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Before-After Accident Analysis for Two Shoulder Upgrading Alternatives

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The Texas State Department of Highways and Public Transportation has tried several techniques to improve operating conditions on rural two-lane highways. One common treatment has been the addition of paved shoulders. An innovative treatment that provides additional capacity at a minimum cost has been the conversion of two-lane roadways with full-width paved shoulders to undivided, four-lane roadways without shoulders. Although both treatments improve traffic operations, their effect on safety has not been fully quantified. A study was conducted to establish the consequences related to safety whenever these two treatments are implemented. An accident frequency comparison for accident type by class of roadway was made for the before and after improvement time periods. Separate comparisons were made for both all accidents and nonintersection accidents. To supplement this analysis, a paired t-test was used to determine significant changes in either accident type or severity. The findings of the analysis are as follows: (a) Addition of full-width paved shoulders to a two-lane roadway is effective in reducing the total number of accidents, (b) conversion of a paved shoulder to an additional travel lane results in fewer total accidents only if traffic volume is greater than 3000 vehicles/day, and (c) the type of accident change varies with type of roadway and volume level.

The Texas State Department of Highways and Public Transportation (TSDHPT) has tried several techniques to improve operating conditions on rural two-lane highways. The most common of these treatments has been the addition of paved shoulders. An innovative treatment that provides additional capacity at a minimum cost has been the conversion of two-lane roadways with full-width paved shoulders into undivided, four-lane roadways without shoulders. This treatment results in what is commonly known as a "poor-boy" highway and entails resurfacing and restriping, or restriping the existing pavement. Increased capacity is obtained without incurring expenses for earthwork, drainage, intersections, and structures. Although both treatments improve traffic operations, their effect on safety has not been fully quantified.

The level of safety performance is one of the major characteristics of a particular roadway. Previous safety research on shoulders and shoulder width has shown diversity in the exact relations between shoulder characteristics and accident experience. Several studies (1-3) either found mixed results or concluded that no relation existed between shoulder widths and accident rates.

Rinde (4) used a before-and-after technique to evaluate shoulder-widening projects on rural two-lane roads in California. Accident rates were reduced by 29 percent for shoulder widths of from 7 to 10 ft [average daily traffic (ADT) > 5000]. The reduction was statistically significant at the 95 percent confidence level. Head-on accidents decreased by about 50 percent, and fixed-object accidents decreased by 25 percent.

Sanderson (5) analyzed the effect that shoulder width had on the accident rates of two-lane highways in New Brunswick. He compared data on sections where the major roadway and traffic characteristics were relatively uniform. Sites were stratified and grouped into class intervals by both traffic volume and shoulder width. His results were that accident rates decreased with increasing shoulder widths.

Zegeer (6) investigated the effect of lane and shoulder widths on accident rates on rural two-lane highways in Kentucky. His stratified analysis found that wide shoulders were associated with fewer run-off-road and opposite-direction accidents.

Heimbach (7), using North Carolina data, found a significantly lower accident experience and accident severity index associated with various types of two-lane highways that had 3- to 4-ft paved shoulders when these were compared with counterpart unpaved shoulder sections.

To determine the effectiveness of the two treatments--addition of paved shoulders and conversion to four-lane poor boy--a study was undertaken to evaluate their effect on safety (8). The analysis was made for rural highways. The purpose of the analysis was to establish the safety-related consequences of adding full-width paved shoulders to a two-lane roadway or converting a two-lane highway with full-width paved shoulders to a four-lane poor-boy roadway. A previous paper (9) has described the accident effects related to the presence or absence of paved shoulders. This paper presents a comparison of accident frequency for the time periods before and after improvement.

SITE SELECTION

A stratification matrix of roadway characteristics was developed that delineated traffic volume, type of improvement, and number of lanes. Table 1 gives details on the six classifications used in the before-after analysis. To ensure a statistically valid and representative data sample, it was desired that there be a minimum of 10 sites in each classification and that each site contain 5 or more miles of geometrically consistent roadway.

The TSDHPT roadway geometric computer files, called RI-2-TLOGs, were used to screen all rural roadways in the state as potential sites. Since this process involved more than 29 000 roadway segments and 10 years of data, it was a substantial undertaking. For each segment, key geometric features in the 1977 file were checked against the same features in the 1968 file. This comparison was used to determine whether during that time period the roadway had been either reconstructed from a two-lane roadway without shoulder to a two-lane roadway with shoulder or converted from a two-lane roadway with shoulder to an undivided, four-lane roadway without shoulder. A manual examination of the two files found 390 segments (77 different sites) that had been so modified. After these roadways had been identified, their geometric files for the other eight years (1969-1976) were checked in order to determine when the modification took place. For a site to be selected, it had to have a two-year period both before and after the modification without any additional changes. In addition, candidate sites were checked for uniform cross sections, consistent traffic volumes, and standard geometric features. Roadways that did not meet these criteria were discarded.

The results of this initial screening process indicated that there was not a uniform distribution of candidate sites among the different roadway classes. There were more than enough class 1 roadways (shoulders added to a low-volume, two-lane highway) suitable for this study. The number of class 2 roadways (shoulders added to a midvolume, two-lane highway) was sufficient to choose sites that met most of the selection criteria. Class 3 roadways (shoulders added to a high-volume, two-lane highway) were virtually nonexistent since only three possibilities were found. Sites suitable for evaluating the conversion from a two-lane roadway with shoulder to an undivided, four-lane roadway without shoulder were limited by two conditions: Either the conversion took place less than three years after a shoulder had been added, or it was directly converted from a two-lane roadway without shoulder. Several additional sites were dropped from the sample because the change took place after 1975; i.e., two years of accident data after the conversion were not available. In addition, several sites were less than 5 miles in length. Because of these problems and the relatively small sample size, few additional sites were eliminated. The process by which the study sites were selected is summarized in Table 2.

In summary, an adequate number of low-volume (class 1 and 4) roadways were found that either met or exceeded the minimum selection criteria. The number of moderate-volume (class 2 and 5) roadways had been expanded to a desirable size by including several roadway segments that were less than 5 miles in length. The number of high-volume (class 3 and 6) roadways was inadequate, and both samples encompassed a broad range of conditions. An initial finding of this study is that, even with a large number of candidate roadway segments, the selection criteria restricted the number of sites eligible for study to a relatively small number. However, even with this shortcoming, the sample size was larger and more uniform than those used in previous before-after accident studies (4).

DATA COLLECTION

For each study location, the TSDHPT accident files were used to obtain the accident histories for each site during the two years before and two years after the modification took place. At this time, checks for both milepoint compatibility and construction-related accidents were made. This ensured that data were collected for the same section of roadway and also that the modification was completed within a one-year time period. During this process, several adjustments to the data set were required to account for extended construction activity. In some cases, this necessitated the use of up to six years of accident data.

Compilation of the accident data was another labor-intensive task. Each accident record had to be manually transcribed from a microfiche card reader to a coding form before it could be placed in a computer data file. Each record contained more than 30 variables. To compound this problem, minor changes in both format and variable descriptions occurred from time to time. Conversion to a compatible data base was done manually. Although each item of data was coded, only the information that was relevant to this type of study was analyzed. The variables that were analyzed are listed below:

1. Accident type--Angle, head-on, right-turn, left-turn, rear-end, same direction, fixed-object, run-off-road, animal, other, and total;
2. Severity measures--Personal injury and fatality (PI&F) accidents, fatality accidents, number of injuries, and number of fatalities;
3. Time of day--Daytime, nighttime, and total; and

Table 1. Site classification.

Classification No.	Modification Condition	ADT
100	Add paved shoulders to two-lane highway	1000-3000
200	Add paved shoulders to two-lane highway	3000-5000
300	Add paved shoulders to two-lane highway	5000-7000
400	Convert two-lane with shoulders to four-lane without paved shoulders	1000-3000
500	Convert two-lane with shoulders to four-lane without paved shoulders	3000-5000
600	Convert two-lane with shoulders to four-lane without paved shoulders	5000-7000

Table 2. Site selection.

	Candidate RI-2-TLOG Segments				Sites Selected	
Class	No.	Length (miles)	No. of Potential Sites	No. of Eligible Sites	No.	Length (miles)
1	10 515	7101	260	18	16	135
2	3 969	1885	51	18	11	68
3	1 346	516	32	3	3	11
4	453	187	15	15	13	78
5	554	223	19	17	11	68
6	403	80	13	6	6	34
Total	27 240	9992	390	77	60	394

4. Location--All and nonintersection.

Finally, it should be noted that accidents not necessarily related to roadway type were excluded from the data set.

For comparative purposes, a frequency analysis was run for each site on a yearly basis--two years before and two years after modification. Accident frequencies for the after conditions were adjusted to account for changes in ADT. Separate analyses are provided for total accident frequencies and nonintersection accident frequencies.

FREQUENCY ANALYSIS

All Accidents

The results of the frequency analysis for the all-accident data set are summarized in Tables 3 and 4. Although nine types of accidents were studied, they have been grouped into three broad categories for this discussion: multivehicle accidents, run-off-road and fixed-object single-vehicle accidents, and other single-vehicle accidents. A more detailed breakdown is not necessary since both categorization schemes support the same conclusions. Major findings from this study are discussed below.

When full-width paved shoulders were added to a two-lane roadway (Table 3), total accidents decreased in number. This was true for all volume levels studied. In the low-volume category (1000-3000 vehicles/day), there were a total of 16 sites. The average volume on these roadways was 1450 vehicles/day in the after condition. Although the number of total accidents decreased, only single-vehicle run-off-road and fixed-object accidents contributed to this reduction. There were 11 sites in the moderate-volume category (3000-5000 vehicles/day). The average volume on these roadways was 2550 vehicles/day in the before condition and 2730 vehicles/day in the after condition. Several of the sites were less than 5 miles in length. Although the total number of accidents again decreased, both multivehicle and single-vehicle run-off-road and fixed-object accidents contributed to this reduction. There were only three sites in the high-volume category (5000-7000 vehicles/day). The average volume on these roadways ranged from 3840 vehicles/day in the before condition to 4880 vehicles/day in the after condition. All three sites were less than 5 miles in length. As before, the number of total accidents decreased. However, in this situation, multivehicle accidents were the primary contributor to this reduction.

When a two-lane roadway with paved shoulder was converted to an undivided, four-lane roadway without shoulder (Table 4), total accidents decreased only for volume levels greater than 3000 vehicles/day. The low-volume category included 12 sites. The average volume on these roadways was 2000 vehicles/day in the before condition and 2200 vehicles/day in the after condition. Although the number of single-vehicle run-off-road and fixed-object accidents decreased, there was a small increase (3 percent) in the total number of accidents. In the moderate-volume category, there were 11 sites. The average volume on these roadways changed from 2910 vehicles/day in the before condition to 3310 vehicles/day in the after condition. In this category, all three types of accidents decreased in number. There were only six sites in the high-volume category. The average volume on these roadways was 4100 vehicles/day in the before condition and 5130 vehicles/day in the after condition. As in the previous category, all three types of accidents decreased in number.

Nonintersection Accidents

The results of the frequency analysis for the nonintersection-accident data set are summarized in Tables 5 and 6. Intersection-related accidents have been deleted. Categories for accident types and the sample of study sites are the same as those in the previous discussion. For this reason, their descriptions will not be repeated. Results from the analyses of the two data sets are remarkably similar. The following paragraphs describe the probable causes of these trends.

When full-width paved shoulders are added to a two-lane highway (Table 5), the number of total accidents can be expected to decrease in number. This was true for all volume levels studied. Both the magnitude of the reduction and the types of accidents contributing to it changed with increasing volume. The biggest percentage savings occur at low traffic volumes; however, single-vehicle accidents were the only type of accidents that decreased in number. Since they constitute almost 70 percent of the total accidents in the "before" condition, these results are not surprising. Accidents that occur at these volume levels are often the result of inattentiveness brought on by a low driver workload. Typically, these incidents involve one driver who for some reason loses control of his or her car and runs off the road. Adding paved shoulders to the roadway provides more surface area for motorists to recover from this type of mistake. This results in a decrease in the expected number of single-vehicle accidents.

At moderate volumes, accident reductions are less than half those of the lower-volume category. In this case, both single-vehicle and multivehicle accidents decreased in number. The percentage of single-vehicle accidents in the "before" condition has decreased to about 60 percent. The additional traffic has increased the driver's workload and made him or her more attentive, but at the same time it has increased the driver's probability of hitting another car. Although paved shoulders still provide recovery area, they are now being used for accident avoidance maneuvers. Thus, the expected number of both accident types decreases. At high traffic volumes, accident reductions fall midway between those for the other two volume categories. It is interesting that only multivehicle accidents contributed to this saving. The percentage of single-vehicle accidents in the "before" condition has decreased to 40 percent. High traffic volumes have caused the driver's workload to become extremely heavy. As a result, accidents caused by inattention are infrequent. Since most incidents involve more than one vehicle, any safety benefits that result from the addition of paved shoulders must come from a reduction in the number of multivehicle accidents.

When a two-lane roadway with paved shoulder is converted to an undivided, four-lane roadway without shoulder (Table 6), total accidents can be expected to decrease in number whenever the road carries more than 3000 vehicles/day. If the volume is lower than this, accident frequencies will probably increase. At these low volumes, both single-vehicle and multivehicle accidents can be expected to increase in number. As described previously, accidents that occur at these volume levels are often the result of inattentiveness brought on by a low driver workload. Conversion of the shoulder to a travel lane adds to this false feeling of security and reduces the area available for vehicle recovery. Therefore, it is not surprising that accident rates increased after modification. This type of improvement does reduce accidents at higher volume levels. This saving increases with increasing volumes. It is

Table 3. Safety benefits of adding shoulders to two-lane roadway: all accidents.

Traffic Volume	Type of Accident	No. of Accidents Before	After	Change (%)
1000-3000	Multivehicle	69	69.5	+0.7
	Single vehicle			
	Run-off-road and fixed-object	74	34.2	-53.8
	Other	29	31.7	+9.3
	Total	172	135.4	-21.3
3000-5000	Multivehicle	92	82.3	-10.5
	Single vehicle			
	Run-off-road and fixed-object	77	62.7	-18.6
	Other	31	39.1	+26.1
	Total	200	184.1	-8.0
5000-7000	Multivehicle	44	33.9	-23.0
	Single vehicle			
	Run-off-road and fixed-object	17	14.9	-12.4
	Other	7	8.2	+17.1
	Total	68	57.0	-16.0

Table 4. Safety benefits of converting to four-lane poor-boy highway: all accidents.

Traffic Volume	Type of Accident	No. of Accidents Before	After	Change (%)
1000-3000	Multivehicle	61	68.2	+11.8
	Single vehicle			
	Run-off-road and fixed-object	90	75.3	-16.3
	Other	33	45.3	+37.3
	Total	184	188.7	+2.6
3000-5000	Multivehicle	104	77.0	-26.0
	Single vehicle			
	Run-off-road and fixed-object	83	71.6	-13.7
	Other	42	35.4	-15.7
	Total	229	184.0	-19.7
5000-7000	Multivehicle	80	72.7	-9.1
	Single vehicle			
	Run-off-road and fixed-object	57	35.8	-37.2
	Other	26	24.4	-6.2
	Total	163	132.9	-18.5

Table 5. Safety benefits of adding shoulders to two-lane roadway: nonintersection accidents.

Traffic Volume	Type of Accident	No. of Accidents Before	After	Change (%)
1000-3000	Multivehicle	35	36.4	+4.0
	Single vehicle			
	Run-off-road and fixed-object	58	26.1	-55.0
	Other	27	25.1	-7.0
	Total	120	87.6	-27.0
3000-5000	Multivehicle	68	53.9	-14.7
	Single vehicle			
	Run-off-road and fixed-object	67	52.9	-21.4
	Other	29	36.7	+26.6
	Total	164	143.5	-12.5
5000-7000	Multivehicle	27	16.9	-37.4
	Single vehicle			
	Run-off-road and fixed-object	12	12.0	0
	Other	6	8.2	+36.6
	Total	45	37.1	-17.6

Table 6. Safety benefits of converting to four-lane poor-boy highway: nonintersection accidents.

Traffic Volume	Type of Accident	No. of Accidents Before	After	Change (%)
1000-3000	Multivehicle	35	44.8	+28.0
	Single vehicle			
	Run-off-road and fixed-object	72	69.4	-3.6
	Other	33	43.4	+31.5
	Total	140	157.6	+12.6
3000-5000	Multivehicle	73	44.0	-39.8
	Single vehicle			
	Run-off-road and fixed-object	72	68.7	-4.6
	Other	40	37.1	-7.3
	Total	185	149.8	-19.0
5000-7000	Multivehicle	53	39.6	-25.3
	Single vehicle			
	Run-off-road and fixed-object	55	28.8	-47.6
	Other	29	30.3	+4.5
	Total	137	98.7	-28.0

interesting to note that the number of single-vehicle accidents did not decrease until the volume reached 5000 vehicles/day. This indicates the point at which the workload on a four-lane highway becomes great enough to capture the driver's attention.

PAIRED t-TEST COMPARISONS

To supplement the previous analysis, a paired t-test was used to compare accident frequencies for the two years before and the two years after the modification. The data were examined for significant changes in either accident type or severity on a class-by-class basis. A two-tailed t-test at the 90 percent confidence level was used to test for these differences. Findings from this analysis are discussed below.

All Accidents

Significant differences in before-after accident frequencies for the all-accident data are given in Table 7. When paved shoulders were added to a two-lane roadway, the total number of accidents decreased. This difference was significant in both the high- and low-volume categories. Few changes in the frequency of occurrence for specific types of accidents were noted. The data do indicate that paved shoulders will decrease accident severity on low- and moderate-volume roadways; however, they appear to increase accident severity on high-volume roads. The reasons for this can best be described in the following manner. The average speed on two-lane roadways is not affected by the presence or absence of a paved shoulder until the volume on the facility reaches 5000 vehicles/day. Above this point, the average speed on a roadway with shoulder is at least 10 percent greater than it is on a similar section without shoulder. Previous research (10) has shown that higher speeds are normally associated with increased accident severity. Thus, the benefits that result from a reduction in total accident frequency and a savings in travel time are being partially offset by an increase in the severity of those accidents that do occur.

When a two-lane roadway with paved shoulder was converted to an undivided, four-lane roadway without shoulder, the number of total accidents decreased for roadways with volumes greater than 3000 vehicles/day. However, this difference was significant in the moderate-volume category only. In contrast to the other type of improvement, many changes in the frequency of occurrence of specific types of accidents were noted. As shown, these differences were more common in the moderate- and high-volume categories. Conversion to a poor-boy roadway appears to have an inconsistent effect on accident severity. The frequency with which injury accidents occur increased during the night and decreased during the day. The reasons for these changes are unclear at best; however, the results of the comparative analysis showed that 60 percent of the total accidents on this type of road occur at night. This indicates that darkness may be eliminating visual cues that alert the driver to the closeness of the edge of the roadway.

Nonintersection Accidents

Significant differences in before-after accident frequencies for the nonintersection accident data are given in Table 8. The addition of paved shoulders caused the total number of accidents to decrease. This difference was significant in all three volume categories. At low volumes, the frequency of several types of single-vehicle accidents

Table 7. Statistically significant differences in accident types: all accidents.

Type of Conversion	Type of Accident	1000-3000 ADT Change	1000-3000 ADT Time of Occurrence	3000-5000 ADT Change	3000-5000 ADT Time of Occurrence	5000-7000 ADT Change	5000-7000 ADT Time of Occurrence
Addition of paved shoulders to two-lane roadway	Angle	+	N				
	Head-on						
	Right-turn						
	Left-turn					–	D,T
	Rear-end			–	D,T		
	Same direction					–	T
	Fixed-object			–	N,T		
	Run-off-road	–	D,N,T				
	Animal						
	Other						
	Total number	–	D,T			–	T
	PI+F			–	N,T		
	Fatal			–	N,T		
	Injuries	–	D,T			+	D,T
	Fatalities			–	N,T	+	N,T
Conversion of two-lane roadway with paved shoulder to four lanes without shoulder	Angle						
	Head-on			–	D,T	–	D
	Right-turn					+	N
	Left-turn	–	D,T	–	D,T		
	Rear-end					–	D
	Same direction						
	Fixed-object	–	D,T				
	Run-off-road			–	T	–	D,T
	Animal			–	N,T	–	N,T
	Other	+	D			+	T
	Total number			–	D,T		
	PI+F	+	N	+	N	–	D,T
		–	D	–	D		
	Fatal						
	Injuries	+	N	+	N		
		–	D	–	D		
	Fatalities					–	D

Note: + = increase, – = decrease, N = nighttime, D = daytime, and T = total.

Table 8. Statistically significant differences in accident types: nonintersection accidents.

Type of Conversion	Type of Accident	1000-3000 ADT Change	1000-3000 ADT Time of Occurrence	3000-5000 ADT Change	3000-5000 ADT Time of Occurrence	5000-7000 ADT Change	5000-7000 ADT Time of Occurrence
Addition of paved shoulders to two-lane roadway	Angle						
	Head-on						
	Right-turn						
	Left-turn			–	D,T	–	D,T
	Rear-end			–	D,T	–	T
	Same direction					–	T
	Fixed-object	–	D				
	Run-off-road	–	D,N,T				
	Animal	–	T	+	N,T		
	Other					+	T
	Total number	–	D,N,T	+	N	–	T
				–	D,T		
	PI+F			–	T		
	Fatal			–	N,T		
	Injuries	–	T			–	D
	Fatalities			–	N,T	+	N,T
Conversion of two-lane roadway with shoulder to four lanes without shoulder	Angle						
	Head-on			–	D,T		
	Right-turn						
	Left-turn	–	D,T	–	D,T		
	Rear-end			–	D,T	–	N,T
	Same direction	+	T				
	Fixed-object					–	D
	Run-off-road					–	D,T
	Animal			–	N,T	–	N,T
	Other	+	D,T	+	N,T	+	T
	Total number	+	T	–	D,T	–	D,T
	PI+F					–	D,T
	Fatal						
	Injuries	+	N			–	D
	Fatalities						

Note: – = decrease, + = increase, D = daytime, N = nighttime, and T = total.

decreased. At moderate and high volumes, the frequency of several types of multivehicle accidents decreased. This reinforces the premise that shoulders are effective in reducing the occurrence of different types of accidents at the various volume levels. These data also indicate an overall decrease in accident severity when shoulders were added to two-lane roads; however, the number of fatalities did increase in the high-volume category. Again, this increase is probably the result of higher speeds after the modification.

The conversion of a two-lane roadway with paved shoulder to an undivided, four-lane roadway without paved shoulder resulted in an increase in the total number of accidents at low volumes and a decrease at moderate and high volumes. The frequency of occurrence for the various accident types exhibits similar characteristics. The number of injury accidents increased at low volumes and decreased at high volumes. It is interesting to note that the increase occurred at night and the decrease occurred during the daytime. Again, this observation points to a potential nighttime safety problem.

CONCLUSIONS

Based on the findings from the comparative before-after analysis, several conclusions can be drawn. These involve changes in both accident frequency and accident type after modification of two types of rural Texas highways, as discussed below.

Addition of Shoulders

The addition of full-width paved shoulders to a two-lane roadway was effective in reducing the total number of accidents that occurred. The magnitude of the reduction and the characteristics of the accidents varied with the traffic volume. These changes were similar for both the all-accident and the nonintersection-accident data bases. At low volumes, the addition of shoulders resulted in fewer single-vehicle accidents (run-off-road and fixed-object). Thus, the shoulder provides additional paved recovery area for drivers inadvertently exiting from the travel way. These results should be expected, since at low traffic volumes the potential is low for multivehicle accidents and high for driver boredom. At moderate volumes, the addition of shoulders reduced the total number of accidents and the severity of those that did occur. Both single-vehicle and multivehicle accidents decreased in number. This indicates that shoulders are being used for accident avoidance as well as recovery maneuvers. On high-volume roadways, these improvements resulted in fewer total accidents; however, they increased the severity of those that did occur. This increase is attributed to increased operating speeds after the shoulder was added to roadways in this volume category.

Poor-Boy Roadways

When two-lane roadways with paved shoulders were converted to undivided, four-lane roadways without shoulders, the results varied with the volume of traffic. At low volumes, the total accident frequency actually increased after the conversion. At moderate- and high-volume locations, poor-boy roadways resulted in fewer total accidents. The magnitude of the reduction increased with increasing volumes. This type of modification appears to have an inconsistent effect on accident severity. The frequency with which injury accidents occur increases during the night and decreases during the day. These results indicate that darkness may be eliminating visual cues that alert the driver to the hazards associated with this type of roadway.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

The findings and recommendations drawn from the analysis are summarized below:

1. Addition of full-width paved shoulders to a two-lane roadway is effective in reducing the total number of accidents that occur.
2. Conversion of a paved shoulder to an additional travel lane probably should not be considered unless the volume on the roadway exceeds 3000 vehicles/day.
3. The potential nighttime safety improvements resulting from improved edge-line delineation systems on poor-boy highways should be evaluated.
4. The potential safety improvements resulting from the addition of full-width paved shoulders at major intersections on two-lane roads without shoulders should be evaluated.

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Abridgment

Guidelines for Treatment of Right-Turn Movements on Rural Roads

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A survey of state departments of transportation conducted to identify the criteria currently used in selecting road designs to accommodate right-turning vehicles on rural roads revealed that the decisions are based primarily on judgment. The survey also identified factors to be considered in establishing criteria. Field work identified the range of traffic and roadway conditions encountered at selected rural locations and the effectiveness of the treatments. Guidelines were developed through an analysis of survey responses, field data, and judgment. They are based on the peak-hour (or design-hour) volumes for right-turning traffic and total traffic on the approach to the right-turn treatment. Guidelines are available for two- and four-lane roadways. Other factors to be considered are noted.

The objective of the research reported in this paper was to develop guidelines for the treatment of right-turn maneuvers on rural roads that would be applicable for a wide range of conditions at intersections. The treatments considered were a radius, a 150-ft taper, and a full-width turn lane. The volumes and speeds of right-turning and through traffic were the primary factors considered, and the research was limited to treatments for nonsignalized intersections. Information on which to base the guidelines was obtained from a survey of state departments of transportation, conversations with traffic engineers in Virginia, and studies of selected rural intersections.

SURVEY OF STATE DEPARTMENTS OF TRANSPORTATION

The survey of state departments of transportation (DOTs) was conducted by telephone. If a policy or procedure was in use, a written document was requested. Responses were obtained from 41 of the 48 contiguous states. Of the 25 states without criteria, most consider special right-turn treatment on a project-by-project basis. Whereas several states seldom consider special treatment for right turns in rural areas, 39 percent, or 16, of the state DOTs contacted used some form of criteria. Five guidelines were based on volume conditions, 4 on roadway type, 2 on capacity, and 5 on rule of thumb at intersections. The guidelines should provide efficient use of treatments for right-turn movements and consistent treatment of right-turn movements throughout the state.

Based on the literature review and survey, the following parameters were selected for consideration in the guidelines: (a) total or through traffic volume, (b) right-turn traffic volume, (c) speed prior to the intersection, (d) traffic conflicts due to right-turning vehicles, (e) capacity analysis, and (f) accident history.

FIELD WORK AND ANALYSIS

The traffic data were collected in two stages: a 48-h count and two 2-h peak-period observations. For the 48-h traffic count, counters were placed prior to the intersection for total volume counts on the approach to the study site and at the intersection for right-turn volume counts. The average daily traffic count and peak 2-h period were determined through a computer analysis. In the next stage, observations were made during two 2-h peak periods to obtain volume counts for all approaches, traffic conflicts due to right-turning vehicles, and speed data on the study approach. Data were collected over 15-min intervals by using a procedure developed by Glauz and Migletz (1).

Twenty-one sites were selected under three classifications. Eight sites were four-lane arterials intersecting two-lane roads, 8 were intersections of two-lane arterials and two-lane roads, and 5 were intersections of two secondary roads. There were 7 sites for each right-turn treatment. There were 11 T-intersections and 10 cross (or four-legged) intersections. There was variability in the lengths and widths of right-turn treatments, and the minor roadway was controlled by a stop sign.

The data analysis used the Statistical Package for the Social Sciences (2) and consisted of two stages: (a) the Pearson correlation to identify parameter pairs that were strongly related and (b) a regression analysis to define the linear relations between these pairs. The study sites were grouped in three ways: by site classification, by type of right-turn treatment, and by right-turn treatment and number of lanes on the major approach. The third grouping was most useful in developing the guidelines.

The analyses indicated that the strongest correlations were between peak-hour-volume right-turn conflicts (PHV conflict) and peak-hour-volume percentage of right turns (PHV % right turns) and between PHV conflict and PHV right turns. The peak-hour period was selected because it is the recommended design period in the American Association of State Highway Officials "Blue Book" (3). There was a strong interest in using PHV total and right-turn volumes. For existing intersections, the