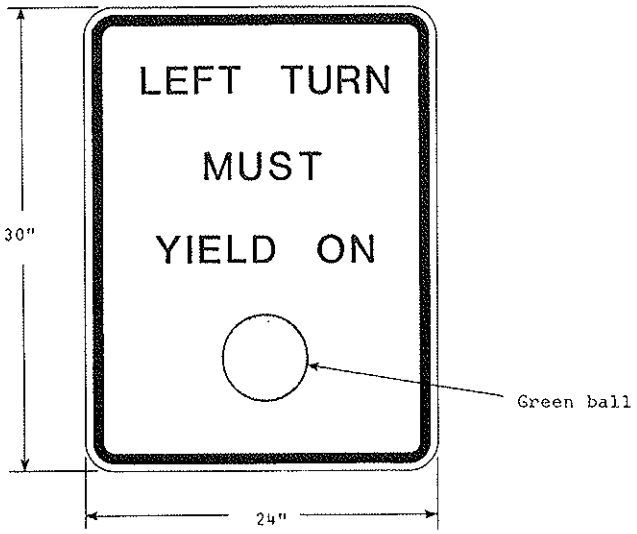
Accident data were analyzed for periods before and after installation of the signals. Where possible, this analysis included 1-year periods before and after installation. For three of the sites, due to the recency of the installation, only limited after data were available (3 to 6 months). For four sites, no before data were available.

Table 2 gives the total number of accidents that occurred at four intersections in the 1-year periods before and after installation of the E/P signals. At some intersections the total number of accidents declined over the 2-year period; however, the number of left-turn accidents increased. The breakdown at individual sites showed that the data from one site probably skewed this table such that little can be

Table 1. Summary of signal site intersections.

Site	Type	Location	Speed Limit (mph)	Approach Volume	Left-Turn Volumes	
					Green Ball	Green Arrow
1	4-lane urban arterial	City of Charlottesville	25	4,434	172	433
2	4-lane divided suburban arterial	County of Albemarle	45	10,711	649	977
3	2-lane urban arterial	City of Charlottesville	25	3,134	245	530
4	4-lane divided suburban arterial	County of Albemarle	45	8,401	616	296
5	2-lane suburban arterial	County of Chesterfield	45	3,255	183	128
6	4-lane divided suburban arterial	City of Virginia Beach	50	6,426	117	35
7	2-lane suburban arterial	County of Roanoke	35	3,449	275	265
8	4-lane divided urban arterial	City of Virginia Beach	45	5,493	721	813
9	4-lane divided suburban arterial	Prince William County	45	4,219	547	860
10	4-lane divided suburban arterial	Prince William County	45	8,272	491	734
Avg.				5,800	401	507

Figure 1. Supplemental E/P regulatory sign.



said about the increase or decrease in left-turn accidents during the 1-year period after the E/P signal was installed.

Table 3 gives the monthly distribution of all accidents subsequent to the installation of the E/P signals. The number of accidents decreased over time. In the first 6 months an average of 1.95 accidents/month occurred per intersection. During the second 6 months this number was reduced to 1.03 accidents/month. The decrease in left-turn accidents, however, was not as drastic. In the first 6 months after the E/P signals was installed the average for left-turn accidents was 0.63/month per intersection. During the next 6 months this rate was reduced to 0.53/month. Also, the table shows that left-turn accidents comprised anywhere from 23 to 100 percent of the total accidents at the 8 intersections. In the first 6 months after E/P installation 40.5 percent of the accidents recorded were related to left turns; in the next 6 months 60.0 percent were left-turn related. Thus, these data allow no conclusions as to the effect of the passage of time on the accident rate at E/P signalized intersections. The data are simply too limited. A more in-depth analysis of 25 to 40 intersections would be needed before any such conclusions could be drawn.

Table 2. One year before and after E/P installation accident summary.

Location	All Accidents		Left-Turn Accidents	
	Before	After	Before	After
Site 4	11	22	0	14
Site 5	6	3	0	1
Site 6	47	27	12	4
Site 7	6	6	4	4
Total	70	58	16	23

Table 4 represents the most conclusive evidence regarding the possible effect of E/P signals on accident rates at the intersections. The table gives before-and-after accident data for four E/P signal sites. Left-turn accidents increased by an average of almost 20 percent during periods after installation. Little can be said about individual intersections, except that the higher-volume intersections appear to show the greatest propensity for left-turn accidents. Individual intersection analyses would require more data that take into account the myriad of intersection characteristics that affect accident rates.

RESULTS OF QUESTIONNAIRE SURVEY

Motorist Familiarity With and Confusion at E/P Intersection

Respondents were asked to estimate the number of times each week that they made a left turn at an intersection pictured on the questionnaire. The respondents averaged about 8 turns/week; the greatest number made 11 or more turns/week. Only 7.4 percent of the respondents said that they made fewer than 3 turns/week at the intersection. This information established that those who participated in the survey were familiar enough with the signal to answer questions about it.

The responses to two questions aimed at determining the degree of confusion caused by the new signal showed that more than one-third of the motorists

Table 3. Distribution of accidents by month after E/P installation.

Month After Installation	Number of Accidents											
	Site 2		Site 4		Site 5		Site 6		Site 7		Site 8	
	All Accidents	Left-Turn Accidents	All Accidents	Left-Turn Accidents	All Accidents	Left-Turn Accidents	All Accidents	Left-Turn Accidents	All Accidents	Left-Turn Accidents	All Accidents	Left-Turn Accidents
1	7	3	2	2	0	0	2	0	0	0	0	0
2	4	3	3	3	0	0	2	0	0	2	0	0
3	2	0	1	0	1	0	4	0	4	1	0	0
4	2	1	0	0	1	0	4	0	1	0	3	0
5	3	1	2	1	1	1	4	0	0	0	0	0
6	3	0	3	1	0	0	3	1	0	0	2	1
7			3	2	0	0	5	1	0	0	2	1
8			1	1	0	0	2	1	0	0	5	1
9			2	2	0	0	0	0	0	0	1	0
10			0	0	0	0	1	1	0	0	0	0
11			4	3	0	0	0	0	0	0	2	2
12			1	0	0	0	0	0	1	1	1	0
Total	21	8	22	15	3	1	27	4	6	4	16	5

Table 4. Summary of left-turn accidents.

Site	Length of Reporting Period (months)	Accidents in Before Period			Accidents in After Period			Change in Left-Turn Accidents (%)
		All	Left Turn		All	Left Turn		
			Number	Percentage of Total		Number	Percentage of Total	
4	12	11	0	0	22	15	68.2	+68.2
5	12	6	0	0	3	1	33.3	+33.3
6	12	47	12	25.5	27	4	14.8	-10.7
7	12	6	4	66.7	6	4	66.7	0
Total		70	16	22.9	58	24	41.4	18.5

Table 5. Change in motorists' confusion over time.

Site	Time Since Installation (months)	Percentage of Confused Motorists		
		At First	Now	Change
1	24	3.6	0	100.0
2	24	17.2	10.3	40.1
3	17	6.5	0	100.0
4	16	38.3	19.1	50.1
5	12	26.2	8.2	68.7
6	12	50.0	27.3	45.4
7	9	31.8	4.5	85.8
8	7	36.5	9.5	74.0
9	5	61.5	9.6	84.4
10	5	71.4	38.1	46.6

Note: A total of 460 motorists responded to survey.

(36.5 percent) were confused the first time they passed through the intersection, but only 12.4 percent remained confused. Moreover, as given in Table 5, motorists' confusion about the E/P signal reduced over time at every site. However, the table also shows that the degree to which confusion reduced over time varied among the sites. For instance, the E/P signals at sites 1 and 2 had been in place for about the same length of time. The confusion disappeared at site 1 but at site 2 it dropped only 40 percent. The situation was similar for sites 9 and 10. These signals had been in place for the same amount of time, yet the responses showed that a great deal more confusion still existed at site 10 than at site 9. Obviously, factors other than unfamiliarity with a new type of signal were responsible for the continuing confusion. Such variables as speed limit, through volume, turn volume, intersection configuration, geometrics, and sight distance affect a driver's ability to understand the E/P signal indication.

Cross-tabulations between the responses to the question on confusion revealed that individuals who were still confused by the E/P signal were generally more negative toward it than were those who were not confused. Also, more often than not, those who were not confused had seen this type of signal elsewhere.

Respondents were overwhelmingly in support of placing a supplementary sign near the signal to explain that a left-turning vehicle must yield on a green ball (Figure 1). Only 9.3 percent thought that such a sign was unnecessary. Forty percent of the respondents thought that the best placement for such a sign would be adjacent to the signal head. Another 37.6 percent thought that the signs were necessary both adjacent to the signal head and in the median, where one exits. Note that five of the E/P signals, all located in cities, were not signed. For the surveys made at these five locations 67.8 percent of the respondents thought that a sign was necessary adjacent to the signal head, in the median, or both. For the five sites that included a supplementary sign this opinion was held by 86.6 percent of the respondents. However, all but one of the E/P signals not accompanied by the sign continued to confuse motorists. The addition of a sign might reduce confusion.

General Opinion About Impact of E/P Signals on Intersections

Each respondent was asked to give an overall opinion of E/P signal phasing at the intersection in question. Slightly more than 70 percent were in favor of this type of signal, about 11 percent were neutral, and about 17 percent were against it. Note

Site 9		Site 10		Average per Site		
All Accidents	Left-Turn Accidents	All Accidents	Left-Turn Accidents	Total Accidents	Left-Turn Accidents	Percentage Left-Turn to Total Accidents
5	4	3	1	2.4	0.75	53
0	0	2	2	1.5	1.25	73
3	1	4	4	2.4	0.75	37
2	1			1.9	0.29	23
				1.7	0.33	30
				1.8	0.33	27
				2.0	0.80	40
				1.6	0.60	38
				0.6	0.40	67
				0.2	0.20	100
				1.2	1.00	83
				0.6	0.20	33
—	—	—	—			
10	6	9	7	1.49	0.58	44

Table 6. Summary of responses regarding intersection impacts of E/P signal.

Question	Percentage Responding (N = 460)		
	Yes	No	No Response
Has signal reduced delays?	77.0	19.3	3.7
Has signal created a hazard?	30.5	65.4	4.1
Have you been involved in a crash or near miss?	20.9	78.0	1.1

also that at E/P-signalled intersections where the conflict and accident rates were high public opinion generally was more negative than it was at less conflict- and accident-prone intersections.

Table 6 gives a summary of responses to questions concerning the impact of the E/P signal on the intersection. Overall, 70.0 percent of the respondents thought that E/P signal phasing had reduced delay. However, about 30.0 percent thought that a hazardous situation was created by the E/P signal and roughly 21.0 percent indicated that they had been involved in a crash or near miss at one of the E/P intersections. Cross-tabulations revealed the existence of some interesting relations between the answers to these questions and certain other variables. As would be expected, respondents who had a positive opinion about the E/P signal thought it had had a positive effect on the intersection; that is, it had reduced delays and had not created a hazard. Individuals who had seen this type of signal in other areas were more likely to think that the signal had had a positive effect on the intersection than were those who had not.

Both this and the preceding relation were significant at the 99 percent level of confidence. The implication here is, again, that familiarity with the E/P treatment tends to reduce apprehension about it. Furthermore, cross-tabulations showed that individuals who had seen the E/P signal in other areas were less likely to have been involved in a crash or near miss at the intersection. This relation was significant at the 95 percent level of confidence and exhibits the probability that advance familiarity with the E/P signal treatment might reduce vehicle conflicts and accident rates.

Advance Publicity: Will It Reduce Intersection Confusion?

Familiarity with the E/P signal is an aid to the motorist. To take this concept one step further would be to suggest that advance publicity on E/P installations would be of even more help. Although this suggestion is embodied in responses to previous questionnaire items, it is strengthened by responses to a question regarding the type of advance publicity that might be helpful. More than 82 percent of the respondents said that they had known nothing of the E/P signal until after it had been installed and they had entered the intersection.

Roughly 83 percent of the respondents thought that advance knowledge of the newly signalled intersection would have been beneficial to them. As was expected, the newspaper was considered the most effective method for publicity of this type (38 percent); a mailed flyer was the second most effective. This preference, then, indicates that, should a public information campaign be launched to inform the motorist that an E/P signal is being installed, a mailed flyer and newspaper coverage should be used. Radio and television coverage were not deemed to be as desirable and, therefore, should be used only minimally.

SUMMARY AND SUGGESTIONS FOR FURTHER RESEARCH

The study has shown that more than one-third of the motorists questioned were confused the first time they encountered E/P signal phasing. This confusion was found to dissipate over time at every test site. Familiarity with this type of signal treatment reduces motorists' confusion. Such confusion can be further reduced through advance publicity of the signal modification or new installation. The most preferred method of publicity was the newspaper, and a mailed flyer was the second most preferred. A sign placed adjacent to the signal head was also found to aid in the reduction of confusion. More than 90 percent of the survey respondents thought such a sign was helpful.

The majority of those surveyed (70 percent) were in favor of E/P signal phasing. About 77 percent thought that this treatment reduced delay at the intersection. Thirty percent, however, perceived that the E/P signal phasing had produced a hazardous situation. Those familiar with E/P signals tended to be more positive about this treatment than those who were unfamiliar with them.

Vehicular conflicts were most frequent at intersections that had high volumes of left-turning traffic and multiple avenues of movement. Indications are that intersections that have one or more right-turn-on-red movements may be prone to high conflict

and accident rates. The conflict rate was never found to be attributable to any single intersection characteristic but was probably the result of the combination of several. Some evidence suggests that modification of existing signals may result in a slightly higher conflict rate than will the installation of a new signal, but the supporting data are sketchy at best. The same is true for accident rates. At best, all that can be said about accidents based on the data gathered in this study is that, in general, the ratio of accidents involving left-turning vehicles to all accidents that occur at the intersections increases after E/P signals are installed.

This study has made some determinations, but more work is still to be done. A study is under way at the research council to determine what types of intersections lend themselves to E/P signal treatment. To establish guidelines for the installation of E/P left-turn phasing at new locations and for modifying existing locations, a comparison is being made of existing E/P intersections and non-E/P intersections on the basis of such characteristics as approach and left-turn traffic volumes, traffic mix, speed limit, geometrics, sight distance, accident and conflict rates, intersection configuration, and commercial development.

ACKNOWLEDGMENT

The support given to this study by W.C. Nelson, Jr., Mark Hodges, and Frank Puryear of the Department's Traffic and Safety Division is gratefully acknowledged. Special thanks are due to Neal Robertson, Research Scientist at the Research Council, for his traffic engineering expertise and insight. Gratitude is also extended to Jerry Korf, Philip Harris, and Delores Green of the data systems group; to John Shelor and Steve Blackwell of the traffic operations group; to Harry T. Craft, who edited this paper; and to Jan Kennedy, who typed this manuscript.

The research conducted was financed with HPR funds in cooperation with FHWA.

REFERENCES

1. K.R. Agent. An Evaluation of Permissive Left Turn Signal Phasing. Division of Research, Kentucky Department of Transportation, Lexington, April 1979.
2. K.R. Agent. Development of Warrants for Left-Turn Signal Phasing. Division of Research, Kentucky Department of Transportation, Lexington, April 1976.

Notice: The opinions, findings, and conclusions expressed in this paper are those of the author and not necessarily those of the sponsoring agencies.

Safety Effects of Rumble Strips on Secondary Roads

R.L. CARSTENS

Research was undertaken to identify specific locations where rumble strips could improve safety on rural secondary roads. Of the 685 rumble-strip installations on secondary roads in Iowa, 207 were selected for detailed study. At 88 locations a before-and-after comparison of the accident experience was made because accident records were available for at least one full year both preceding and following the installation of rumble strips. (Accident records were available only for 1977-1980.) The accident experience at the 119 locations that have rumble strips installed before 1978 was compared with a sample of comparable locations that do not have rumble strips. No difference was found in the accident experience at secondary road locations between the periods before and after the installation of rumble strips. Secondary road locations that have rumble strips for longer periods experienced slightly more accidents than did comparable control locations that did not have rumble strips. Comparisons were made on the basis of both the total number of accidents and the number of accidents attributed to running a stop sign. Furthermore, no correlation could be demonstrated between the occurrence of accidents at the locations in the sample and factors such as traffic volume, sight distance, and distance from the last stop.

The use of rumble strips on paved rural secondary roads has often been suggested as a means of enhancing safety. Rumble strips are used widely in some jurisdictions in advance of intersections controlled by stop signs. A few jurisdictions also make use of rumble strips in advance of railroad grade crossings or at other locations thought to require supplemental warning devices.

No definitive guidelines or warrants have been developed to suggest locations at which rumble strips should be installed. Some of the research reported in the literature indicates that they can be effective in reducing accidents at some locations. On the other hand, several studies of rumble-strip use have shown that the number of accidents does not change following the installation of rumble strips, although the number of certain types of accidents may be reduced.

BACKGROUND

Research was undertaken to identify specific locations where rumble strips could be expected to improve highway safety. Factors that were considered include intersection sight distances, approach gradients, accident experience, and distance from the last stop. These factors were quantified through a field inventory of selected locations in Iowa where rumble strips had been installed. Analysis of the correlation of these factors with safety made use of the accident records available in Iowa through the accident location and analysis system (ALAS).

The goal of the research was to improve safety on rural secondary roads by recommending guidelines or warrants for the use of rumble strips. To accomplish this goal those factors were to be identified and quantified that could be used to distinguish between locations where rumble strips could be shown to be effective in reducing accidents and those locations where no beneficial effect on accident frequency may be expected. The effect of each factor was to be quantified so that numerical warrants could be developed.

SURVEY OF RUMBLE STRIPS ON SECONDARY ROADS IN IOWA

Sample

The sample was developed by means of a mailed survey sent to each of the 99 county engineers in Iowa. Information was requested on all rumble strip loca-