Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-83/11+265-1		

4. Title and Subtitle	5. Report Date
OPERATIONAL AND SAFETY EFFECTS OF DRIVING ON PAVED SHOULDERS IN TEXAS -- EXECUTIVE SUMMARY	September 1982
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s)	
Daniel B. Fambro	Research Report 265-1
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute Texas A&M University College Station, Texas 77843	11. Contract or Grant No. 2-18-79-265
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	
Texas State Department of Highways and Public Transportation; Transportation Planning Division P.O. Box 5051 Austin, Texas 78763	Executive Summary
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the U.S. Department of Transportation Federal Highway Administration
Research Study Title: Operational Effects of Driving on Paved Shoulders

16. Abstract

In Texas, paved shoulders are used by many drivers for a large variety of traffic maneuvers and for satisfying numerous driving task demands. Unfortunately, there is little information as to the types and frequency of this usage and the impacts and conditions under which they occur. The objective of this report is to provide answers to some of these questions. State Department of Highways and Public Transportation respondents to a combination questionnaire and personal interview indicated that shoulder usage provided operational and safety benefits only under certain conditions. A laboratory study assessed motorist understanding of the legal issues involved with driving on paved shoulders. Results indicate confusion in certain situations; therefore, several potential changes to the Texas Motor Vehicle Laws are recommended.

In order to quantify the benefits and/or disbenefits of paved shoulder usage, both operational and safety studies were made on three types of Texas highways--two-lane highways without paved shoulders, two-lane highways with paved shoulders and undivided four-lane highways without paved shoulders. As a result of this investigation, it was recommended that priority for adding shoulders to two-lane highways without them should be given to those highways carrying one-way traffic volumes in excess of 200 vehicles per hour. In addition, a paved shoulder probably should not be considered for conversion to an additional travel lane unless the volume on the highway exceeds 2000 vehicles per day.

17. Key Words	18. Distribution Statement
Shoulder Usage, Paved Shoulders Traffic Operations, Traffic Safety	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

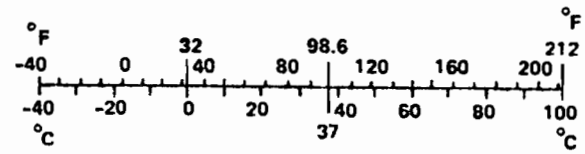
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



OPERATIONAL AND SAFETY EFFECTS OF DRIVING ON PAVED SHOULDERS IN TEXAS -- EXECUTIVE SUMMARY

by

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Research Report 265-1

Operational Effects of Driving
on Paved Shoulders

Research Study Number 2-18-79-265

Sponsored by the Texas
State Department of Highways and Public Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
Texas A&M University
College Station, Texas

September 1982

ACKNOWLEDGEMENTS

The research reported herein was performed within the research project "Operational Effects of Driving on Paved Shoulders" by the Texas Transportation Institute and was sponsored by the Texas State Department of Highways and Public Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

The author wishes to thank Mr. Ernest W. Kanak of D-18T, Mr. John F. Nixon of D-10R and Mr. Harold D. Cooner of D-8 of the Texas State Department of Highways and Public Transportation and Mr. Ted Miller of the Federal Highway Administration for their technical inputs and constructive suggestions throughout the duration of this project. A special thanks is extended to Inspector Glenn E. Simmons and Captain Dudley M. Thomas of the Texas Department of Public Safety. The assistance of Messrs. Daniel S. Turner, Ramey O. Rogness, Carroll J. Messer, Thomas E. Kessler, Steven R. Bartlett, David M. Petty and the secretarial staff of the Traffic Operations Program of the Texas Transportation Institute is also gratefully acknowledged.

The contents of this paper reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. 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.

ABSTRACT

In Texas, paved shoulders are used by many drivers for a large variety of traffic maneuvers and for satisfying numerous driving task demands. Unfortunately, there is little information as to the types and frequency of this usage and the impacts and conditions under which they occur. The objective of this report is to provide answers to some of these questions. State Department of Highways and Public Transportation respondents to a combination questionnaire and personal interview indicated that shoulder usage provided operational and safety benefits only under certain conditions. A laboratory study assessed motorist understanding of the legal issues involved with driving on paved shoulders. Results indicate confusion in certain situations; therefore, several potential changes to the Texas Motor Vehicle Laws are recommended.

In order to quantify the benefits and/or disbenefits of paved shoulder usage, both operational and safety studies were made on three types of Texas highways--two-lane highways without paved shoulders, two-lane highways with paved shoulders and undivided four-lane highways without paved shoulders. As a result of this investigation, it was recommended that priority for adding shoulders to two-lane highways without them should be given to those highways carrying one-way traffic volumes in excess of 200 vehicles per hour. In addition, a paved shoulder probably should not be considered for conversion to an additional travel lane unless the volume on the highway exceeds 2000 vehicles per day.

KEY WORDS: Shoulder Usage, Paved Shoulders, Traffic Operations, Traffic Safety

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I. INTRODUCTION

Paved shoulders in Texas apparently are used by many motorists for making a large variety of traffic maneuvers and satisfying numerous driving task demands. Texas drivers commonly pull onto the paved shoulders of rural two-lane highways at relatively high speeds as a courteous gesture to let faster vehicles pass them. Paved shoulders may also be used by through traffic to bypass left-turners at driveways or nonchannelized intersections. Furthermore, they are sometimes used as an auxiliary lane by some road users. Many operational benefits result from these maneuvers being made on the shoulder--traffic congestion and delays are reduced and fuel consumption and vehicle emissions are minimized. Evidently, most of these benefits are apparent to motorists because they voluntarily drive in this manner; however, there has been little documentation as to the types and frequency of shoulder usage and the impacts and conditions under which they occur. As a result, this study was initiated in order to quantify the benefits and/or disbenefits associated with shoulder usage in the state of Texas. To satisfy this objective, the following specific tasks were formulated:

- Identify existing shoulder usage experience.
- Determine driver understanding of the traffic laws governing shoulder usage and driver preferences for using paved shoulders.
- Document the accident experience of several highway types as related to shoulder design options.
- Quantify the magnitude and conditions under which shoulder usage occurs along rural and suburban highways (nonfreeway facilities).
- Determine the benefits and disbenefits of shoulder usage.
- Develop suitable criteria, warrants, guidelines, policies and procedures for design, implementation, regulation and enforcement of paved and unpaved shoulder usage.

This report summarizes the research that was directed at providing answers to these questions. Supporting documentation is contained in Report No. FHWA-TX-81-/31+265-2F, "Operational and Safety Effects of Driving on Paved Shoulders in Texas." Six additional papers were prepared in order to present the findings from this project to as large a group of researchers and practitioners as possible. Their titles along with places of publication and/or presentation are as follows:

1. "Safety Benefits of Paved Shoulders on Rural Two-Lane Highways." SAFE Journal. July 1980.

2. "The Effects of Paved Shoulders on the Accident Rates for Rural Texas Highways." Transportation Research Record 819, 1981.

3. "A Before-After Safety Comparison of Shoulder Upgrading Projects in Texas." Proceedings of the 19th Annual SAFE Symposium, 1981.

4. "Intended and Legal Usage of Paved Shoulders in Texas." Paper Submitted for Presentation at the 61st Annual Meeting of the Transportation Research Board, January 1982.

5. "Before-After Accident Analysis for Two Shoulder Upgrading Alternatives." Paper Presented at the 61st Annual Meeting of the Transportation Research Board, January 1982.

6. "Shoulder Upgrading Alternatives to Improve the Operational Characteristics of Two-Lane Highways." Paper Presented at the 61st Annual Meeting of the Transportation Research Board, January 1982.

II. EXISTING SHOULDER USAGE EXPERIENCE

In order to gain additional insight and credible information regarding Texas field experience with driving on paved shoulders, the 25 State Department of Highways and Public Transportation (SDHPT) district offices were surveyed by a combination questionnaire and personal interview. Highway design, traffic operations and roadway maintenance personnel were queried. Twenty-four engineers from 23 of the districts provided shoulder usage information on intended functions, operational problems, safety problems, field experience and relative benefits. Although much useful data were obtained, there was a wide range of answers for many of the questions. The most frequent responses were as follows:

- Intended Function--Accomodation for emergency stops.
- Shoulder Delineation--Contrasting colors.
- Field Experience--Most drivers will use a paved shoulder.
- Operational Problems--Shoulder usage as a passing lane (passing on right).
- Safety Problems--Shoulder usage near narrow bridges.
- Maintenance Problems--Truck traffic.
- Maintenance Priority--Below mainlanes and traffic control devices.

Of particular interest were the responses to the questions concerning field experience and operational problems with driving on paved shoulders. The SDHPT personnel felt that most drivers would pull onto the paved shoulder of a rural two-lane highway in order to let faster vehicles pass and that Texas drivers were much more likely to perform this maneuver than were out-of-state drivers. In fact, several respondents cited improved operations as a result of this type of driving behavior. However, when a paved shoulder

is used as either a passing lane (passing on the right) or an extra lane (four-lane highway), one-third of the respondents indicated that operational and/or safety problems would result. Therefore, shoulder usage by moving vehicles appears desirable to practitioners only when motorists are allowing faster vehicles to pass them.

III. DRIVER UNDERSTANDING AND PREFERENCE

It was anticipated that Texas drivers were not aware of the legal aspects involved with driving on paved shoulders. As a result, a laboratory study was designed to test their understanding of the pertinent legal issues. In addition, the study investigated driver preference for and experience with shoulder usage. The same basic study was used to ascertain Department of Public Safety (DPS) officers' interpretation of the legal issues involved and their observations of shoulder usage throughout the state. Ninety-six "average" drivers and ninety-one law enforcement officers participated in the study. Each group of subjects was shown ten sets of slides which depicted several different shoulder usage situations. As each scenario was displayed, a verbal description of the driving maneuver was given and the subjects were asked several questions. The most significant findings from the laboratory study are discussed in the following paragraphs.

Texas drivers perceive a difference between using a paved shoulder to pass vehicles turning left into an intersection and turning left into a driveway. Results of this study indicate that motorists are more likely, have more experience and feel more secure when performing the intersection pass. In addition, drivers are uncertain about the legality of the driveway pass. On the other hand, DPS officers did not indicate a difference between the two driving situations in any of the study areas--preference, experience, safety or legality. If, in fact, there is no difference, it may be appropriate to add the words "at either an intersection or a driveway" to the appropriate section of the Texas Motor Vehicle Laws.

Both the drivers and the DPS officers seem certain it is legal to pass someone who is driving on the shoulder without crossing the center line of the

highway. However, drivers are uncertain whether it is legal for someone simply to drive on a paved shoulder or whether it is a legal requirement to pull onto the paved shoulder to let a faster vehicle pass. Shoulder contrast, edge line markings or type of vehicle made no difference in the response to these questions. As it is a legal requirement for vehicles proceeding at less than the normal speed of traffic to give way to the right and be driven as close as practicable to the right-hand edge of the roadway, an interesting paradox exists. Is the paved shoulder a part of the roadway? Results from this study indicate confusion. Therefore, the following recommendations have been made:

1. A paved shoulder should not be considered a part of the roadway.

2. It should be legal for motorists to drive on a paved shoulder unless signs or markings prohibit such a maneuver or it is unsafe to do so.

3. It should be legal to pass, without crossing the center line of the highway, someone who is driving on a paved shoulder.

4. It should be legal for a motorist traveling at less than the normal speed of traffic to pull onto the paved shoulder in order to let faster vehicles pass; however, it should not be a requirement.

Texas drivers seem certain that to use the shoulder to pass a nonturning vehicle on the right is dangerous, is not legal and should not be legal. DPS officers agree that it is dangerous and should not be legal; however, they are uncertain whether or not it is currently legal. Again, this confusion is probably related to whether the paved shoulder is a part of the roadway. Based upon the results of this study, it is recommended that using the shoulder to pass a nonturning vehicle on the right should not be legal and that the Texas Motor Vehicle Laws be amended so as to reflect this point.

IV. SAFETY EFFECTS OF PAVED SHOULDER USAGE

The SDHPT does not have a documented data base for establishing design policies and practices concerning the upgrading of two-lane highways without paved shoulders to two-lane highways with paved shoulders, or for upgrading two-lane highways with paved shoulders to undivided four-lane highways without shoulders ("poor-boy" highways). Because the safety benefits of these improvements have not been quantified, one of the purposes of this study was to establish the accident effects related to the presence or absence of a paved shoulder. For this study, any paved shoulder less than six feet wide was considered as "none or inadequate".

Two separate accident investigations were conducted in order to determine the effects of paved shoulders on the safety of rural Texas highways. The initial investigation was an analysis of accident rates, patterns and characteristics on three types of highways--two-lane highways without paved shoulders, two-lane highways with paved shoulders and undivided four-lane highways without paved shoulders. The second was a before-and-after study to determine the change in safety characteristics caused by the addition of paved shoulders to a two-lane highway or by the conversion of paved shoulders to additional travel lanes.

Texas Roads: Lengths and Usage

Of the more than 56,000 miles of rural two-lane highways in Texas, less than 25 percent have paved shoulders. For the three highway types studied, 66 percent of the mileage and 75 percent of the vehicular travel are on two-lane highways without shoulders with an average daily traffic (ADT) of less than 1000 vehicles per day. At extremely low volume levels, the two-lane highway without shoulders is the dominant type of highway. Ninety-eight percent of

these highways carry less than 3000 vehicles per day while less than one-half of one percent carry over 5000 vehicles per day.

As the ADT passes 1000 vehicles per day, the two-lane highway with shoulders becomes the dominant roadway type. About two-thirds of these highways fall into the 1000 to 3000 vehicles per day category. Less than six percent of them carry over 5000 vehicles per day. Only about one percent (560 miles) of the rural roads in Texas are four-lane highways without shoulders. Most of them carry from 1000 to 5000 vehicles per day (73 percent), with decreasing use as volume rises. Approximately one-fourth of these highways carry more than 5000 vehicles per day.

Comparative Analysis

Site Selection. A matrix of desired characteristics (see Table 1) was created to stratify potential sites by traffic volume, shoulder type and number of lanes. It was desired to study ten sites in each class, with each site containing five or more miles of consistent highway. All highway segments in the state (over 29,000) were screened as potential sites through a computer listing of the highway geometric file, commonly referred to as the RI-2-TLOG; 85 sites were selected for further study. (Fewer than ten sites were found for Classes 3, 7, 8 and 9 because of the limited mileage in these categories.)

Data Collection. The SDHPT's computerized accident files were scanned for all accidents occurring on the 85 sites during the three-year period 1975-1977. A total of 16,334 accidents were included in the study's data base. Each comprehensive accident record contained 393 characters of information about the collision and the highway upon which it occurred. This allowed a very thorough examination and cross classification of the data base.

TABLE 1. SITE CLASSIFICATION FOR COMPARATIVE ACCIDENT STUDY

Classification Number	Type of Highway	Type of Shoulder	A.D.T. Range
1	two-lane	unpaved	1000-3000
2			3000-5000
3			5000-7000
4	two-Lane	paved	1000-3000
5			3000-5000
6			5000-7000
10*	four-lane	unpaved	1000-3000
7			3000-5000
8			5000-7000
9			7000-9000

*This category was not included in the original design, but was added later to allow direct comparison of all three highway types at low volumes.

Highway sections where unusual conditions contributed to the cause of several accidents were removed from the sample.

Geometric data were taken from the RI-2-TLOG to calculate the vehicular miles of travel for each site. These figures were combined with the number of accidents on each highway to yield accident rates in terms of accidents per million vehicle miles of travel. A separate analysis was performed on non-intersection accidents (8815) to isolate and remove the disproportionate effects such collisions might cause among sites. Figures 1 and 2 illustrate the results of the accident rate investigation for the all-accident and non-intersection accident data sets, respectively.

Accident Rate. When all accidents were considered, the accident rate for each highway type increased as the traffic volume increased. Two-lane highways without paved shoulders had the highest accident rates and were the most sensitive to changes in traffic volume. Two-lane highways with paved shoulders had the lowest accident rates. "Poor-boy" highways were the least sensitive to volume level and had an accident rate in between the other two types of highways. Thus, the presence of paved shoulders had a noticeable effect in reducing the accident rate on rural Texas highways.

When intersection accidents were removed, the highway types retained the same rank. Paved shoulders were again shown to have positive effects in reducing accident rates. An extension of the data indicated that two-lane highways with paved shoulders had lower accident rates than "poor-boy" highways at all volume levels below approximately 7500 vehicles per day.

Two-lane highways without paved shoulders are very sensitive to intersection accidents, especially at high volume levels. "Poor-boy" highways are somewhat sensitive, while two-lane highways with paved shoulders are

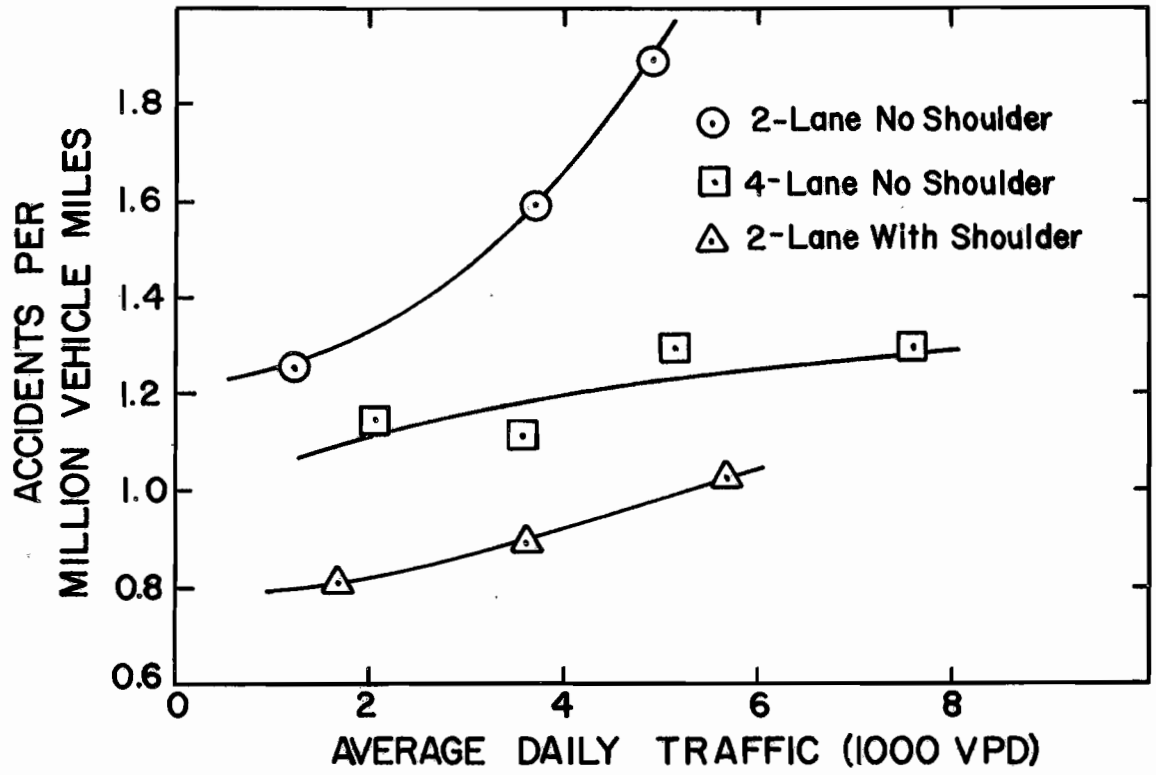

FIGURE 1. ALL ACCIDENT DATA, ACCIDENT RATES FOR DIFFERENT CLASSES OF HIGHWAYS (1975-1977).

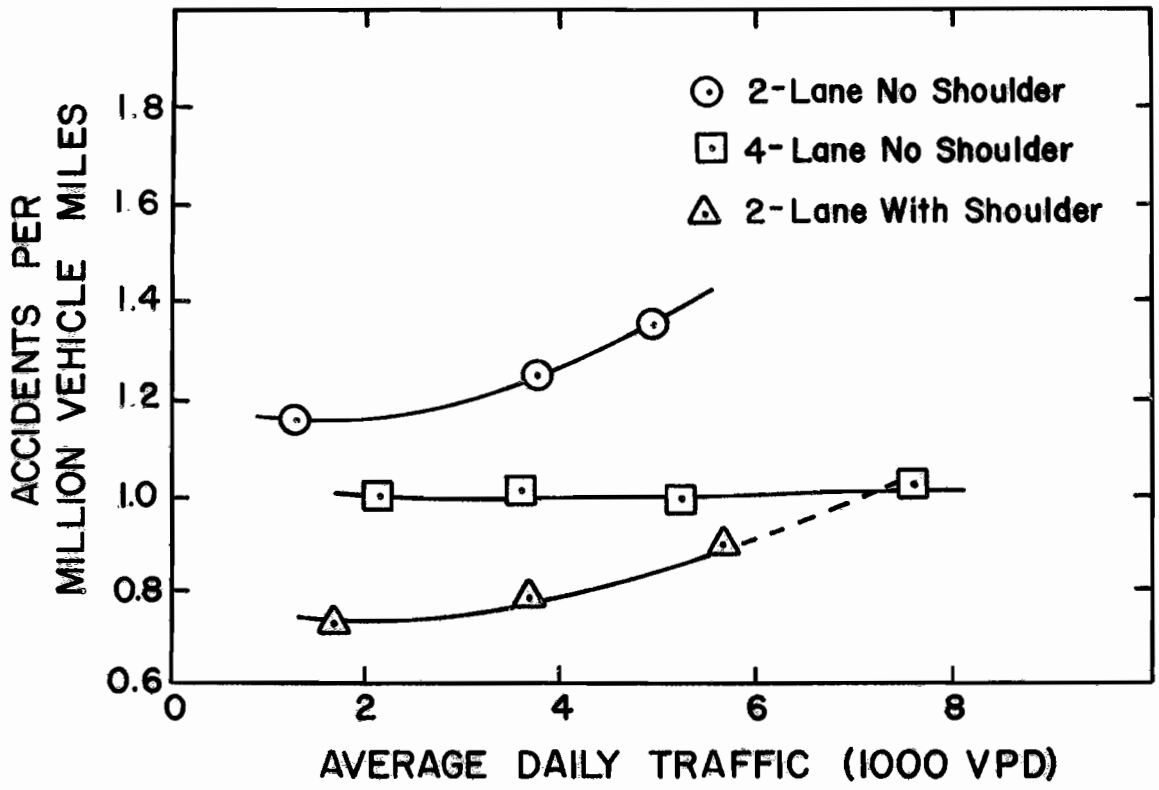

FIGURE 2. NON-INTERSECTION DATA, ACCIDENT RATES FOR DIFFERENT CLASSES OF HIGHWAYS (1975-1977).

relatively insensitive to such accidents. Thus, it appears that the construction of full-width paved shoulders at rural intersections may be effective in reducing the number of accidents on high volume two-lane highways.

Accident Characteristics. The severity analysis revealed that injury accident rate curves are approximately parallel to total accident rate curves, while fatality accident rate curves are very low and fairly uniform for the range of traffic volumes studied. This trend was similar for all three types of highways. The lowest fatality rate was 0.06 fatal accidents per million vehicle miles of travel on two-lane highways with paved shoulders.

The absence of full-width paved shoulders increased the run-off-road accident rate, especially at low volume levels. The most probable reason for the high run-off-road rates at low volume is driver inattentiveness and lack of a paved recovery zone for vehicles accidently exiting the travel lane.

Hit-other-car accidents tended to increase drastically with increasing volumes, with two-lane highways without shoulders having more of these accidents than the other two highway types. At lower volumes, other types of collisions were more frequent. For example, on "poor-boy" highways, the run-off-road accident is the most frequent type of accident at all volumes below 4000 vehicles per day. Rates for hit-fixed-object accidents were found to closely resemble the rates for run-off-road accidents on highways without shoulders. Again, this reflects the lack of a paved recovery area and the presence of fixed objects in the clear zone adjacent to the roadway.

Before-After Analysis

Site Selection. A stratification matrix of roadway characteristics (see Table 2) was developed delineating traffic volume, type of improvement and number of lanes. It was desired to have a minimum of ten sites in each

TABLE 2. SITE CLASSIFICATION FOR BEFORE-AFTER ACCIDENT STUDY

Classification Number	Modification Conditions	ADT Range
1	Add paved shoulders to two-lane highway	1,000-3,000
2	Add paved shoulders to two-lane highway	3,000-5,000
3	Add paved shoulders to two-lane highway	5,000-7,000
4	Convert two-lane with shoulders to four-lane without paved shoulders	1,000-3,000
5	Convert two-lane with shoulders to four-lane without paved shoulders	3,000-5,000
6	Convert two-lane with shoulders to four-lane without paved shoulders	5,000-7,000

classification, with each site containing five or more miles of geometrically consistent highway. The SDHPT's highway geometric computer files were again used to screen all rural highways in the state as potential sites. For each segment, key geometric features on the 1977 file were checked against the same features on the 1968 file to determine if, during that time period, the highway either had shoulders added or had existing shoulders converted to an additional travel lane.

Manual examination of the two files found 390 segments (77 different sites) that had been so modified (only Classes 1 and 2 contained at least 10 sites). After these highways 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. Candidate sites were checked for uniform cross-sections, consistent traffic volumes and standard geometric features. Highways not meeting these criteria were discarded.

Data Collection. The SDHPT's accident files were used to obtain the accident histories for each site during the two years before and the two years after the modification took place. Accidents not necessarily related to highway type were excluded from the data set. The accident records were then used to create a computerized data file and a frequency analysis was run for each site on a yearly basis. Accident frequencies during the after conditions were adjusted to account for changes in the average daily traffic. Summarized results of the frequency analysis for the non-intersection accident data set are presented in Tables 3 and 4.

TABLE 3. SAFETY BENEFITS FROM ADDING SHOULDERS TO A TWO-LANE HIGHWAY, NON-INTERSECTION ACCIDENTS

Volume Range	Type of Accident	No. of Accidents		Percent Change
		Before	After	
1000-3000	Multi-Vehicle	35	36.4	+ 4.0
	Single-Vehicle[a]	58	26.1	-55.0
	Other[b]	27	25.1	- 7.0
	Total	120	87.6	-27.0
3000-5000	Multi-Vehicle	68	53.9	-14.7
	Single-Vehicle[a]	67	52.9	-21.4
	Other[b]	29	36.7	+26.6
	Total	164	143.5	-12.5
5000-7000	Multi-Vehicle	27	16.9	-37.4
	Single-Vehicle[a]	12	12.0	-0-
	Other[b]	6	8.2	+36.6
	Total	45	37.1	-17.6

[a]Run-off-road and hit-fixed-object accidents.
[b]Other single vehicle accidents.

TABLE 4. SAFETY BENEFITS FROM CONVERTING TO A FOUR-LANE "POOR-BOY" HIGHWAY, NON-INTERSECTION ACCIDENTS

Volume Range	Type of Accident	No. of Accidents		Percent Change
		Before	After	
1000-3000	Multi-Vehicle	35	44.8	+28.0
	Single-Vehicle[a]	72	69.4	- 3.6
	Other[b]	33	43.4	+31.5
	Total	140	157.6	+12.6
3000-5000	Multi-Vehicle	73	44.0	-39.8
	Single-Vehicle[a]	72	68.7	- 4.6
	Other[b]	40	37.1	- 7.3
	Total	185	149.8	-19.0
5000-7000	Multi-Vehicle	53	39.6	-25.3
	Single- Vehicle[a]	55	28.8	-47.6
	Other[b]	29	30.3	+ 4.5
	Total	137	98.7	-28.0

[a]Run-off-road and hit-fixed-object accidents.
[b]Other single vehicle accidents.

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

Shoulder Conversion. When two-lane highways with paved shoulders were converted to "poor-boy" highways, the results varied with the volume level. At low-volumes, the total accident frequency actually increased after the conversion. At moderate and high-volume locations, conversion to "poor-boy" highways 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. This indicates that darkness may be eliminating visual cues that alert the driver to the hazards associated with this type of highway.

V. OPERATIONAL EFFECTS OF PAVED SHOULDER USAGE

The SDHPT has tried several techniques to improve the operating conditions on their rural two-lane highways. The most common of these treatments has been the addition of paved shoulders to roadways without them. An innovative treatment that provides additional capacity at minimum costs has been the conversion of two-lane highways with full-width paved shoulders into undivided four-lane highways without shoulders. In order to document those operational benefits that do exist, several field studies were planned.

Site Selection

The roadway classification matrix developed for the comparative accident study (Table 1) was used to stratify sites for the field studies. For each of the nine highway classes (Classes 8 and 9 were combined because of the small number of sites in each category), the accident study sites were ranked by their respective accident rates. The two extremes (highest and lowest rates) from each category were tentatively selected for further study. Extremely short or widely separated segments were discarded and replaced by the next ranked site in the category.

Study Methodology

A procedure was developed to collect operational data on traffic composition, traffic volume, vehicle speeds, lateral placement and platooned vehicles. Highway geometrics and other pertinent information also were recorded. At each of the 18 sites, a study vehicle was equipped with an on-board moving radar gun, a distance measuring instrument, a CB radio and several cameras. The vehicle operator was responsible for classifying vehicles and calling out their speeds. A second individual was responsible for photography, reading longitudinal distances and recording data.

Features that could be easily referenced were selected as the ends of the study sections. Several "drive-throughs" of the site were made to select intermediate reference points within the section. Data were collected for a six-hour period. During this time, the study vehicle was driven in a continuous circuit from one end of the section to the other.

Type, speed, lane position and longitudinal placement for each vehicle that was met were manually recorded. For platoons, the lead vehicle's speed and longitudinal position were recorded along with the number and composition of vehicles in the platoon. Lane position referred to whether the vehicle was driving on the shoulder of the two-lane sections or the outside lane of the four-lane sections. Longitudinal placement was used to identify locations where shoulder usage occurred. Data were collected for over 21,000 vehicles.

Study Results

Vehicle Speeds. Increasing volumes have the most impact on the average speed of two-lane highways without shoulders. Speeds also decreased on two-lane highways with paved shoulders, but only until the one-way volume reached about 200 vehicles per hour. Further reductions did not occur. Above volumes of 200 vehicles per hour, the average speed on the highways with shoulders is about 10 percent higher than it is on comparable highways without shoulders. For the four-lane highways 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 one-way volumes above 150 vehicles per hour.

Platoon Characteristics. Not surprisingly, increasing volumes have the most impact on the platoon characteristics of two-lane highways. At low volumes, the percentage of all vehicles in a platoon ranged from 2 to 7 percent.

At moderate volumes, the range was from 12 to 17 percent. At high volumes more than 18 percent of the vehicles were in a platoon. At this point, the value of this parameter on two-lane highways with shoulders began to stabilize at about 20 percent even though it was still increasing on the two-lane highways without shoulders. This reinforces the premise that operational benefits on two-lane highways with shoulders are not noticeable until the one-way volume reaches about 200 vehicles per hour.

Shoulder Usage. One of the primary objectives of the study was to quantify the frequency of shoulder usage for the three highway types. On two-lane highways without shoulders, shoulder usage consisted primarily of vehicles stopped alongside the paved surface. About 2 to 4 percent of the vehicles "use the shoulder" on this type of highway. Such a low figure was expected as driving maneuvers are not normally executed on an unpaved shoulder. On two-lane highways with shoulders, the shoulder is used by between 5 and 13 percent of the vehicles. On undivided four-lane highways without shoulders, vehicles driving in the outside lane were considered to be using the shoulder. Between 65 and 75 percent of the vehicles use this part of the roadway.

Driving patterns on two-lane highways with shoulders and undivided four-lane highways without shoulders are suprisingly different. Texas motorists do not continually drive on the shoulder, but only use it in a passing situation. In fact, only about 5 percent of the traffic use the shoulder at a given location. If these same highways are converted to four-lane highways the motorists will drive to the right, in the outside or "shoulder" lane. Even when the riding quality of the outside lane is worse than that of the inside lane, Texas drivers still retain their "trained" behavior of driving in the outside lane.

The highways operate in the same manner only in a passing and overtaking situation, or during a slow vehicle movement. On two-lane highways 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 when passing a left-turning vehicle. This leaves the paved shoulder available for a recovery area. On the undivided four-lane highway without paved shoulders, more than two-thirds of the drivers position their vehicles in the outside (shoulder) lane and only leave it to pass vehicles that are in that lane. For all practical purposes, the recovery area no longer exists.

Conclusions

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 one-way volumes greater than about 200 vehicles per hour (approximately 3000 vehicles per day). At this point, paved shoulders appear to raise the average speed on the highway by at least 10 percent and limit the number of vehicles that are in platoons to less than 20 percent. Surprisingly, only about 5 percent of the total traffic actually uses the shoulder at any one location.

Conversion of the shoulder to an additional travel lane offers no apparent operational benefits until the one-way volume reaches about 150 vehicles per hour (approximately 2000 vehicles per day). On higher volume highways, this modification could be expected to increase the average speed by about 5 percent and to 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 or "shoulder" lane.

VI. RECOMMENDATIONS

The results from this study can be used to make several policy and procedure recommendations concerning shoulder usage in the state of Texas. Those that involve proposed changes in the Texas Motor Vehicle Laws will be presented first. In its legal definition, a paved shoulder should not be considered a part of the roadway. It should be legal for motorists to drive on a full-width paved shoulder unless signs or markings prohibit such a maneuver or it is unsafe to do so. It should also be legal to pass someone who is driving on the shoulder. It should be legal for a motorist to pull onto the paved shoulder in order to let a faster vehicle pass; however, it should not be a requirement. Finally, it should not be legal on a two-lane road to pass a nonturning vehicle on the right.

The second type of recommendation involves the decision of when and in what manner to upgrade a two-lane highway. Even though the addition of full-width paved shoulders results in safety benefits at all volume levels, operational benefits occur only when the one-way traffic volume exceeds 200 vehicles per hour (approximately 3000 vehicles per day). Therefore, priority for this type of improvement should be given to those highways currently carrying more than 3000 vehicles per day. The conversion of a paved shoulder to a travel lane should probably not be considered unless the volume on the highway exceeds 2000 vehicles per day. Below this point, few, if any, operational or safety improvements accrue as a result of this improvement. In fact, there are indications that safety may actually decrease when this treatment is used on lower volume highways.

In addition to the aforementioned recommendations, two potential problems that may merit additional study were identified. First, an evaluation should

be made of the potential safety improvements resulting from the addition of full-width paved shoulders at major intersections on two-lane highways without shoulders. Secondly, an assessment should be made of the potential nighttime safety improvements resulting from improved edge line delineation systems on "poor-boy" highways.