deviations from the design obstacle height than to deviations from the design eye height. Thus, objects larger than the design obstacle will come into view at the AASHO stopping distance for drivers whose eyes may be considerably lower than the design eye. For example, on a hill crest designed to the current AASHO practices (i.e., a 45-in-high eye and a 6-in obstacle), an 8.5-in obstacle will come into the view of a 39-in-high eye at the design sight distance; and a 15-in obstacle (e.g., the federally mandated minimum height for tail lamps) would be in view at the design sight distance for an eye only 28 in above the pavement. Accident studies or considerations of driver visual performance limitations could very well show that a 12- or 15-in-high design obstacle is more representative of real-world objects that drivers can see and need to avoid. If so, the sight distances designed to the 6-in-high target provide a considerable safety margin, and traffic safety on hill crests is not likely to be very sensitive to the changes in eye height associated with the downsizing of the passenger-car fleet.

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Shoulder Upgrading Alternatives to Improve Operational Characteristics of Two-Lane Highways

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A research project was undertaken to develop upgrading warrants for use in determining when to add paved shoulders to rural two-lane roadways or when to convert two-lane roadways with paved shoulders into four-lane undivided roadways by low-cost treatments such as remarking the shoulder to indicate that it is a travel lane. The latter treatment is known as a "poor-boy" highway in Texas. The findings of one portion of the research—the effects of paved shoulders on vehicle operating characteristics—are described. Field studies were performed at 18 sites around Texas for three types of highways: (a) two-lane roadways without shoulders, (b) two-lane roadways with shoulders, and (c) four-lane, undivided roadways. Operational characteristics were recorded for more than 21 000 vehicles. Data were gathered on speed, platooning, shoulder use, and vehicle type. The findings indicate that operational benefits derived from a full-width paved shoulder increase as traffic volumes increase. These benefits are minimal at low and moderate volumes, but they become significant at volumes greater than about 200 vehicles/h. Above this volume, paved shoulders appear to increase the average speed on the roadway by at least 10 percent. They also limit the number of vehicles in platoons to less than 20 percent. No more than 5 percent of all vehicles used the shoulder at any of the sites. Conversion of the shoulder to an additional travel lane offers no apparent operational benefits until the volume reaches 150 vehicles/h. On higher-volume roads, this modification could be expected to cause average roadway speeds to increase by approximately 5 percent and limit platooning to 5 percent. Significantly, such a conversion results in more than two-thirds of the traffic using the outside (shoulder) lane.

There are thousands of miles of existing two-lane rural roadways that are providing adequate service at low levels of vehicle flow. But, as traffic volumes grow and other characteristics change, these highways experience serious safety and operational deficiencies. It frequently becomes necessary to upgrade them to provide increased service to the higher traffic volumes.

A study was conducted in Texas to consider two improvement alternatives involving paved shoulders on rural roads: (a) adding paved shoulders to two-lane roads that previously did not have them and (b) converting two-lane highways with full-width paved shoulders into four-lane "poor-boy" roadways. The latter option is accomplished at low cost by remarking the roadway surface to indicate that the shoulder has become a travel lane. This upgrading treatment produces an undivided four-lane roadway without shoulders.

The research project was undertaken to develop upgrading warrants by quantifying the safety and operational characteristics associated with paved shoulders and by establishing the driver's understanding of the legality of driving on paved shoulders. This paper documents the findings of one portion of the research: the effects of paved shoulders on vehicle operating characteristics.

PREVIOUS RESEARCH

Many previous studies have dealt with the basic questions of shoulder design, field performance, and safety improvement; however, very few have looked at operational considerations. Several of these are reviewed below.

Operational Studies

Several studies have attempted to identify current general practices. A national survey (1) conducted in 1973 revealed that there were four states that allowed slower traffic to drive on the shoulder in order to facilitate passing maneuvers. Unfortunately, the reasons for allowing this maneuver have been neither investigated nor reported. A comprehensive state-of-the-art review of paved shoulders was published in 1976 (2). This review noted that shoulders affected traffic in the following ways:

1. Increased lateral separation between oncoming vehicles,
2. Eased driver tension through a sense of openness and provision of space for emergency maneuvers,
3. Maintained capacity by allowing room for stopped vehicles,
4. Increased capacity where slow-moving vehicles pulled onto the shoulder to allow faster vehicles to pass (where legal), and
5. Improved traffic operations by acting as pseudo acceleration and deceleration lanes.

The results of a 1979 nationwide study on the design and use of highway shoulders (3) indicated that five states permit regular use of shoulders for slow-moving vehicles. An additional 10 states permitted such use under certain conditions.

Although these studies document general conditions when the various states allow shoulder use, they do not indicate the degree of improvement that might be expected to result from such use. Increased speed and decreased platooning are two of the benefits that probably occur, but the literature review failed to disclose any instances in which the degree of improvement had been quantified.

Messer (4) devised a technique for measuring vehicle operational characteristics during an Illinois study. While driving along a test roadway, he measured speed and location characteristics for opposing vehicle flow. Through repetitive trips along the test roadway, he acquired sufficient data to relate roadway features to operational characteristics. This field observation technique was adopted by the project staff to gather data for use in quantifying the operational improvements associated with paved shoulders in Texas.

Driver Understanding

Concern has been expressed that motorists do not adequately understand the road-marking code and do not totally agree on the legality of driving on the shoulder. Gordon (5) examined this hypothesis in a laboratory study that involved 254 motorists from the Washington, D.C., area. He found that as many as 60 percent of the subjects thought that it was legal to use the shoulder to pass a disabled vehicle located in the main lane. Other researchers have found that, even in states where driving on the shoulder is legal, there is a great deal of driver uncertainty about which specific maneuvers are legal.

The accepted document for interpretation and application of the road-marking code is the 1978 Manual on Uniform Traffic Control Devices for Streets and Highways (MUCTD) (6), and the Uniform Vehicle Code and Model Traffic Ordinance (revised in 1968) (7) outlines accepted rules governing vehicle actions. Even though these two documents are well known to traffic engineers, the motoring public does not seem to be well informed about what shoulder markings and codes imply.

Accident Studies

The bulk of all previous shoulder research has been safety oriented. An excellent summary was prepared by Roy Jorgensen and Associates in 1978 (8). This summary noted conflicting results from previous researchers. Several of these researchers concluded that, as the shoulder width on rural two-lane highways increases, the accident rate decreases. Others have found that under some circumstances the accident rate increases as shoulder width increases. Still others found mixed results or no relation between accident rate and shoulder width.

The apparent conflicts among previous studies can be traced mainly to small or localized data samples or failure to control all variables in the study. The majority of past studies support the concept of reduced accident rates on roadway sections with wide shoulders.

Recent research has placed emphasis on accident rate and the presence or absence of paved shoulders. Heimbach (9) performed a study on 3000 rural highways in North Carolina. He found a significantly lower accident experience and severity index for two-lane highways with 3- to 4-ft paved shoulders in comparison with similar highways without paved shoulders.

At least five research projects (8-12) have developed techniques for selecting optimum paved shoulder widths based on such factors as traffic volumes, pavement widths, traffic speeds, and construction costs. In each case, the researcher used benefits from accident reduction to justify the costs of shoulder construction.

Summary

In general, the effects of paved shoulders on traffic operations have not been quantified. No studies could be located that predicted changes in speed, platooning, or shoulder use based on shoulder type or width. At least 15 states allow vehicle travel on the shoulder under some conditions, whereas 5 allow regular use.

Shoulder accidents have been studied in detail, and the consensus is that paved shoulders produce positive benefits by reducing accidents. Several methods have been established to choose optimum shoulder widths based on these benefits. These methods do not consider operational benefits of paved shoulders.

Although there are national documents that give explicit guidance on shoulder markings and vehicle behavior, studies have shown that motorists do not always understand or behave according to the guidance in the documents.

SITE SELECTION

The research project was conducted on three types of highways: (a) two-lane roadways without shoulders, (b) two-lane roadways with shoulders, and (c) four-lane, undivided roadways without shoulders. Examples of each roadway type are shown in Figure 1. All roadways in Texas were screened as potential sites through use of a computer listing of the roadway geometric file, commonly referred to as the RI-2-TLOG. Control was established by defining the characteristics typical of rural Texas roadways and then rigorously screening the geometric file to locate candidate sites.

General Study

A matrix of desired characteristics was created to stratify the sites by traffic volume, shoulder type,

Figure 1. Typical examples of three highway classes.

and number of lanes. The table below gives the 10 classifications used to allow a comparative analysis of the effects of these variables on accident rate and traffic operations. To ensure a large and representative data sample, it was desired that 10 sites in each class be studied and that each site contain 5 or more miles of consistent roadway:

Site No.	Type of Highway	Type of Shoulder	Average Daily Traffic
1	Two-lane	Unpaved	1000-3000
2			3000-5000
3			5000-7000
4	Two-lane	Paved	1000-3000
5			3000-5000
6			5000-7000
7	Four-lane	Unpaved	3000-5000
8			5000-7000
9			7000-9000
10			1000-3000

Once the general site criteria had been defined, the RI-2-TLOG file was carefully reviewed to obtain a list of potential rural sites that fit the requirements outlined in the table. The initial screening was a substantial undertaking that involved a manual evaluation of more than 29 000 roadway segments. A series of geometric parameters was carefully checked to ensure uniform characteristics for all eligible sites in each category.

A great deal of effort was expended in checking the eligible sites to ensure that they were typical of their respective categories. For example, average daily traffic was reviewed at each location to verify that no major changes had occurred. Pavement widths and shoulder types were scrutinized for uniformity in each class. Divided roadways were deleted from the investigation. Careful reviews were conducted in which county, highway district, and state maps were used to isolate and remove sites that contained major intersections, towns, or other factors that might bias the results of the study.

At the close of the site-screening procedure, there were 10 or more potential sites in only 6 of the categories. Class 3 had 8 sites, class 7 had 9 sites, and classes 8 and 9 had 4 sites each. The primary reasons that the desired number of sites could not be obtained were the limited mileage of roads in the categories and the rigorous screening process used to remove nonhomogeneous sites.

Accident Study

For the accident study, 10 sites were selected where possible for each category. They were numbered, and three years of accident data were used to calculate the accident rates at each site. This study is described in detail elsewhere (13,14), and the information will not be repeated here.

Operational Study

For the operational study, to ensure that the data sample would be representative of statewide operating conditions, the following site-selection procedure was adopted. For each of the 10 highway classes, the accident-study sites were ranked by their accident rates. The two extremes (highest and lowest rates) from each category were tentatively selected for further study. As neither extremely short nor widely separated segments lend themselves to maximizing a data-collection effort, section lengths and geometric locations were checked. Sites that did not meet these criteria were discarded and replaced by the next-ranked site in the category. Figure 2 indicates the general location in Texas of the field study sites. As shown, most of the state's geographic regions were represented in the sample. General descriptions of each site are given in Table 1.

STUDY OF OPERATIONAL EFFECTS

The major thrust of this paper is to report on the findings of a study of operational characteristics conducted on rural Texas highways. The techniques devised by Messer (4) were used to gather several types of data in order to quantify the parameters influenced by the roadway shoulder. Traffic volume, passing opportunities, and minimization of traffic blockages were felt to be the primary factors that influence operational characteristics. For purposes of this study, shoulders were defined as being paved and 6 ft or more in width.

Methodology

The procedure developed to collect operational data was constrained by practical considerations of mobility, accuracy, economy, and minimum distraction to motorists. Primarily, it was designed to collect five types of traffic data: traffic composition, traffic volume, vehicle speeds, lateral placement, and platooning characteristics. Roadway geometrics and other pertinent information were also recorded.

At each site, a study vehicle and two members of the research team were required to collect the field data. The vehicle was equipped with an on-board moving radar gun, a distance-measuring instrument, and several cameras. To simplify operations, most of the equipment was mounted on the dash of the car. The vehicle operator was responsible for driving the car, classifying approaching vehicles, and calling out their speeds. The responsibilities

Figure 2. Field operational study sites.

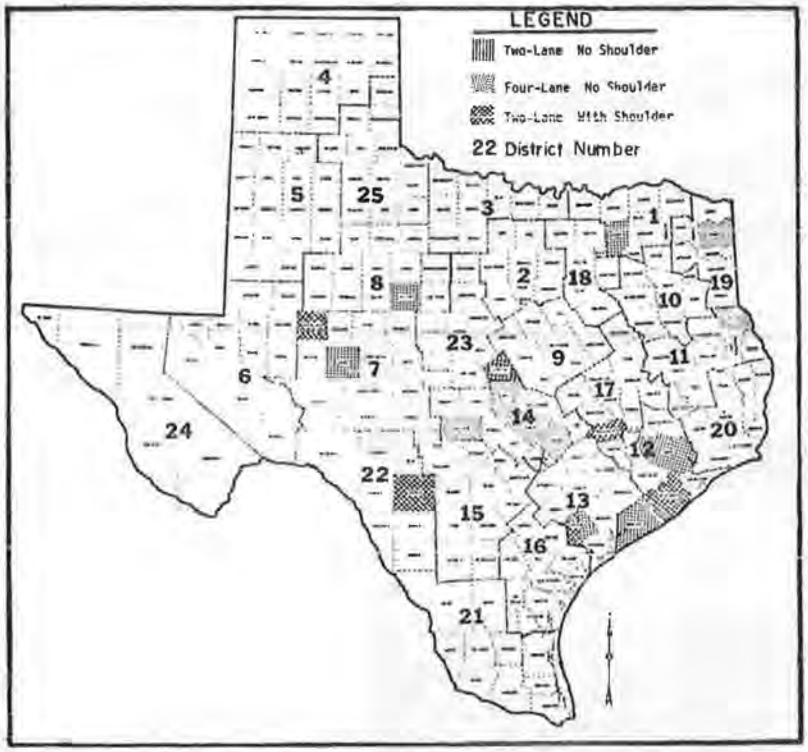


Table 1. Location and description of field study sites.

Type of Highway	Site No.	Highway	County	Type of Curvature: Horizontal	Type of Curvature: Vertical
Two-lane, no shoulder	101	US-67	Irion	Mild	Moderate
	108	US-277	Taylor	Moderate	Moderate
	205	US-276	Hunt	Moderate	Moderate
	208	TX-35	Matagorda	Mild	Mild
	303	FM-2100[a]	Harris	Mild	Mild
	308	US-87	Victoria	Mild	Mild
Two-lane, with shoulder	408	TX-105	Washington	Moderate	Moderate
	409	TX-158	Glasscock	Mild	Mild
	501	US-90	Uvalde	Mild	Mild
	508	US-190	Lampassas	Moderate	Moderate
	604	TX-35	Brazoria	None	None
	606	US-77	Victoria-Refugio	Mild	Mild
Four-lane, no shoulder	1002	TX-21	Burleson-Lee	Moderate	Moderate
	1009	US-290	Gillespie	Severe	Moderate
	703	US-290	Bastrop	Mild	Moderate
	705	TX-29	Burnet	Severe	Moderate
	803	US-183	Travis	Mild	Mild
	906	US-59	Cass	None	Moderate

[a]Farm-to-market road.

of the study coordinator included reading longitudinal distances, recording all data, and taking photographs.

When the research team arrived at a site, features that could be easily referenced (such as intersections, bridges, and county lines) were identified to mark the ends of the study section. Several "drive-throughs" were made to familiarize the team with the site and with local traffic characteristics and to select several intermediate reference points within the section. An additional drive-through was used to videotape the site and to take 35-mm slides of the general roadway appearance. Data were collected for a 6-h period. During this time, the study vehicle was driven in a continuous circuit from one end of the section to the other. A citizens band radio was monitored to determine whether the radar had been detected or observed. Although a few speeding drivers noticed the radar (and in some instances slowed down), the overall effect on average speed was negligible. At the conclusion of the study, lane and shoulder widths were measured and recorded. Other pertinent information, such as severity of curvature and apparent aggressiveness of drivers, was also documented.

For each vehicle met by the study team, type, speed, lane position, and longitudinal placement were manually recorded. For platoons of vehicles, the speed and longitudinal position of the lead vehicle were recorded along with the number and composition of vehicles in the platoon. Vehicle classifications used in this study included passenger cars, pickups, recreational vehicles, farm vehicles, trucks, and motorcycles. These classifications were more specific than those normally associated with traffic studies; however, the research staff anticipated that agricultural or recreational vehicles might be related to shoulder-use

Figure 3. Observed shoulder use.

characteristics. Lane position referred to whether the vehicle was driving on the shoulder of the two-lane sections or in the outside lane of the four-lane sections. Longitudinal placement was used to identify locations where use of the shoulder occurred.

Study Summary

Field data were collected at a total of 18 different sites from around the state. Three types of highways were studied: (a) two-lane highways without paved shoulders, (b) two-lane highways with paved shoulders, and (c) undivided, four-lane highways without paved shoulders. The sample included two sites from each roadway classification except for classes 8 and 9. Operational characteristics of more than 21 000 vehicles were observed and recorded. For each study site, the data were reduced, compiled, and summarized for each direction.

In the course of the field studies, many different types of shoulder use were observed. Some of these are shown in Figure 3.

Study Results

Three major factors were analyzed by using the study data: speed, platooning characteristics, and shoulder use.

Vehicle Speeds

Average travel speeds for all vehicles, as well as those for trucks only, are presented in Table 2 and illustrated in Figure 4. From these data, several interesting trends can be observed. Even though speeds varied between sites, they fell into a tight range of 52-62 mph. Truck speeds were examined separately to determine any restricting characteristics they might impose. Truck speeds ranged from 50 to 61 mph. For the most part, they are about the same or slightly less than the average speed on the roadway. Only at site 1009 was this not the case. The reason for this divergence is not clear; however, this particular roadway carried much less traffic than any other site even though it was a four-lane highway. The percentage of trucks at each site ranged from 5 to 15 percent. Although these numbers are higher than what might be expected for rural roadways, it should be noted that the definition of "truck" adopted for this study included single-unit as well as tractor-trailer trucks.

For two-lane roads without shoulders, the average speed drops from 61 mph at low volumes to 52 mph at high volumes (top of Figure 4). The data appear to be a reasonable approximation of a linear pattern, showing a marked decrease in speed as volume increases. The average truck speed exhibits a similar, although less pronounced, reduction. This suggests that increasing the volume on this type of highway will have less effect on truck speeds than on the speeds of other vehicles. For two-lane roads with paved shoulders, the average speed drops from 61 mph at low volumes to 57 mph at high volumes (middle of Figure 4). Again, the average truck speed exhibits a similar but less pronounced reduction. It should be pointed out that increasing volume on this type of highway will have less effect on average speeds than it will have on two-lane roads without shoulders. For the undivided, four-lane roadway (no shoulder), the average speed dropped from 59 mph at low volumes to 57 mph at high volumes (bottom of Figure 4). In this case, the reduction in average truck speed is the same. This suggests that increasing the volume on this type of highway has little effect on average vehicle speeds.

A direct comparison of the average speeds on the three types of highways is shown at the top of Figure 5. Increasing volumes have the most impact on two-lane roads without shoulders. Speeds drop rapidly as volumes increase on this type of highway. Speeds also decreased at about the same rate on two-lane roads with paved shoulders but only until the volume reached about 150 vehicles/h. Further reductions did not occur with increases in volume past this point. At volumes greater than 200 vehicles/h, the average speed on the roadways with shoulders is about 10 percent higher than it is on comparable roadways without shoulders. For the four-lane roadways without shoulders, speed did not decrease with an increase in volume. Conversion of the paved shoulder to an additional travel lane appears to increase the average speed by about 5 percent at volumes greater than 150 vehicles/h.

Average travel speeds were subjected to regression analysis to determine predictive equations. Equations 1-3 produced the best fit for two-lane roadways without shoulders, two-lane roadways with shoulders, and four-lane roadways without shoulders, respectively:

$$S = 62.2 - 0.0350\ V \quad (1)$$

$$S = 66.5 - 0.0718\ V + 0.0001\ V^2 \quad (2)$$

$$S - 59.0 - 0.0034\ V \quad (3)$$

where S is speed in miles per hour and V is volume in vehicles per hour.

The measures of effectiveness (R^2 and standard error) for Equation 1 are quite strong, which indicates that it is an excellent fit to the data. The equation depicts a linear relation of decreasing speed with increasing volume, which reinforces the observations for Figure 5.

Equation 2 was selected after extensive efforts to find the best fit for two-lane roadways with shoulders. The measures of effectiveness are much weaker than those for Equation 1. The difficulty was attributable to the change in the character of data at volumes greater than 150 vehicles/h. Below that point, linear regression (similar to Equation 1) fit quite nicely but, when all data were considered, linear techniques were not appropriate.

Equation 3 is linear with a very flat slope. A

Table 2. Results of operational field studies.

	Direction A				Direction B			
	Total Vehicles		Trucks		Total Vehicles		Trucks	
Site No.	No.	Avg Speed (mph)	Percent	Avg Speed (mph)	No.	Avg Speed (mph)	Percent	Avg Speed (mph)
101	217	62.39	10.14	58.55	174	61.71	13.22	57.96
108	230	60.70	19.10	57.80	219	61.20	16.00	59.50
208	472	57.24	20.34	56.32	465	56.72	22.58	56.32
205	253	54.20	10.30	51.80	257	53.40	9.30	54.00
308	637	54.53	7.22	54.14	563	53.30	5.68	51.75
303	828	51.80	13.16	49.90	738	53.00	10.03	57.40
409	382	62.20	25.00	60.10	316	63.40	20.00	61.60
408	319	57.99	14.32	56.59	413	60.79	17.19	57.29
501	470	58.37	22.13	57.46	518	60.56	23.75	59.74
508	650	54.73	12.00	51.05	629	54.48	13.51	55.27
604	1204	55.91	10.47	54.96	1039	56.58	12.32	54.52
606	1656	58.24	22.83	58.96	1465	56.97	22.80	56.36
1002	348	59.29	12.93	55.82	376	58.51	20.74	56.31
1009	107	60.96	7.48	62.38	138	58.70	13.77	61.00
703	757	60.14	15.46	59.41	674	61.32	12.61	59.01
705	674	52.80	8.90	52.60	727	54.60	10.50	54.50
803	676	57.01	12.13	54.92	643	58.32	11.20	56.32
906	1235	58.18	19.27	56.95	1143	59.58	21.61	58.59

Figure 4. Average vehicle speeds on three types of Texas highways.

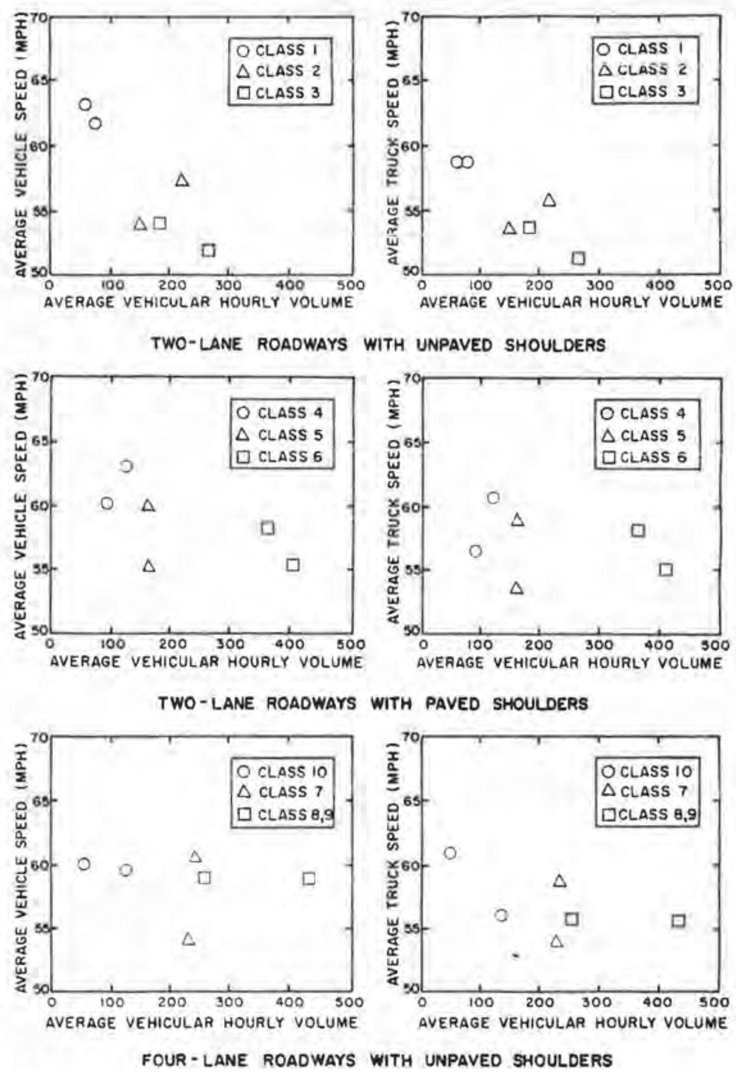
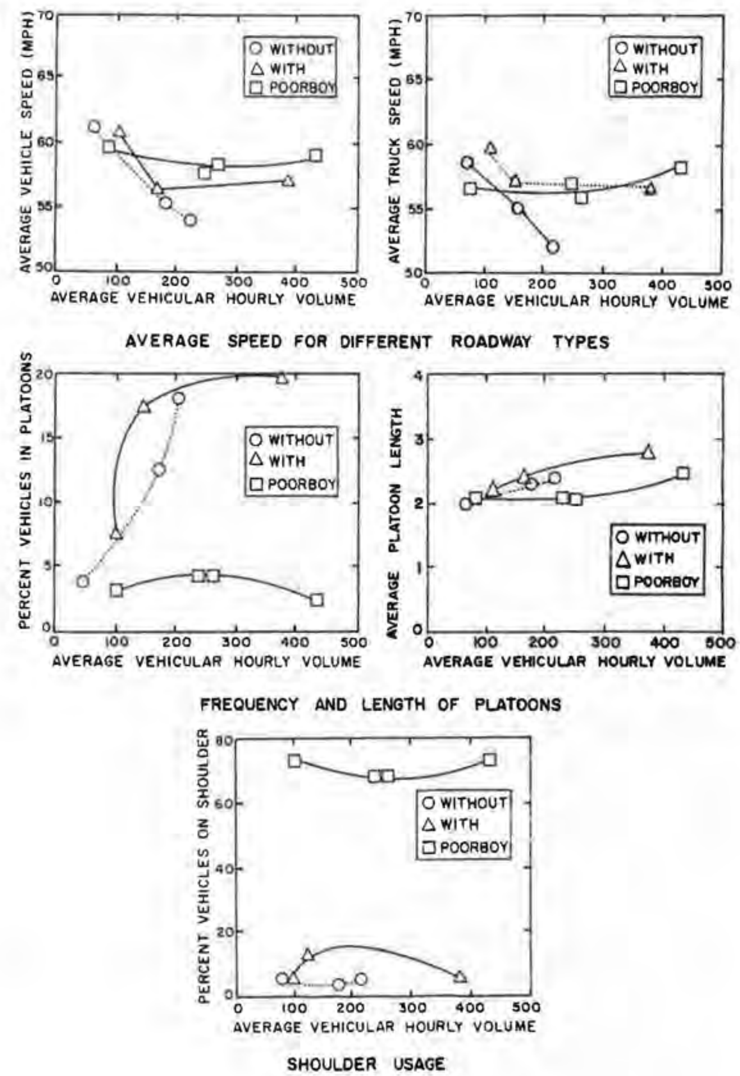


Figure 5. Operational characteristics on three types of Texas highways.



t-test (90 percent confidence level) indicated no significant difference between the designated sloped coefficient and a hypothetical slope of zero. This implies that speed on four-lane roadways without shoulders may be independent of traffic volume.

Based on these observations, the following premises have been formulated:

1. The addition of full-width paved shoulders to two-lane roadways that carry more than 200 vehicles/h will increase the average speed by at least 10 percent.
2. The conversion of a full-width paved shoulder to an additional travel lane will increase average speed by about 5 percent on roadways that carry more than 150 vehicles/h.

Platoon Characteristics

Delay is experienced by motorists whose speeds are impeded by slower vehicles in front of them; therefore, the platooning characteristics of a roadway are an important indicator of its operational efficiency. Data from the field study were used to quantify two of these parameters: (a) average percentage of the vehicles in a platoon and (b) average length of the platoon. A direct comparison of these variables for the three types of study highways is shown in the middle of Figure 5.

As the graph on the left-hand side shows, increasing volumes have the most impact on the platoon characteristics of two-lane roadways. During conditions of low traffic flow, roadways with and without shoulders act the same. At low volumes (1000-3000 vehicles/day), the number of vehicles in a platoon ranged from 2 to 7 percent; at moderate volumes (3000-5000 vehicles/day), the range was from 12 to 17 percent; at high volumes (5000-7000 vehicles/day), more than 18 percent of the vehicles were in a platoon. At this point, the value of this parameter on two-lane roadways with shoulders began to stabilize at about 20 percent even though it was still increasing on the two-lane roadways without shoulders. This reinforces the premise that operational benefits on two-lane roadways with shoulders are not noticeable until the volume reaches 200 vehicles/h. The percentage of vehicles platooning on four-lane roadways was relatively stable for the volume levels used in the study: Typical values were 2-4 percent. These observations were confirmed by a paired t-test (90 percent confidence level).

The average length of each platoon on the three types of roadways is shown in the graph on the right-hand side of Figure 5 (middle). As expected, the average length increased with increasing volume. Comparatively, this increase was slight on the four-lane and much greater on the two-lane roadways. The data indicate parallel trends for both types of two-lane roadways and a strong degree of similarity with four-lane roadways. Surprisingly, the longest platoons occurred on the with-shoulder roadways. This observation was probably the result more of traffic volume than of roadway type. For this reason, average platoon length may not be a good measure for assessing the operational efficiency of the roadway. A more representative measure might be the percentage change in platoon length as volume increases.

Shoulder Use

Although shoulder use on rural highways is probably greater in Texas than in any other state, its frequency of occurrence has never been determined. Therefore, one of the primary objectives of this entire study was to quantify this variable for the three roadway types. The graph at the bottom of Figure 5 illustrates the results of this effort. On the two-lane roadways without shoulders, shoulder use consisted primarily of vehicles stopped alongside the paved surface. As the lower curve shows, about 2-4 percent of the vehicles use the shoulder on this type of road. Such a low figure would be anticipated, since driving maneuvers are not normally executed on an unpaved shoulder. On the two-lane roadways with shoulders, the shoulder is used by 5-13 percent of the vehicles. This rate appears to be two or more times that of the roadways without shoulders. On the undivided, four-lane roadways without shoulders, vehicles driving in the outside lane were considered to be using the shoulder. As shown by the upper curve, between 65 and 75 percent of the vehicles use this part of the roadway. The implications of these results are discussed in the following paragraphs.

Driving patterns on two-lane roadways with shoulders and undivided four-lane roadways without shoulders are surprisingly different. Some have previously held the viewpoint that wide, paved shoulders breed sloppy driving habits and encourage use of the roadway as a pseudo four-lane roadway. The data indicate the opposite--that Texas motorists do not continually drive on the shoulder but tend to use it only in a passing situation. In fact, at a given location, only about 5 percent of the traffic uses the shoulder at all. If these same roadways are converted to four lanes, motorists will drive to the right in the outside (shoulder) lane. This modification often consists of simply restriping the roadway. If the original shoulder is not constructed to the same standards as the main lanes, the riding quality of the outside lane may be worse than the riding quality of the inside lane. Even with these conditions, drivers still retain their trained behavior of driving in the outside lane.

Thus, motorists' driving on the two types of roadways is diametrically different. Only during two maneuvers (the passing and overtaking situation or a slow-vehicle movement) do the roadways operate in the same manner. On two-lane roadways with shoulders, 95 percent of the drivers position themselves in the travel lane except when they pull onto the shoulder to let a faster vehicle through or to pass a left-turning vehicle. This leaves the paved shoulder available for a recovery area. On undivided, four-lane roadways without paved shoulders, more than two-thirds of the drivers position their vehicles in the outside (shoulder) lane and leave it only to pass vehicles that are in that lane. For all practical purposes, shoulder recovery areas no longer exist. A paired t-test confirmed that shoulder use is significantly different for poor-boy roadways than for the other study roads.

CONCLUSIONS

Field measurements were made to quantify operational characteristics on three different rural highway types: (a) two-lane roadways without shoulders, (b) two-lane roadways with shoulders, and (c) undivided, four-lane roadways without shoulders. The results of these studies support several conclusions concerning the operational benefits attributable to the presence or absence of a paved shoulder.

As traffic volume increases, the operational benefits derived from a full-width paved shoulder increase. Although these benefits are minimal at low and moderate volumes, they are significant at volumes greater than about 200 vehicles/h. At this point, paved shoulders appear to increase the average speed on the roadway by at least 10 percent and limit the number of the vehicles that are in platoons to less than 20 percent. It appears that only about 5 percent of the total traffic actually uses the paved shoulder at any one location.

Conversion of the shoulder to an additional travel lane offers no apparent operational benefits until the volume reaches about 150 vehicles/h. On higher-volume roads, this modification could be expected to increase the average speed by about 5 percent and limit the number of vehicles that are in a platoon to less than 5 percent. Significantly, this conversion results in more than two-thirds of the traffic using the outside (shoulder) lane.

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The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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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