TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-87/32+395-1		

4. Title and Subtitle Safety and Operational Evaluation of Shoulders on Urban Freeways	5. Report Date February 1987 6. Performing Organization Code
7. Author(s) Thomas Urbanik II and Carlos R. Bonilla	8. Performing Organization Report No.
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843	10. Work Unit No. 11. Contract or Grant No. Study No. 2-18-84-395
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Interim - September 1983 February 1987 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA, and California DOT.
Research Study Title: Safety and Operational Evaluation of Shoulders on Urban Freeways

16. Abstract

SEE SUMMARY on page v.

17. Key Words	18. Distribution Statement
Shoulder Removals, Outside Shoulders, Inside Shoulders, Safety, Operational Impacts, Shoulder Lanes, Peak Operating Period, Partial Shoulders, Full Shoulders.	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	191	

Form DOT F 1700.7 (8-69)

METRIC CONVERSION FACTORS

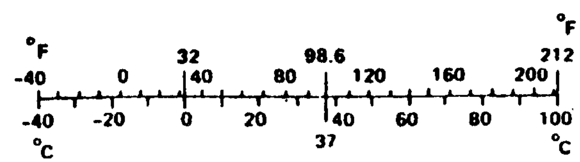
Approximate Conversions to Metric Measures

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



SAFETY AND OPERATIONAL EVALUATION OF SHOULDERS ON URBAN FREEWAYS

by

Thomas Urbanik II
Associate Research Engineer
and
Carlos R. Bonilla
Assistant Research Engineer

Research Report Number 395-1
Research Study No. 2-18-84-395

Sponsored by
Texas State Department of Highways and Public Transportation

In cooperation with,
California Department of Transportation and
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

August 1986

ACKNOWLEDGEMENTS

This study is the result of an informal cooperative arrangement supported by the Texas State Department of Highways and Public Transportation (SDHPT) and the California Department of Transportation (CALTRANS). Funding was provided by the U.S. Department of Transportation, Federal Highway Administration. The study is also the result of projects developed by highway engineers who challenged the simple application of standards when the standards appeared to be detrimental to the improvement of existing problems.

The study was under the capable direction of Herman Haenel, D-18T, who supported the project throughout its sometimes uncharted course. Other Department personnel supporting the research included R.L. Lewis, D-8 (retired), and Harold L. Cooner, D-8.

The authors have also developed a deep respect for CALTRANS personnel, many unmentioned, who willingly provided time and expertise. Wes Lum, CALTRANS Sacramento, was instrumental in developing the informal cooperative arrangement between the two independent study efforts. Others at CALTRANS providing assistance include Rich Jones, Richard Smith, Walt Hagen, James Borden, Tom Almany, and Len Newman.

Assistance from the California Highway Patrol was provided by Hal Richards and Joe Phillips. Pete Canizaro of TTI was responsible for much of the data collection effort. C.P. Damon, Federal Highway Administration, forced the study to dig harder and deeper into the issues. His critiques have resulted in a better study.

SUMMARY

Shoulder removals are a controversial subject as they are contrary to standards and have the appearance of compromising safety. Initial research indicated that shoulder removals did not adversely affect safety, and the number of projects with shoulder removals increased. As the number of projects with less than standard width shoulders increased, the concerns about safety were renewed. This study addresses two issues concerning shoulder removals: safety and traffic operations.

Improvement of traffic flow is the primary reason for considering shoulder removals. This objective is met for most projects; however, extensive removal of both shoulders appears to be counter productive. Significant numbers of nondeferrable stops occur on any freeway, and the lack of any area for emergency parking will result in increased mainlane stops. The delay caused by increased mainlane stops on a no shoulder section appears to outweigh the benefits of added capacity through removal of all shoulders.

Overall safety is improved on study sections where inside shoulders are removed to add capacity on very congested roadways (ADT greater than 20,000 vehicles per lane per day) and the congestion is reduced (ADT per lane less than 18,000 vehicles per lane per day). The improved safety appears to be the result of improved traffic operation. If congestion is less severe, then safety appears to be unchanged where inside shoulders are removed. Inside shoulder removals appear to be preferable to outside shoulder removals.

Outside shoulders have generally been removed for two reasons. In a number of cases, outside shoulder removals were easier to implement because the lane addition functioned as an auxiliary lane between ramps. The second reason for removing outside shoulders is that there was no inside shoulder. This research suggests that inside shoulder removals are preferable to outside shoulder removals, all other things equal. Removal of right shoulders should only be considered where some emergency parking area exists beyond the shoulder or the section is very short.

Another concern regarding shoulder removals is that safety may be improved short-term, but may become worse as traffic volumes increase. Several projects studied have been in place for 7 to 11 years without a return to the before accident rate. Another project had higher lane volumes after the change and a lower accident rate. The projects evaluated are spot improvements typically between major interchanges and the improved operation appears to be permanent.

A final concern regarding accidents is severity. Even if accident rates do not change significantly, some concern would exist if severity increases. The limited data available on severity suggests that no increases in severity are taking place.

This study implicitly indicates that 11-foot traveled lanes do not create safety problems. All the removals involved lane width reductions from 12 feet to 11 feet (infrequently 10.5 feet). The use of 11-foot lanes as a remedial measure to reduce congestion appears to operate safely.

Shoulders are desired by both the driving public and highway engineers. The inclusion of a right shoulder on any new facility is essential. Full left shoulders are also desirable on new freeways of six-lanes or more. Nevertheless, left shoulder removals appear to be safe and effective capacity improvements. On severely congested freeways (ADT greater than 20,000 vehicles per lane per day) left shoulder removals appear to aid safety if congestion levels are reduced. Right shoulder removals should be limited to situations where other remedies are not possible and potential benefits and disbenefits have been very carefully assessed.

The removal of left shoulders to provide a median transitway has been previously demonstrated to be a cost-effective means of increasing person movement in existing corridors. Initial analysis of the Katy Transitway (I-10) indicates no safety problems. The Katy data are consistent with other inside shoulder removal projects and suggests that median transitway projects are similar to other inside shoulder removal projects. An evaluation of median transitway projects is an ongoing part of this study.

When considering a shoulder removal project, care must be exercised to avoid creating operational problems. This caveat is not specific to shoulder reduction projects. If additional capacity results in a serious overload at the downstream end of the project, accidents are likely to increase. Shoulder removal projects have good safety records and offer an effective means to balance short sections on a congested freeway system. Likewise, shoulder reductions can be used on freeways to provide barrier protected HOV facilities which also implicitly require congestion to be effective.

IMPLEMENTATION STATEMENT

The study findings indicate that inside shoulder reductions (all but 2 feet) are a simple and safe method of reducing congestion on existing freeways. The safety benefits of removing inside shoulders suggest that spot improvement projects should be undertaken when bottlenecks exist and analysis suggests that congestion can be reduced. Initial evaluation also suggests that median transitways involving inside shoulder removals are a simple and safe method of improving person movement in Texas freeway corridors experiencing congestion and for which right-of-way acquisition is not practical.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation, Federal Highway Administration or the Texas State Department of Highways and Public Transportation.

<u>**TABLE OF CONTENTS**</u>

TABLE OF CONTENTS CONTINUED

INTRODUCTION

With increasing traffic congestion on Texas roadways, the problem of how to increase freeway corridor capacity in a safe and cost effective manner is becoming more difficult. Given limited funds relative to needs, it has been suggested (1) that full compliance with AASHTO standards (2) is not always the most effective use of available space. One means of providing additional capacity quickly and inexpensively has been to reduce or eliminate shoulders. Despite the fact that the safety records of shoulder removal projects which have been evaluated are good, there is continuing concern as to the appropriateness of shoulder removals given the limited amount of evaluation.

Present design standards in Texas call for inside and outside shoulders on all freeways. Outside shoulders must be 10 ft. wide and inside shoulders 4 feet. If freeways operate with six or more lanes, then a 10-ft.-wide inside shoulder is required. This is in conformance with national guidelines on acceptable practices as presented in "A Policy on Geometric Design of Highways and Streets 1984" (2). However, there is limited documentation relating accident rates with the use or lack of freeway shoulders, and even less on the use of partial shoulders. A recent NCHRP study on shoulder geometrics (3) concluded that a comprehensive study on shoulders was needed.

California, New Jersey, Arizona, Texas and other states have tried taking or reducing freeway shoulders to provide travel lanes or high occupancy vehicle lanes. A review of the better documented cases is presented later in this report.

Currently, Texas is studying various freeway locations where there is a need to increase capacity but where available right-of-way, environmental concerns, and cost severely limit the ability to add additional capacity. In the available right-of-way of existing freeways, increasing capacity can sometimes be accomplished by narrowing of existing lanes and reducing shoulder width. Past research in this area is limited. There is a need to quantify the relationship between shoulder width and accidents to help on the decisions between safety and other concerns. There is a need to better understand motorist's need for stopping on freeway shoulders and to identify how frequently they stop.

This report presents accident investigations and finding of various Texas and California freeway segments, where data and cross section characteristics allowed for statistical comparisons. This report presents the findings of motorist surveys and observations of vehicles stopped on freeway shoulders. It also analyzes the placement of autos and trucks traveling the inside lane where concrete barrier walls have been erected.

The principal objective of the study is to document the safety and operational impacts of freeway cross sections operating with shoulders of less than standard width. This report investigates freeway segments provided with no, partial, and full shoulders; that is, those whose shoulder widths are zero to two feet, three to seven ft. and eight or more ft. respectively.

REVIEW OF PAST PROJECTS

The use of paved freeway shoulders as a travel lane has been regarded by some professionals as potentially dangerous and by others as an effective and safe method to increase capacity. Various studies have been conducted of urban freeways where shoulders have been reduced or eliminated to increase capacity. A review of recent projects has been made based on a survey of state agencies and on available written reports documenting safety and operational experience. Projects dating prior to 1978 are documented in the FHWA publication, Freeway Modifications to Increase Traffic Flows, by McCasland and Biggs (4); a summary and an update follows.

Summary of Experience Prior to 1978

A principal concern of the McCasland and Biggs report was to search for ways to reduce traffic congestion while improving the quality and safety of travel. Increasing the vehicle handling capacity of existing freeways by narrowing lanes and using the shoulders as additional travel lanes was considered one of the methods.

McCasland and Biggs identified six types of situations that can be improved through the conversion of shoulders to other uses. Capacity can be increased by using a shoulder to: 1) add a lane between ramps, 2) bypass a queue at an exit ramp, 3) clear bottlenecks on the mainlanes due to roadway geometrics, 4) reduce merge conflicts, 5) provide an HOV lane, and 6) allow for maintenance or construction needs to close one or more lanes.

McCasland and Biggs presented various considerations in the design and implementation of shoulder use projects. The major expressed concern in modifying surface geometrics is the retention of a cross section which provides adequate width for mainlanes, emergency parking and lateral clearance. Although the desirable freeway lane width is 12 feet, narrower lanes have been successfully operated. The desirable width for shoulders in urban freeways of three or more lanes is 10 ft.on both sides. Lateral clearance of 6 ft. or less is widely believed to reduce the capacity of the roadway. There is, however, some indication that effects of 11 ft. lanes and no inside shoulder may not be as severe as generally believed (5, 6).

The reduction or elimination of highway shoulders as well as the reduction of lane width was considered a compromise of freeway standards by agencies involved in these projects. The possible reduction in highway safety was considered a trade-off for the sake of reducing delays and fuel consumption. Yet, McCasland and Biggs (4) found that the safety experience of those projects was excellent. Most project reports reviewed indicated no evidence of safety problems or that accident experience between before and after project implementation was reduced.

Thirty-four different projects (4) in seven different states investigated accidents, with most reporting a decrease in accident rate after the project was implemented. Houston and Los Angeles are prominent with the most documented cases; however, the level of documentation varies substantially from one project to another. Table 1 is a summary of the accident experience of the projects.

It should be noted that the average accident rate for those projects went down. An unweighted average of all sites reflects 2.12 accidents per million vehicle miles before improvements and 1.33 accidents per million vehicle miles after improvements. No statistical analysis was conducted since each rate belongs to a specific project with different characteristics or treatments; however, a decrease in accident rates is evident.

Narrowing lanes to 11 ft. or (occassionally 10.5 ft.) while maintaining shoulders did not bring about a change in accident rates either (5). Projects where one or both shoulders were eliminated during peak periods did not experience increases in accident severity. However, there was a doubt on future effects when increasing volumes would bring back the level of congestion that existed prior to improvements. Since the projects to increase capacity also brought about an immediate improvement of freeway level-of-service, it was believed that the congestion reduction benefits overshadowed the negative effect of reducing or eliminating shoulders. The

Table 1. Summary of Accident Experience Through 1978

Location	Freeway	Accident Rate *		Comments
		Before	After	
Denver	I-25	NA	NA	No increase in accident experience.
Houston	US 59 (SW Fwy.)	3.68	2.90	
Houston	I-45 (N. Fwy)	NA	NA	No increase in accident experience.
Houston	I-610 (W. Loop)	NA	NA	Greatly improved overall safety.
Houston	I-610 (S. Loop)	NA	NA	Accidents reduced sharply.
Houston	I-610 (W. Loop)	NA	NA	Project started December 1978.
Los Angeles	I-10 (Santa Monica)	1.45	1.05	
Los Angeles	San Bernardino	NA	NA	Project greatly improved overall safety
Los Angeles	Pomona Project 1	1.18	1.13	
Los Angeles	Pomona Project 2	1.32	1.05	Eastbound East LA to Route 7
Los Angeles	Ventura	1.86	0.78	
Los Angeles	Golden State	1.86	1.47	
Los Angeles	Pomona Project 3	1.5	1.02	Westbound Route 7 to East LA
Los Angeles	Santa Ana Proj. 1	1.39	0.90	
Los Angeles	San Diego	NA	NA	Accident rates remained same. Frequency of accidents <u>increased</u> slightly
Los Angeles	Santa Ana Proj. 1	2.39	2.17	Accident frequency <u>increased</u> 50 percent for 8 months. Changes in signing, pavement markings, hours of usage accounted for reduced rate shown.
Nashville	I-65, I-265	1.92	0.91	
Pensacola	I-10	NA	NA	One accident reported in year after mod.
Portland	I-5, I-405	4.69	1.30	
Portland	Banfield	NA	NA	Accidents increased slightly.
San Diego	I-5	NA	NA	No increase in accident experience.
San Francisco	Route 280	NA	NA	No problems reported. **
San Jose	I-280	NA	NA	No problems reported.
Seattle	Route 520	NA	NA	No increase in accident experience.
	Unweighted Average	2.12	1.33	

*Accident Rates/Million Vehicle Miles.

**Subsequent information indicatews some problems resulted from this project.

Source: Adapted from McCasland, W.R., Biggs, R.G.; <u>Freeway Modifications to Increase Traffic Flow</u>, Federal Highway Administration, January 1980.

following update of selected projects indicates that the reduction in accident rates has remained for several years.

Long Term California Experience

A review of accident rates of a few California projects reveals that higher accident rates have not yet materialized. Table 2 shows accident rates for three Los Angeles Freeways. The US 101 project is examined in more detail later in the report. Accident rates differ between the California and TTI analyses due to differences in project limits.

The data in Table 2 indicates that 8 to 11 years after operational improvements, safety has not worsened. The Ventura project is a 3 mile (westbound) segment downstream of the San Diego Freeway interchange. The Route 60 project is a 2.8 mile section (both directions) between the East Los Angeles (ELA) and Route 7 interchanges. These "spot" type improvements represent operational improvements even though volumes increased to lane volumes near or greater to before volumes. The metering effect of the interchanges helps to maintain the operational benefits of the project.

Table 2. Accident Rates In Los Angeles' Freeway Capacity Improvement Projects

Time Period	US 101[1] Ventura (Haskell to W. Oak)	RT 60[2] Pomona (Rt 7 to ELA)	
		Eastbound	Westbound
Before Improv.	1.86	1.32	1.51
After Improv.	0.78	1.05	1.02
1981	0.92	0.76	0.88
1982	0.91	0.71	0.71
1983	0.86	1.00	1.16

[1]Project implemented June 1972.

[2]Project implemented June 1975.

Rates are expresed in accidents per million vehicle mile. Recent rates quoted over the phone by CALTRANS in September 1984.

The above freeways have in common that the median shoulder width was significantly reduced to use as part of a traffic lane. The traffic lanes were also narrowed. The three segments were provided with a concrete median barrier. In the Ventura and Pomona Freeways, where improvements were made during the 1970's, the initial reduction in accident rates has been attributed to project implementation. However, contrary to expectations, accident rates have not gone back to previous levels. Years 1981 through 1983 reflect rates comparable to those experienced shortly after project implementation. Recent accident rates for the San Diego Freeway project are very similar to those experienced at the Ventura and Pomona Freeways, but the before and after accident rates are not available.

Long Term Texas Experience

A Texas project has experienced similar results. In Houston, a segment of the Southwest Freeway (US 59) in Houston had the outside shoulder of the southbound (outbound) lanes turned into an extra travel lane to increase capacity, as shown in Figure 1. Specifically, in 1976 the right shoulder of the Southwest Freeway from the Weslayan entrance ramp to the Westpark exit ramp, excluding the I-610 interchange, was converted to an extra travel lane. The width of the lanes was reduced to 10.5 feet, as shown in Figure 2. In 1978 that shoulder lane was extended north to the Edloe entrance ramp, for a combined project length of approximately 3.1 miles. The project has a full left shoulder and limited right side parking opportunities. The latter extension was made to improve the flow of upstream traffic. Initial decreases in accident rates were reported by McCasland (5).

A recent update of accident rates on the US 59 southbound lane project reflects that rates of the two sections studied have remained down since the shoulder lane was restriped to increase capacity. Table 3 shows accident rates before restriping and for a period of seven years after restriping, as reported by McCasland (7).

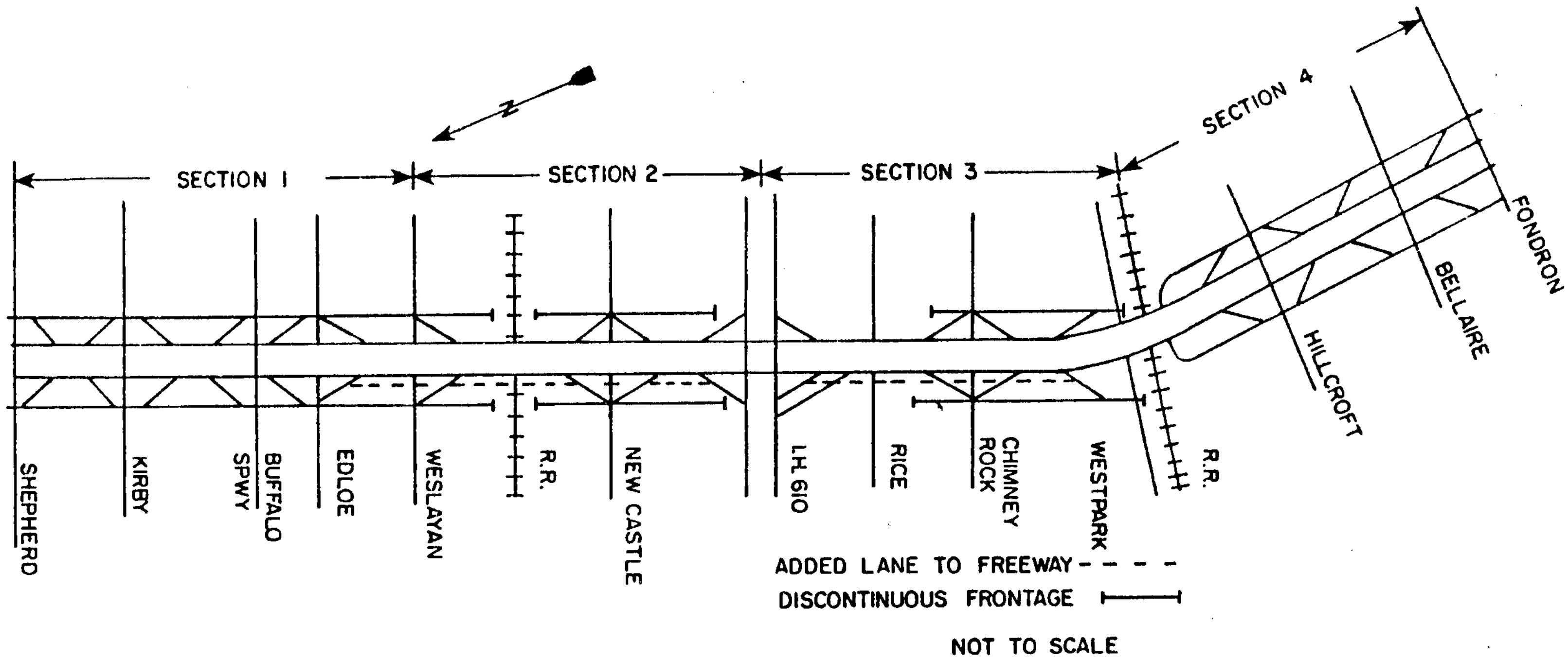


Figure 1. Shoulder Change, US 59 (Southwest Freeway), Houston

Table 3. Accident Rates On Southwest Freeway, Southbound
Weslayan To Westpark, Houston

Accidents/Million Vehicle Miles (24-Hour Rates)

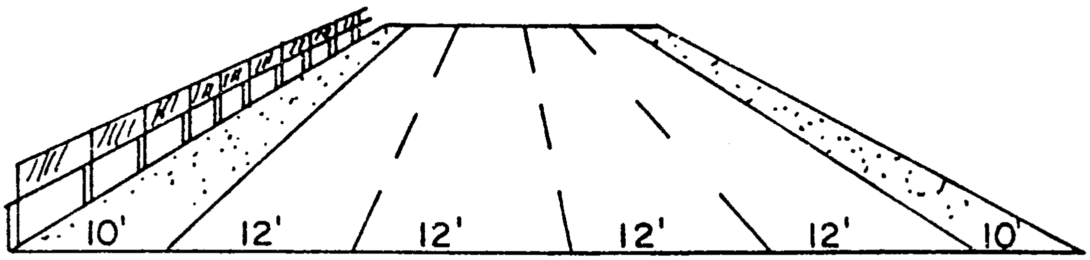
Section	Before Restriping	After Restriping						
		1976	1977	1978	1979	1980	1981	1982
Weslayan to I-610	3.42	2.98	2.82	3.02	2.95	2.91	2.22	2.71
I-610 to Westpark	3.78	3.38	3.03	2.24	2.74	2.68	2.78	2.71

Source: McCasland, W. R., The Use of Freeway Shoulders to Increase Capacity, Research Report 210-10, Texas Transportation Institute, 1984.

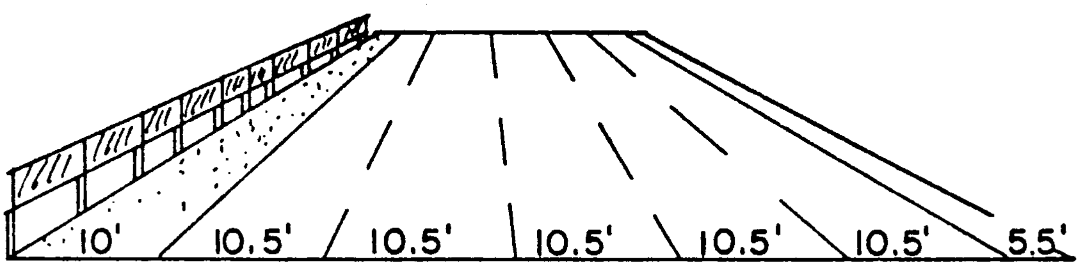
Recent Experience

During 1983 as part of this research effort, highway and transportation departments were contacted to obtain information regarding operational and accident experience from projects with segments of mainlane freeways where one or both shoulders had been reduced or eliminated to increase highway capacity. The survey addressed only projects implemented since 1978, and for which documentation was available. All states were contacted and 36 responded; eleven of those indicated they had undertaken such projects. Appendix A presents a summary of responses. Of the states that had not reduced or eliminated shoulders, two (Indiana and North Carolina) explained that they are considering this option for the future and one state (Kansas) reported to have considered this type of project but rejected such an approach. Other states that did not respond may have shoulder reduction projects.

Of the states that had reduced or eliminated shoulders, six provided details on those projects. These projects, located in Arizona, California, Hawaii, Illinois, New Mexico, Texas and Virginia, are described in Appendix B. Of the above, Arizona and Texas provided safety and operational data



BEFORE
(FOUR LANES)



AFTER
(FIVE LANES)

Figure 2. Cross Section Reconfiguration, US 59, Houston

including accident rates that can be used to better understand their experience. The New Jersey Turnpike Authority, in response to a request from Caltrans, provided their assessment of improvements on two major freeway bridges. The Arizona, Texas and New Jersey projects are briefly described below.

Arizona

The study conducted in Phoenix, Arizona provides the most detailed analysis of operational and safety factors regarding restriping and the use of shoulders (7). In February 1980, while I-10 was closed for repairs to the Salt River Bridge, the six mainlanes were restriped into eight lanes (four each way) to increase traffic capacity. Figure 3 shows the study site. The typical before cross section was three 12-ft. lanes with a 10-ft. outside shoulder and a 4-ft. median shoulder. (The differences between the written description and typical section in Figure 4 exists in the original report). The section was turned into the equivalent of four 11-ft. lanes with 2-ft. inside and outside shoulders, as shown in Figure 4.

A before and after study was conducted to determine the impact on operations and safety of widening to eight-lanes. Before restriping, peak-period traffic (using six lanes) was operating at level-of-service "E through F" with a.m. peak hour volumes of 5,500 vehicles westbound and p.m. peak hour traffic of 5,000 vehicles eastbound. Congestion increased when in early 1979 flooding of the Salt River required several nearby bridges to be closed. As traffic volumes across the high grade river crossings increased, I-10 became more congested. This resulted in level-of-service "F" with slow moving queues approximately three miles long occurring regularly. A temporary plan was developed to increase capacity of I-10 from 24th street to Broadway Road. Restriping took away the right shoulder to use as a travel lane, thereby increasing the number of mainlanes from three to four in each direction.

When in March 1980 the I-10 Salt River bridge was changed to eight mainlanes, the westbound a.m. peak hour volumes increased to 6,290 vehicles while the eastbound p.m. peak hour volume increased to 5,450 vehicles. Based

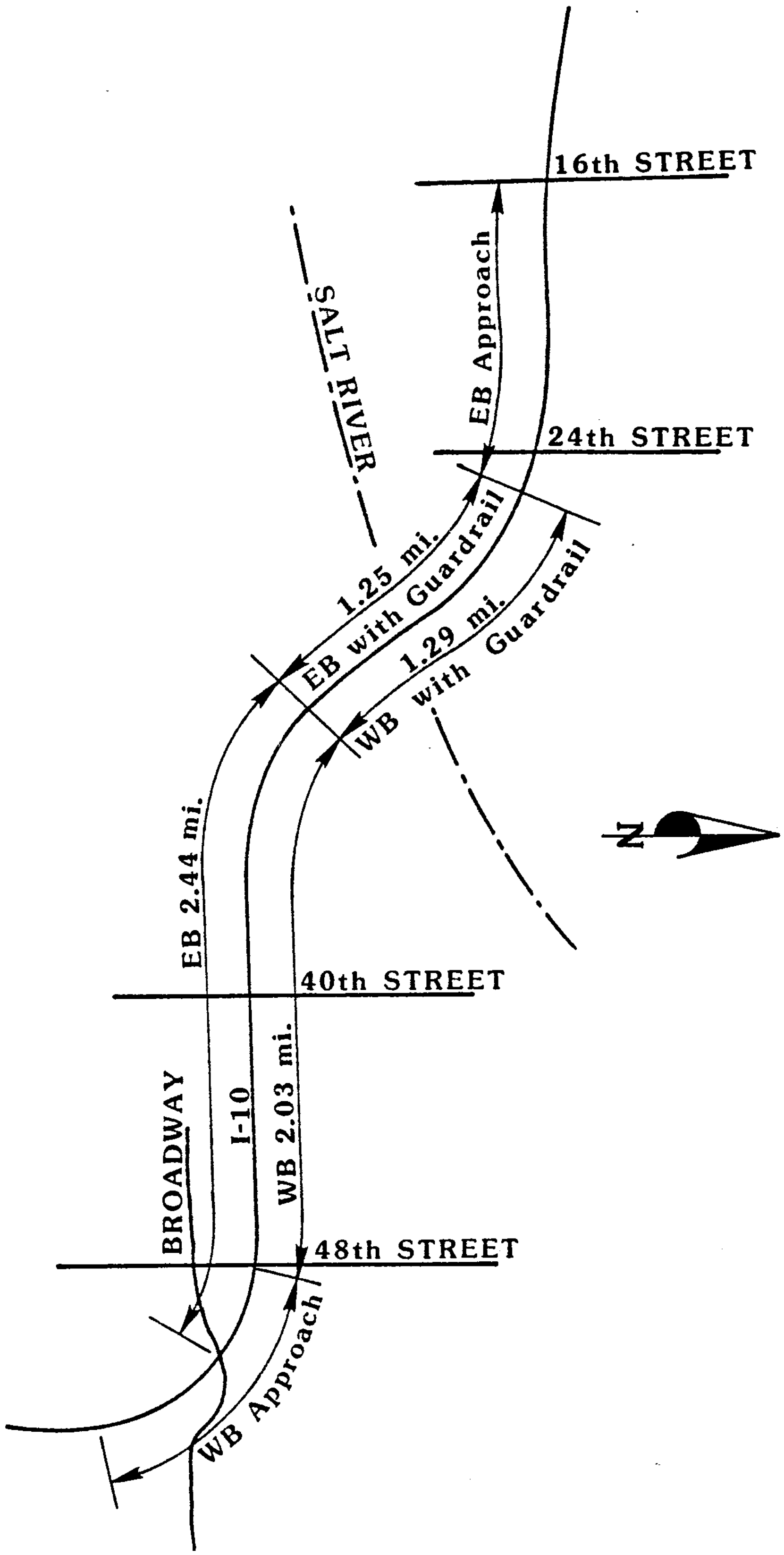


Figure 3. Shoulder Study Sites, I-10, Phoenix

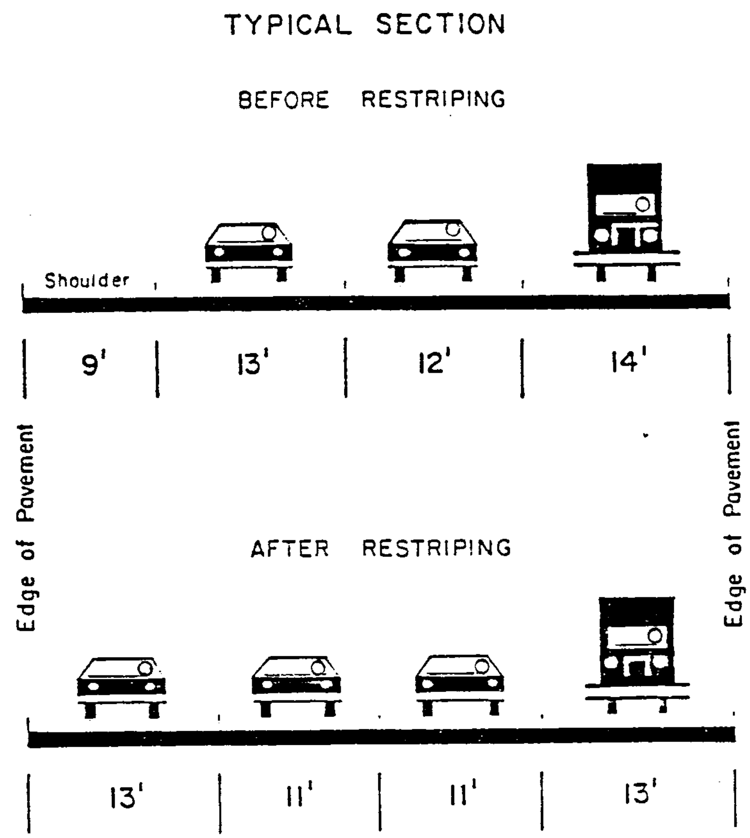


Figure 4. Cross Section Reconfiguration, I-10 Phoenix, Arizona

Source: Evaluation of the I-10 (24th Street to Broadway Road) 6-lane vs. 8-lane Freeway Operations, Traffic Design Services, Arizona Department of Transportation, August 1983 (internal papers).

on capacity computations, the widened study section operated at LOS "C-D" during peak hours and no significant queueing was observed. During the year the 8-lane section was operated, monthly traffic counts were taken. During this time several river crossings were opened, but on the average, I-10 traffic volumes remained at about the same level.

In March 1981 the cross section was brought back to 6-lanes. Peak hour traffic went down to 5,800 vehicles westbound and to 5,200 vehicles eastbound. The study section again operated under LOS "E-F" during peak hours with significant queueing observed.

It is of interest that throughout the study period, weekday daily volumes continued to increase. Initial counts recorded a weekday volume of 105,000 vehicles per day with 6-lanes and all river crossings opened, 115,000 vehicles per day with 8-lanes and most river crossings opened, and 117,000 vehicles per day after returning to the 6-lane configuration. However, the 8-lane section was capable of handling the growing demand at a satisfactory level-of-service during peaks, but the 6-lane section was not.

To analyze accidents on the 8-lane section, three roadway categories were selected: (1) the approach (upstream) segments to the widened roadway, (2) the segments of the 8-lane section provided with guardrail along the Salt River bridge (thus, no shoulders or emergency parking opportunities) and, (3) the segments of the 8-lane section with no shoulder or guardrail, but with some outside parking opportunities.

Overall accident rates for the whole study corridor decreased with the implementation of the 8-lane section and again decreased after the section was returned to 6-lanes as shown in Table 4. The initial decrease following the implementation of the 8-lane section is consistent with past experience (8) as accident rates have been related to the level-of-service or traffic volume per lane per hour travelling a given cross section. Under the original 6-lane operation, the eastbound traffic experienced significant queueing and stopped delay during peak hours. Under the 8-lane operations the level-of-service improved and relatively stable flow was observed. The return to the 6-lane operation brought back congestion and long queues, which in turn should have increased accident rates but the reverse was recorded. This may be partly explained based on a long term decrease in reported accidents throughout the state; however, it is necessary to examine the rates in more detail than overall rates.

Table 4. Accident Rates By Segment, I-10, Phoenix, Arizona

Direction	Segment (Accidents/Million Vehicle Miles)				
	Period	Total	Approach	Guardrail*	Without Guardrail*
Eastbound Accidents	Before	2.28	3.35	2.51	1.69
	During	2.02	0.95	3.80	1.50
	After	1.53	1.88	1.97	1.13
Westbound Accidents	Before	2.57	1.08	2.47	3.07
	During	2.16	1.17	3.00	1.90
	After	1.69	1.04	1.35	2.11

Before: March 4, 1970 to March 13, 1979 (6 lanes)

During: March 1, 1980 to March 13, 1981 (8 lanes)

After: March 16, 1981 to March 31, 1982 (6 lanes)

*The distinction between guardrail and without guardrail sections is that the without guardrail section allowed limited outside parking opportunities.

Source: Evaluation of the I-10 (24th Street to Broadway Road) 6-lane vs 8-lane Freeway Operations, Traffic Design Service, Arizona Department of Transportation, August 1983 (internal paper).

An important difference was observed on the segments with guardrail and no parking. These showed a statistically significant increase in accident rates for each direction once the 8-lane cross section was implemented. When the cross section was returned to 6-lanes the accident rates decreased. This is very different from what happened on the segment provided without guardrail (limited parking available) in magnitude and in the direction of change. Figure 5 shows these relationships. It appears that the increase in accident rates is due to the complete lack of shoulders or emergency parking area. This is consistent with experience elsewhere.

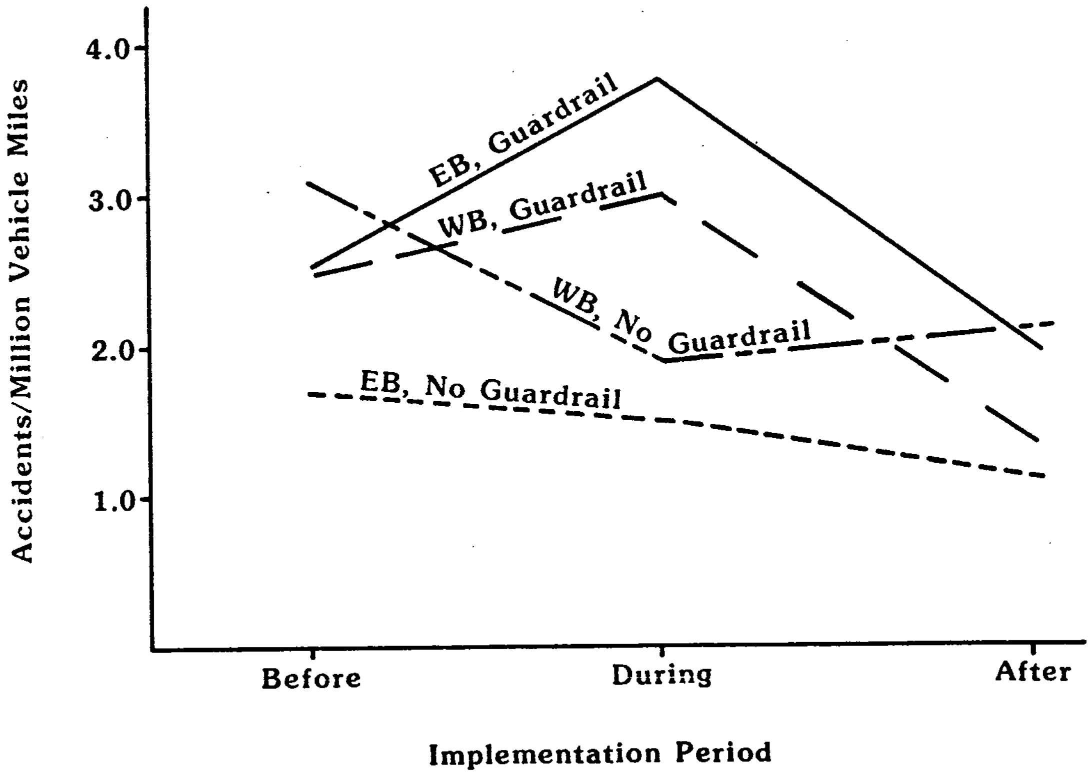


Figure 5. Accident Rates By Time Period, I-10, Phoenix, Arizona

Texas

Recent experience in the utilization of freeway shoulders to increase capacity are primarily from the implementation of additional capacity and the construction of median HOV lanes. The projects are located in Houston, Texas.

US 59. In February 1981, the northbound (inbound) right shoulder of US 59 was converted to a travel lane during the (weekday) morning peak period between the hours of 6:00 to 9:00 a.m. (7). Improvements extended between the Newcastle exit ramp to the Edloe exit ramp for a distance of 0.9 miles, as shown in Figure 6. This freeway section has 10-ft. inside shoulders. Also, the Newcastle entrance ramp to the northbound mainlanes is closed to traffic between 6:00 to 9:00 a.m. by a time-clock-operated railroad barrier gate. During that period, the Newcastle entrance ramp traffic is diverted along the frontage road to downstream on-ramps.

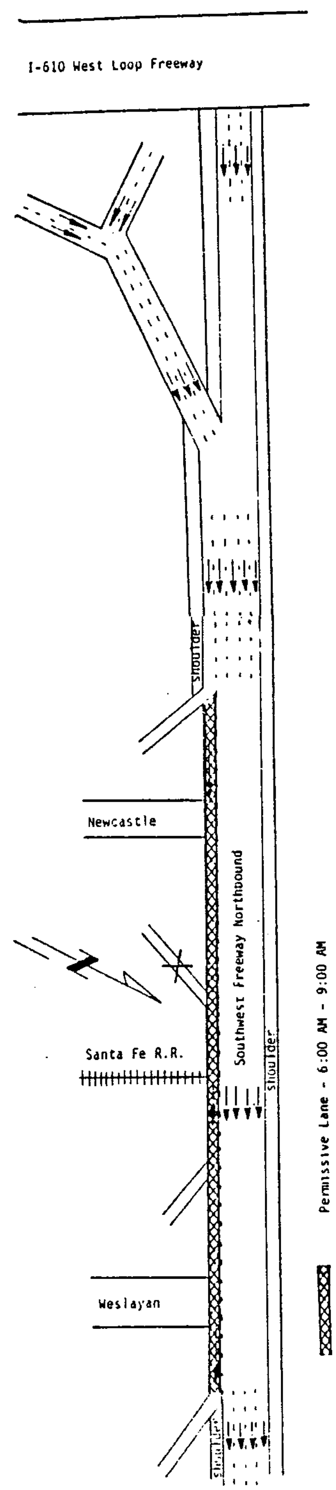


Figure 6. Peak Period Shoulder Lane, US 59, Houston

The U.S. 59 project turned the right shoulder to an a.m. peak hour lane to increase capacity over the Santa Fe Railroad crossing and to improve upstream traffic operations. Peak hour traffic volume (7:00 - 8:00 a.m.) went from 7,800 to 9,125 vehicles per hour (vph) for a net increase of 1,325 vph as a result of improvements. Once opened, the peak period lane was handling 1,058 vph over the railroad crossing or operating at about 60 percent of capacity. Through lane traffic volume increased slightly to approximately 2,020 vph per lane.

The most important benefits were in accident reduction. During the a.m. operating hours, the frequency of accidents between I-610 and Weslayan, a distance of 1.6 miles, went down about 50 percent for the two years following the improvements, and the accident rate dropped about 57 percent, as shown in Table 5. The off-peak period, between 9:00 a.m. through 6:00 a.m. the next day, discloses a different situation. The off-peak period accidents were

Table 5. Accident Frequency and Accident Rates of Designating a Shoulder as a Travel Lane, Southwest Freeway, I-610 to Weslayan, Houston

Section and Time Period I-610 to Weslayan	Two Years Before Modification 1979-1980	Two years After Modification 1981-1982	Percent Change
6 a.m. - 9 a.m., Weekdays (peak period)[1]			
Number of Accidents	58	29	-10
Accidents/million vehicle mile	4.41	1.89	-57
9 a.m. - 6 a.m., Daily (off-peak)[2]			
Number of Accidents	307	301	- 2
Accidents/million vehicle mile	3.14	2.9	- 5

[1]This is the period during which the shoulder is operated as a travel lane.

[2]The shoulder is not in operation as a travel lane during this off-peak time.

Source: McCasland, W.R., The Use of Freeway Shoulders to Increase Capacity, Research Report 210-10, Texas Transportation Institute, 1984.

reduced by only 2 percent and the accident rate by about 5 percent; this was a minor reduction compared with that for the a.m. peak operating period. Thus, the section operating with the additional shoulder lane during the a.m. peak period recorded a 50 percent decrease in accidents and a 57 percent decrease in accident rates, while the same section operating with a right shoulder during off-peak hours remained at about the same level. The following data suggests that the accident reduction is the result of a reduction in the level of congestion and a ramp conflict point.

Other benefits were attributed to the implementation of the peak period shoulder lane. The before and after studies revealed that at the entrance ramps from I-610, the average vehicular speed increased and the vehicle delay became negligible during the shoulder lane operating hours. The shoulder lane improved the flow from I-610 using US 59 to travel northbound. Runs made from the I-610 approaches to a point adjacent to the Weslayan exit ramp confirmed reductions in travel time. Travel time between the I-610 northbound entrance ramp to Weslayan, a distance of 2.4 miles, used to take 11 minutes or more during the period between 7:00 to 7:45 a.m. After improvements, the same run could be made in approximately 4 minutes. The I-610 southbound entrance ramp traffic also observed similar improvements but not as dramatic.

I-10. Preliminary information on the Katy Freeway (I-10) in Houston, comparing before and during construction accidents through sections modified with narrower lanes and reduced or eliminated shoulders due to construction of an HOV median lane, indicates no significant change in accident rates (9). Accident experience was investigated for a 5 mile long project of HOV construction. The project was divided into various segments by cross section used during different time periods. The accident records were related to segment length and to measured average daily traffic to obtain accident rates. Statistical analysis reflected a significant increase in accident rates through the whole project length between the pre- and during construction phases. Traffic safety was adversely affected at the beginning of construction on each segment. As time elapsed, drivers seemed to adjust to the substandard geometrics. Prior to completion of work at each segment, accident rate differences were found not significantly different compared to preconstruction rates.

The narrow lane cross-section, together with reduced shoulders implemented during the HOV lane construction, raised fears of increased accidents and drastically reduced speeds. Those concerns did not materialize except for a brief initial period during construction in which the accident rate increased until drivers adjusted to the new geometrics. There were a few operational and safety problems which may be the result of the detailed traffic management plan used during construction.

Subsequent analysis (10) of the first year of operation of the Katy Freeway authorized vehicle lane is summarized in Table 6. A detailed analysis will be performed as a part of this study when a more detailed accident database is available from the Texas Department of Public Safety. The data to date does suggest that the introduction of the transitway and the elimination of the left shoulder does not appear to have resulted in unsafe operating conditions as measured by the frequency of accidents on the freeway mainlanes.

Table 6. Comparison of Accident Rates
(Westview to Washington, 8.7 miles)

Time Period	Total # Accidents	# of Days	AADT	Distance (miles)	Accidents Per Million Vehicle-Miles
6/82-5/83 before	754	365	154,891	8.7	1.53
6/83-10/84 const.	1182	518	156,471	8.7	1.68
11/84-9/85 after	626	334	158,147	8.7	1.36

Source: Texas State Department of Highways and Public Transportation computerized accident data (10).

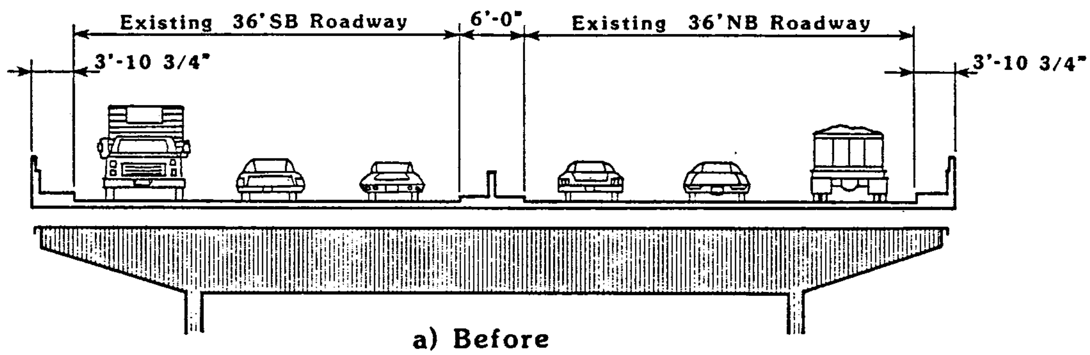
New Jersey

The New Jersey Turnpike was originally built in 1952 with an outside shoulder 10 ft. wide and a 5 ft. wide inside shoulder (11). Subsequently, the outside shoulder was widened to 12 feet. The exception to continuous outside shoulders were two high level bridges. The Passaic River Bridge, 1.3 miles long, and the Hackensack River Bridge, 1.1 miles long, were provided with six traffic lanes with a 2.5 ft. raised inside shoulder and a 3.5 ft. raised outside shoulder. The original cross section is shown in Figure 7.

In the mid-1960's it was decided to add external lanes (dualize) to the northern 30 miles. With dualization completion in 1970, the Authority had the opportunity to divert traffic and build 12-ft. outside shoulders onto the bridges, as shown in Figure 7. Bridge reconstruction to add shoulders took place between 1970 through 1975 and during those years traffic never exceeded two-thirds of the volumes immediately preceding diversion. From 1976 to 1982 traffic volumes increased and approached the levels of the mid-1960's.

The bridge accident rates went down from 1.55 acc/mvm for the 1964-1970 period to 0.78 acc/mvm for the 1976-1982 period (10). This difference is statistically significant at the 0.01 level. In comparison, the turnpike accident rate as a whole went up slightly, but the difference is not statistically significant. Table 7 shows the above rates by year. In addition, fatal accidents totaled five during the 1964-1970 period and to only one after improvements.

The outside shoulders have been credited with the improved accident rates since the most significant change was the provision of outside shoulders.



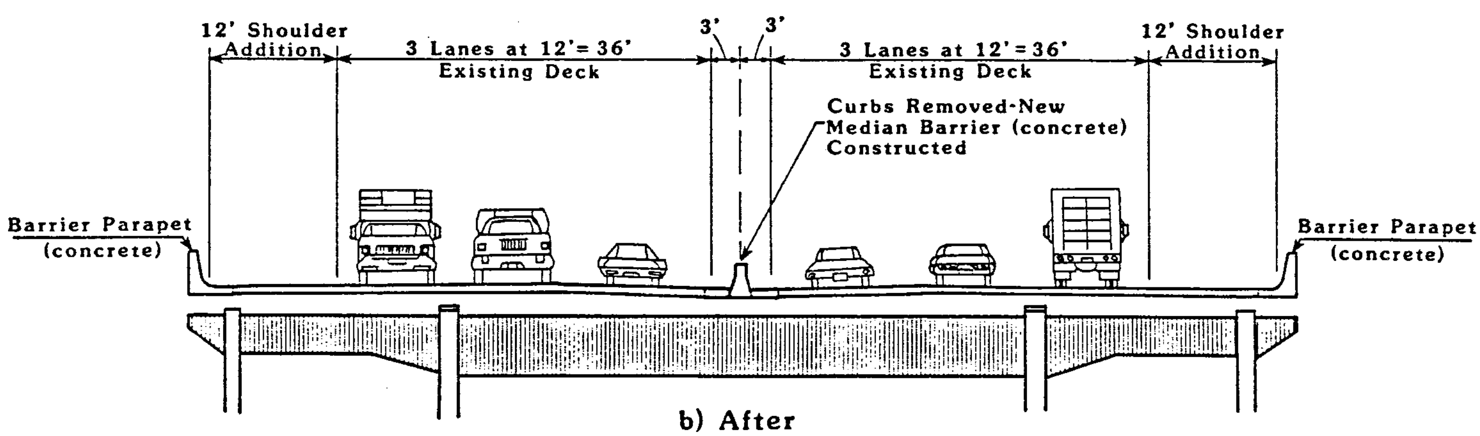


Figure 7. Hackensack-Passaic River Bridges, New Jersey Turnpike

Table 7. **Passaic and Hackensack River Bridge Accidents**

Easterly Roadway 1964 - 1982

Year	Bridges Total Accidents	Bridges Accident Rate	Total Turnpike Accident Rate	Fatal Accidents On Bridges Involving Disabled Vehicles	AADT On Bridges
1964	108	153.5	94.3	2	64,249
1965	99	139.7	91.8	1	64,705
1966	107	145.6	88.0	0	67,115
1967	116	153.3	93.0	0	69,105
1968	107	133.5	94.8	1	73,166
1969	151	183.7	102.8	0	75,063
1970	130	178.0	89.3	1	66,682
1971	41	87.3	85.5	0	42,882
1972	53	97.0	91.5	0	49,856
1973	31	57.1	83.5	0	49,573
1974	40	75.8	71.5	1	48,159
1975	40	74.5	63.8	0	48,997
1976	34	60.0	78.8	0	51,776
1977	56	94.5	94.7	0	54,113
1978	68	105.6	97.1	0	58,785
1979	56	82.6	112.2	0	61,927
1980	43	61.6	98.8	0	63,712
1981	41	58.4	101.4	0	64,071
1982	59	81.5	96.1	1	66,059

1964 - 1970 No shoulders on bridges

1970 - 1975 Under construction, some traffic diverted

1976 - 1982 Shoulders on bridges

Summary of Past Projects

A review has been conducted of recent experience on the operation and safety of using paved shoulders to provide extra lanes to increase capacity of freeways. In general, a substantial reduction in accident rates has occurred immediately after implementing these projects. A previous concern that accident rates would increase with increasing traffic volumes did not come about. After eight to eleven years, accident rates have remained lower than prior to improvements as confirmed by studies of three freeways in Los Angeles and Houston.

A study of US 59 in Houston, where the right shoulder was taken away to provide a peak period travel lane, but with ramps and grass areas available to pull out of the freeway mainlanes, observed lowered accident rates. Total traffic increased, with the through lanes carrying a slightly higher number of vehicles per hour per lane, but the shoulder lane working considerably below capacity. This cross-section allows for parking on the inside shoulder.

A study of a project on I-10 in Phoenix, discloses some additional perspective. Accident rates went down at a time when this temporarily went from six lanes and full right shoulders to eight lanes and no outside shoulders. Partial (2 foot) inside shoulders were provided before and after improvements. The six lane approach to the improved capacity segment (8-lanes) experienced a reduction in accident rate. The improved capacity segment without guardrail (some emergency parking available) also experienced reduced accident rates. However, the 8-lane segment operating with guardrails through a bridge structure where parking away from the mainlanes was not possible, observed an increase in accident rates. These findings indicate a possible difference between having only one full shoulder and having no shoulders (or emergency parking area).

Reduced accident rates were found on two New Jersey Turnpike bridges where full outside shoulders were installed along segments with partial (2.5 ft.) inside and partial (3.5 ft.) outside shoulders. The rate for the whole turnpike remained at about the same level. Safety improvements have been attributed to the ability of giving safe refuge to vehicles that breakdown on the highway.

Overall, the literature review suggests that the taking of the right or both shoulders to increase capacity may not reduce safety if a parking area of some kind exists. The sections of this report that follow go into a detailed analysis of several recent projects located in Texas and California where inside or outside freeway shoulders were taken away to provide a travel lane. The Texas analysis also includes four pairs of comparison sites where one section has shoulders and the other section never has had inside shoulders.

INSIDE SHOULDER ACCIDENT EVALUATION IN TEXAS

The objective of the analysis following is to detect statistically significant differences in accident rates between contiguous freeway segments where the cross section varies from a full-width (8 ft. or more) inside shoulder to a partial (3 to 7 ft.) or no (0-2 ft.) inside shoulder. A before and after study of a segment also is included where work was done to restripe lanes and use the inside shoulder as a travel lane.

When this study was initially undertaken, the only known data was that previously described. The only available approach was to compare different roadway segments with and without shoulders. The roadway segments compared in this section of the report represented the best available comparison sites that could be identified in Texas. As the analysis will show, the study sites do appear to have significant limitations. However, some additional insight can be drawn from the Texas data given the results of the analysis of the California data which is presented later in the report. The Texas analysis of four "paired" sites is provided for completeness and must be viewed cautiously. However, the anlaysis provides valuable data concerning severity.

All freeway segments studied have six or more lanes and full-width outside shoulders. The first four segments are "paired" sites. The I-610 analysis is a before and after study. The segments studied include:

- SH 183 in Dallas, from the western boundary of Dallas County to Carl Road;
- I-30 in Dallas, from West Loop 12 to Beckley Avenue;
- US 59 in Houston, from Almeda Road to Shepherd Drive;
- SH 286 and SH 358 in Corpus Christi, the first segment from Agnes Street to Mansheim Street, and the second from Koztoryz Road to Staples Street.
- I-610 in Houston, from US 290 to I-10; and

SH 183 includes two segments, one with full inside shoulders and the other with no inside shoulders. I-30 includes three segments, one with full inside shoulders, a second with partial inside shoulders and a third with no inside shoulders. US 59 includes two segments, one with full inside shoulders and the other with partial inside shoulders. I-610 is just one segment where before and after comparisons have been made; before restriping it had a full inside shoulders, after it had partial inside shoulders. Last, SH-286 and SH 358 each provide a segment to be compared with the other, the first has full inside shoulders and the second partial inside shoulders.

Procedure

Accident records prepared by the Texas Department of Public Safety (DPS) and maintained in computer files have been accessed for the analysis. These records include accidents dating between 1979 through 1984. The many variables describing each accident allow for the selection of subsets that provide enough observations for statistical analyses. Several variables including time of day, day of the week, object impacted, light condition, type of collision and others that could relate to accident rates were investigated. Many variables were not useable because, in the short segments investigated, accident observations were too sparse to make statistical comparisons.

After looking for different relationships it was decided that the principal factor to be compared would be accidents per million vehicle miles (acc/mvm). This approach uses the total number of segment accidents occurring within a selected period of time but excludes ramp related accidents. All accidents occurring during each quarter (three month period) represented a sample for statistical purposes. Those observations then were divided by the average daily traffic (ADT) to obtain accident rates. The ADTs were obtained from the District Highway Traffic Maps, prepared yearly by the SDHPT. Quarterly rates were calculated and used to conduct a T-test between the two segments (or before and after) in order to detect any rate reduction or increase that would be statistically significant.

Another analysis was prepared to test the difference in accident rates by lane location. These include the inside shoulder (including median space beyond the shoulder), the inside lane, the middle lane (second lane), the outside lane or lanes, and the outside shoulder. Only accidents where the first impact occurred at one of these locations were included. Calculated values are a subset of the whole segment rate since lane rates are obtained by dividing lane accidents by segment vehicle miles. With this breakdown, a T-test was conducted similar to that made for the whole segment.

A third analysis was used to investigate the severity of accidents. The severity of accidents is grouped into five categories by the DPS; they are, accidents that result in: fatalities, incapacitating injuries, non-incapacitation injuries, possible injuries and non-injuries (also known as property damage only). The category of any one accident was determined by the most serious injury involved and each accident counted as one observation regardless of the number of affected parties. The program provided tables of accident frequency by severity category and lane location. Also, it computed the total accident rate by severity category. And last, it printed a frequency table of accidents involving parked cars and pedestrians by severity category and lane location.

Selected Freeway Characteristics

The freeways investigated operate with different shoulder treatments and operating conditions. Two cases, SH 183, and I-30, are used to compare full inside shoulders with no inside shoulders. The two are composed of close-by segments where the motorist population is essentially the same during a given period of time.

Three other cases, I-30, US 59, and SH 286 with SH 358 are used to compare full inside shoulders with partial inside shoulders. The three cases are composed of close-by segment pairs. US 59 has one segment with 6-lanes while the other has 10-lanes. SH 286 (full shoulders) and SH 358 (partial inside shoulder) are nearby segments which are compared. I-610 is just one segment where inside shoulders were reduced to partial (2.5 ft.) shoulders to provide a travel lane and provides data for before and after comparisons.

All six cases are located within an urbanized area and have six or more lanes.

SH 183, Dallas. The first segment, operating with full inside shoulders (12-ft. wide), is 2.2 miles long and the second segment operating with no inside shoulders (1.5-ft. wide), is 3.5 miles in length. A major interchange separating the two segments was excluded from consideration. Both segments operate with six mainlanes, full outside shoulders, and paved medians provided with concrete median barriers (CMB), as shown in Figure 8. Both segments have frontage roads, but the segment with no inside shoulders has more closely-spaced ramps. Also, land use and frontage road traffic is much more intensive along the no inside shoulder segment.

The segment with full inside shoulders had an average ADT of 80,500 vehicles during the 1980-1983 period; 1984 peak hour traffic counts averaged 1,815 vehicles per lane, as shown in Table 8. The segment with no inside shoulders had an average ADT of 104,500 vehicles for the same period; 1984 peak hour traffic counts averaged 1,870 vehicles per lane. The similar peak hour volumes and dissimilar ADTs suggests more extensive peak period congestion on the no shoulder section.

I-30, Dallas. The segment with full inside shoulders (20.5-ft. wide) is 2.6 miles long, another segment with partial inside shoulders (5.5-ft. wide) is 1.9 miles long, and a third segment with no inside shoulders (1.0 ft. wide) is 1.0 mile long. All segments are provided with a median guardrail, but the segment with full inside shoulders has only 4.5 ft. of the inside shoulder paved, and the segments with the partial inside shoulders and no inside shoulders have raised medians. The raised medians were original 6" barrier curbs, but are now generally less due to pavement overlays. Figure 9 shows these and other details on the cross section. All segments operate with six mainlanes and full right shoulders. Only the segments with partial inside shoulders and no inside shoulders have frontage roads, together with adjacent commercial development.

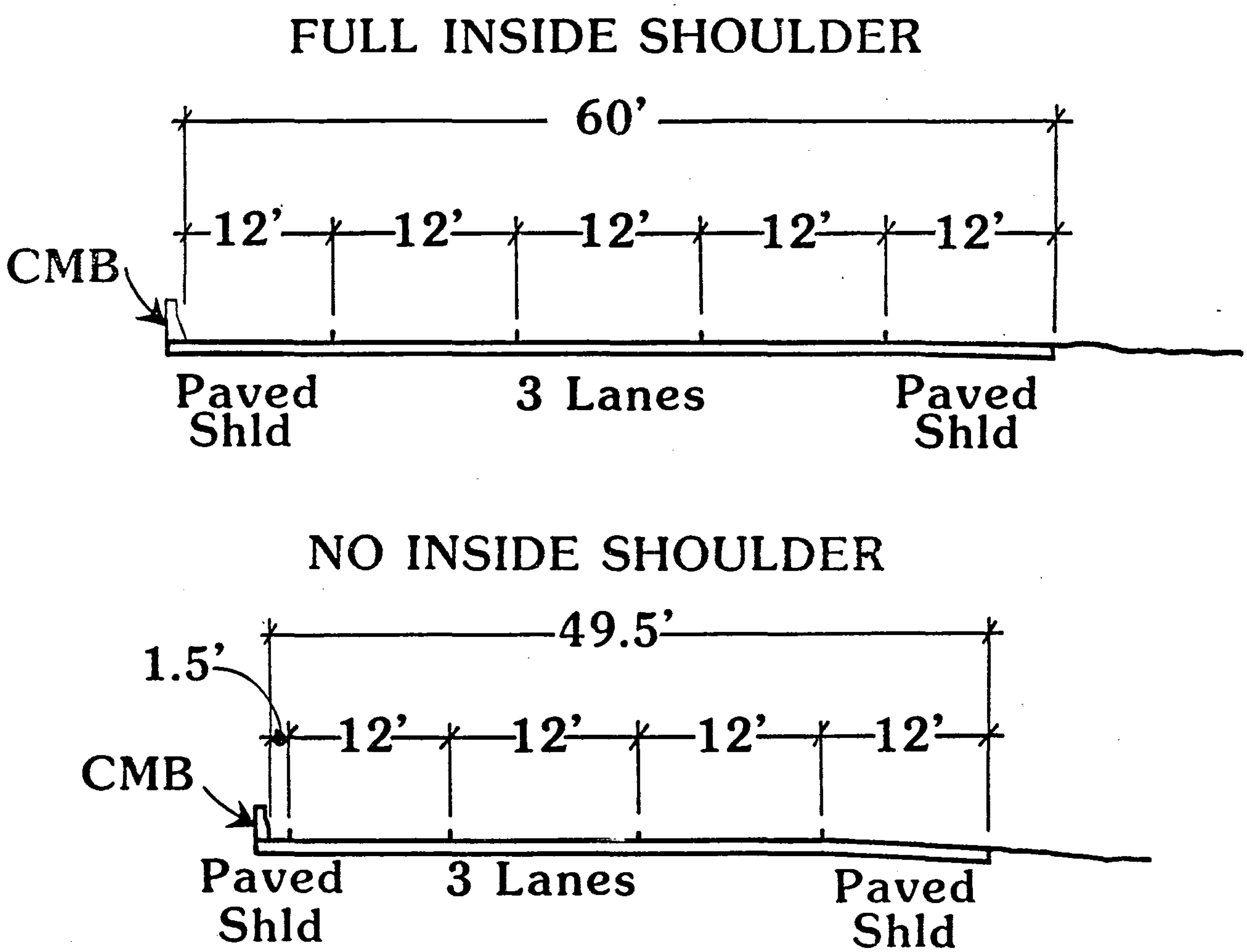


Figure 8. SH 183 Selected Segment Cross-Sections, Dallas

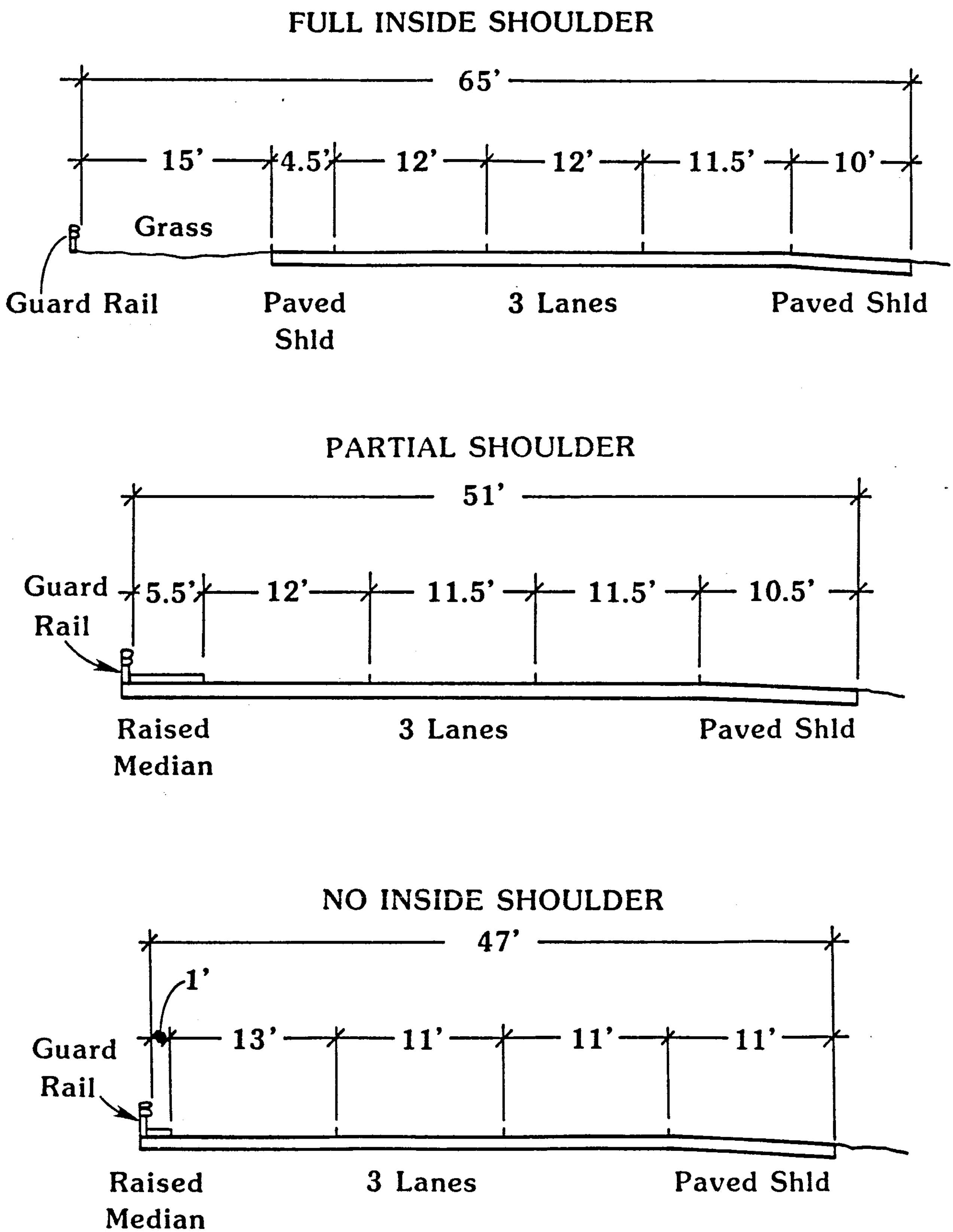


Figure 9. Selected I-30 Cross-Sections, Dallas

Table 8. Traffic Volumes For Selected Freeway Segments

Freeway	Segment[1]	ADT[2]	Peak Hour[3] Vehicles/Lane	Segment Length (mi.)
SH 183, Dallas	Full Shoulders	80,500	1,815	2.2
	No Shoulders	104,500	1,870	3.5
I-30, Dallas	Full Shoulders	70,250	1,740	2.6
	Partial Shoulders	77,750	1,850	1.9
	No Shoulders	82,250	1,960	1.0
I-610, Houston	Full Shoulders	164,600	1,910	1.0
	Partial Shoulders	213,500	2,135E	1.0
US 59, Houston	Full Shoulders	173,040	1,730E	1.3
	Partial Shoulders	128,620	2,140E	0.8
SH 286, Corpus C.	Full Shoulders	60,580	1,620E	3.4
SH 358, Corpus C.	Partial Shoulders	74,380	1,980E	3.1

[1]All have full outside shoulders.

[2]Based on 1980-83 traffic except US 59 based on 1980-84 traffic and, I-610, based on 1979-80 for before and 1982-83 for after.

[3]Average for all lanes in the peak direction. Based on counts, except volumes followed with an "E" which are estimates based on percent of ADT (0.05 for Houston and 0.08 for Corpus Christi).

The segment with full inside shoulders had an average ADT of 70,250 during the 1980 through 1983 period; 1984 peak hour traffic counts in the peak direction averaged 1,740 vehicles per lane. The segment with partial inside shoulders had an average ADT of 77,750 during the same period; 1984 peak hour traffic counts in the peak direction averaged 1,850 vehicles per lane. The segment with no inside shoulders had an average ADT of 82,250 during the period cited above; 1984 peak hour traffic in the peak direction is estimated at 1,960 vehicles per lane.

US 59, Houston. The segment with full inside shoulders (10-ft. wide) is 1.3 miles long, and another segment with partial inside shoulders (3-ft. wide) is 0.8 miles long. A partial interchange separating the two segments (Spur 527) was excluded from the analysis. The segment with full inside shoulders operates with 10-mainlanes; the segment with partial inside shoulders operates with 6-mainlanes where about half the length is provided with an auxiliary right lane in each direction. Both segments have full right shoulders and paved medians with CMBs, as shown in Figure 10. No frontage roads are available.

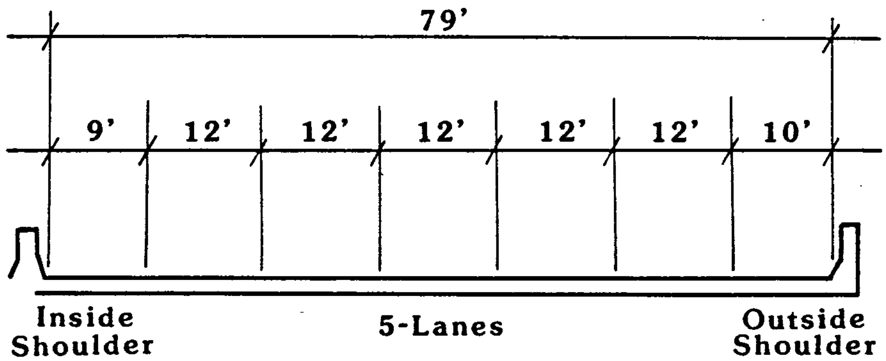
The segment with full inside shoulders had an average ADT of 173,040 during the 1980 through 1984 period; estimated peak hour traffic in the peak direction is 1,730 vehicles per lane. The segment with partial inside shoulders had an average ADT of 128, 620 during the same period; estimated peak hour traffic in the peak direction is 2,140 vehicles per lane.

I-610. This segment of the West Loop is located between two major interchanges and is 1.0 mile long. Since the inside lanes were turned into traveled lanes leaving partial inside shoulders (2.5 ft. wide), the analysis of this case is based on a before and after improvements comparison. The segment now operates with 10 lanes, full right shoulders and paved median with a CMB, as shown in Figure 11. A frontage road is not available. Extensive weaving is required.

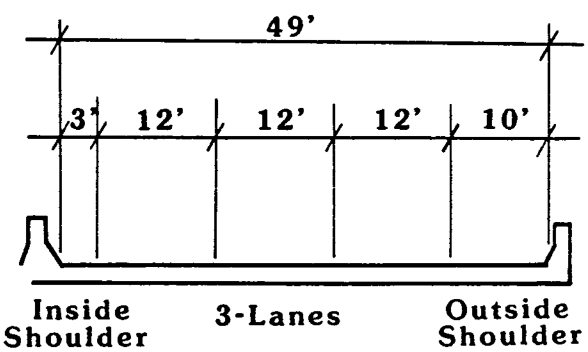
Before improvements, this segment had an average ADT of 164,600; 1980 peak hour traffic counts in the peak direction was 1,910 vehicles per lane. After improvements this segment had an average ADT of 213,500, a considerable increase; peak hour traffic was estimated at 2,135 vehicles per lane.

SH 286 and SH 358, Corpus Christi. The SH 286 segment with full inside shoulders (10-ft. wide), except no shoulders on bridges, is 3.4 miles long, and the SH 358 segment with partial inside shoulders (6-ft. wide) is 3.1 miles long. A major interchange separates the two segments. Both segments operate with six mainlanes, full right shoulders, and paved medians provided with guardrail barriers, as shown in Figure 12. Both segments have full length frontage roads and intensive adjacent land uses.

The segment with full inside shoulders had an average ADT of 60,580 during the 1980 through 1983 period; peak hour traffic in the peak direction is estimated at 1,620 vehicles per lane. The segment with partial inside



a) Full Inside Shoulder



b) Partial Inside Shoulder

Figure 10. US 59 Selected Segments Cross-Sections, Houston

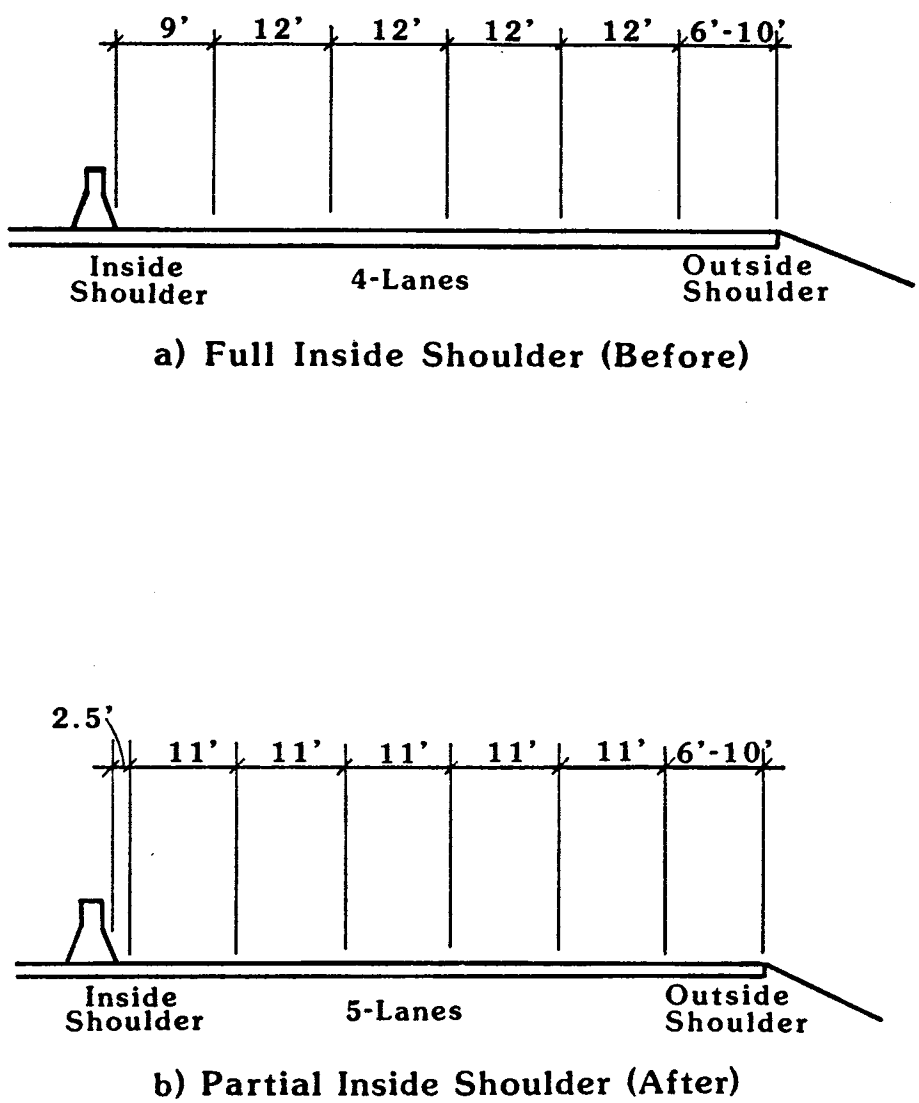
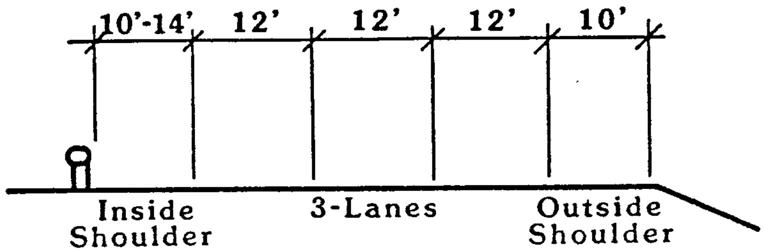
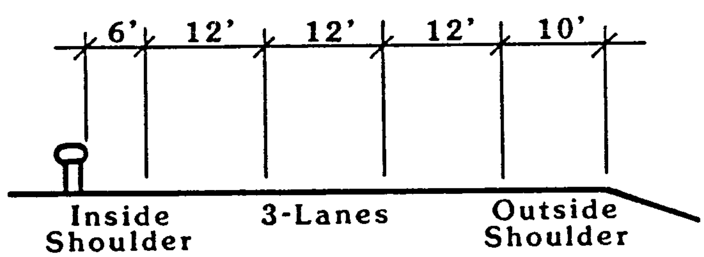


Figure 11. I-610 Selected Segments Cross-Sections, Houston



a) FULL INSIDE SHOULDER (SH 286)



b) PARTIAL INSIDE SHOULDER (SH 358)

Figure 12. SH 286 and SH 358 Segment Cross-Sections, Corpus Christi

shoulders had an average ADT of 74,380 during the same period; peak hour traffic in the peak direction is estimated at 1,980 vehicles per lane.

Overall Accident Rates

Accident rates have been calculated to compare sections with different traffic volumes and/or length. Rates are expressed in terms of accidents per million vehicle miles (acc/mvm). These are obtained by dividing the total number of accidents by the average ADT and by the subsegment length. Accident rates are then compared using a paired T-test when two subsegments are considered to have the same population, or a two-means T-test when, the subsegments are considered to be different. Table 9 presents the results of the computed T-tests for the various cases studied. In this table, the

Table 9. Test of Significance on Overall Accident Rates (Unadjusted for ADT)

- Paired T-test -

Freeway	Samples[1]	Mean Difference	Standard Error	T-Value	Probability of[2] Greater T
SH 183, Dallas NS minus FS[3]	16	0.379	.111	3.43	0.004**
I-30, Dallas					
NS minus PS	16	0.775	0.091	8.51	0.0001**
NS minus PS	16	0.662	0.087	7.63	0.0001**
PS minus FS	16	-0.113	0.056	-2.01	0.06

[1]Each sample corresponds to the accident rate difference in a three month period.

[2]One asterisk (*) means statistically significant at the 0.05 level, and two asterisks (**) means very significant at the 0.01 level.

[3]NS means no inside shoulders, PS means partial inside shoulders and FS means full inside shoulders.

freeway is identified together with the number of samples, mean difference, standard error, T-value, the probability of the T being greater in absolute value, and the statistical significance at the 0.05 or .01 levels. These comparisons do not account for possible effects due to different congestion levels (level-of-service). In addition, freeways with similar peak hour levels of service may be congested for differing amounts of time.

Research by the California Department of Transportation (11) indicates that freeway accidents are directly proportional to ADT for a particular facility such as freeways with a given number of lanes. As ADT increases so do accident rates. Accident rates for freeways with six-lanes increase 0.007 per million vehicle miles while those with 8-and 10-lanes increase 0.005 (12). This helps to account for the higher level of congestion as ADT increases. It should be cautioned that this factor may account for other factors that influence higher accidents such as closer ramps and more intensive weaving, substandard geometrics, etc., which is more common as a motorist approaches business districts associated with higher ADTs. However, this is appropriate for the study sections as the ADTs and peak hour volumes are higher for the no shoulder sections. Also, the no shoulder sections typically have closer ramps, more intensive weaving, and are closer to activity centers. Subsequent analysis includes when possible and appropriate an adjustment for ADT. These adjustments, when made, are clearly identified and the impact of adjustments are noted.

SH 183, Dallas. The overall rate for the segment with full inside shoulders was found to be 0.97 acc/mvm. In contrast, the segment with no inside shoulders had a 1.35 rate. Figure 13 displays the above relationship. The mean difference between the segments is 0.38 and is significant at the 0.05 level (size of the critical region for a two-tailed T-test), as shown in Table 8. This implies that the segment with no inside shoulders had a higher accident rate.

If the rate of the segment with full inside shoulders is adjusted to eliminate differences attributed to ADT, the expected rate of this segment would be 1.14 acc/mvm, as shown in Figure 13. As such, accident rate differences would become smaller between the segment operating with full inside

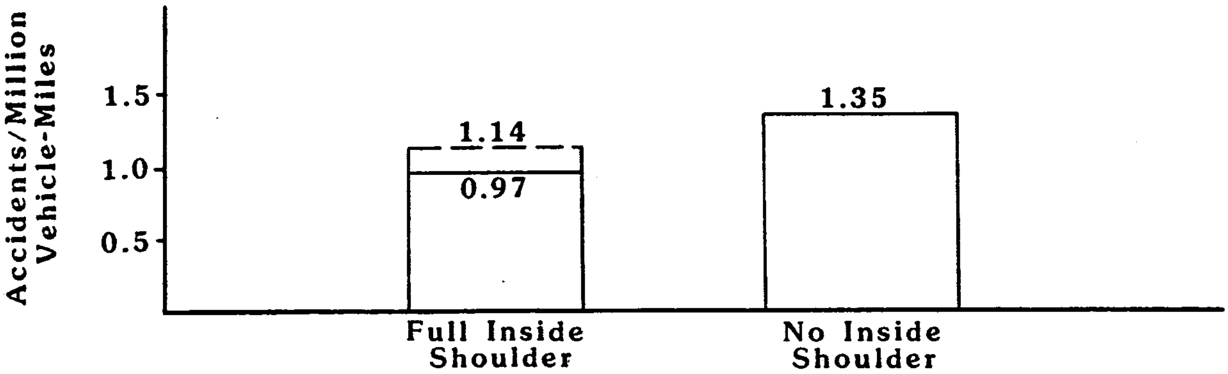


Figure 13. SH 183 Overall Accident Rates

shoulders and the segment with no inside shoulders. If the variability of the adjusted rate is assumed to be the same as the variability of the observed rate, then the recalculated difference is not statistically significant. This is not a rigorous statistical test, but suggests that the differences in accident rates may not be attributed to shoulders.

The importance of the ADT adjustment is reflected in the fact that the peak hour lane densities are similar (1,870 and 1,815 vehicles per lane per hour for the no shoulder and full shoulder sections, respectively), yet the no shoulder section has an ADT that is 24,000 vehicles per day higher than the full shoulder section. The no shoulder section experiences more extensive congestion and would be expected to have a higher accident rate.

I-30, Dallas. On this freeway, three segments were studied: the first has full inside shoulders (except at overpasses); the second has partial inside shoulders; the third has no inside shoulders. The overall accident rate for the segment with full inside shoulders is 0.77 acc/mvm, for the segment with the partial shoulders is 0.66 acc/mvm, and for the segment with no inside shoulders the rate is 1.41. Figure 14 displays the above rates. Clearly, the highest accident rate belongs to the section with no inside shoulders. A T-test reveals significant differences at the 0.01 level, between the segment with no inside shoulder and the other two, as shown in

Table 8. The difference between the segment with partial inside shoulders and the segment with full inside shoulders is not statistically significant.

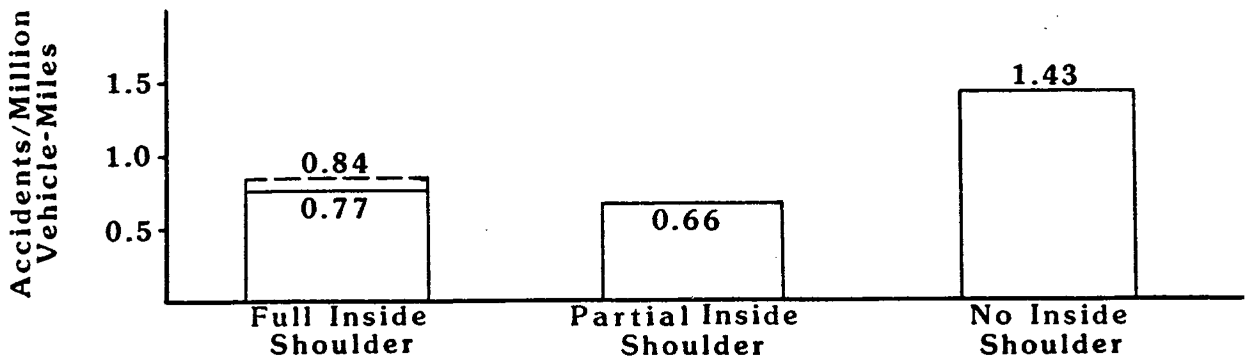


Figure 14. I-30 Overall Accident Rates

Adjusting for ADT makes the overall accident rates of the full inside shoulder segment as compared to the segment with no inside shoulders closer. The segment with full inside shoulders would have an adjusted rate of 0.84 acc/mvm, as shown in Figure 14; the differences remain significant. The segment with no inside shoulders had a significantly higher rate. The differences may not be attributable to the absence of inside shoulders as will be shown later in the analysis by lane location. Adjusting for ADT, the full inside shoulder segment compared to the segment with partial inside shoulders makes the overall accident rates further apart. Yet, differences remain not significant, and both segments can be regarded as having the same rate.

US 59, Houston. There is no statistically significant difference in accident rates between the two segments. The overall rate for the segment with partial inside shoulders was 1.89 acc/mvm, while that for the segment with full inside shoulders was 1.66 acc/mvm. Figure 15 shows the above rates. There is considerable difference in traffic volumes and number of lanes since the segment with full inside shoulders operates with 35 percent more traffic and 10 lanes while the other segment has only six lanes. However, the per lane volumes are higher on the partial shoulder section. A two-means T-test to compare differences between segments is not significant, as shown in Table 10.

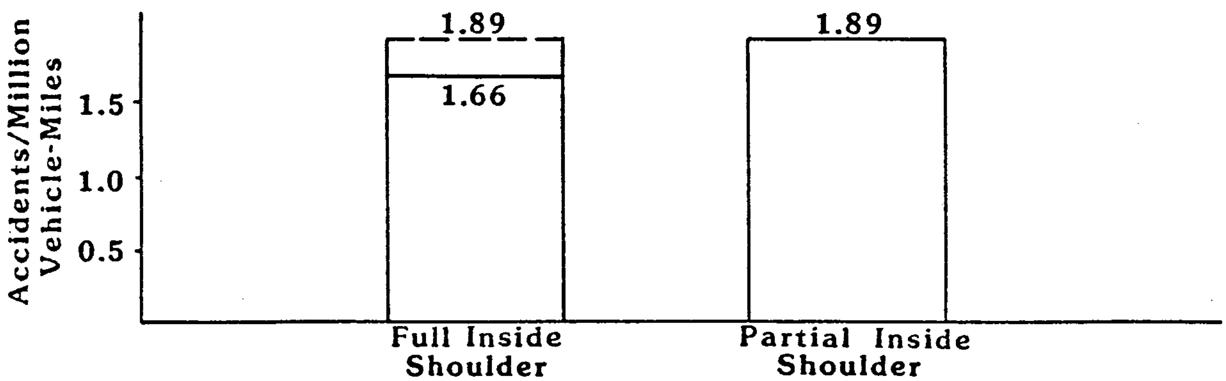


Figure 15. US 59 Overall Accident Rates

Table 10. Test of Significance on Overall Accident-Rates

- Two-means T-test -

Freeway	Inside Shoulder	Samples[1]	Mean	Standard Error	T-Value	Probability of[2] Greater |T|
US 59, Houston	Full	20	1.664	0.072	1.69	0.10
	Partial	20	1.887	0.111		
I-610, Houston	Full	8	2.245	0.161	2.28	0.04*
	Partial	8	1.817	0.096		
SH 286, Corpus C.	Full	16	1.031	0.095	5.16	0.0001**
SH 358, Corpus C.	Partial	16	1.749	0.102		

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) means statistically significant at the 0.05 level, and two asterisks (**) mean statistically very significant at the 0.01 level.

Adjusting for ADT makes the difference negligible. Both segments then show a 1.89 rate.

<u>I-610, Houston</u>. The overall rate for the segment, before changes to take the inside lane and increase capacity, was 2.24 acc/mvm. The overall rate for the same segment after conversion dropped to 1.82 acc/mvm, as shown in Figure 16. A two-means T-test reflects a significant difference in accident rates between the two periods, as shown in Table 9. The above indicates that this segment had a higher accident rate before taking the shoulder to provide an extra travel lane.

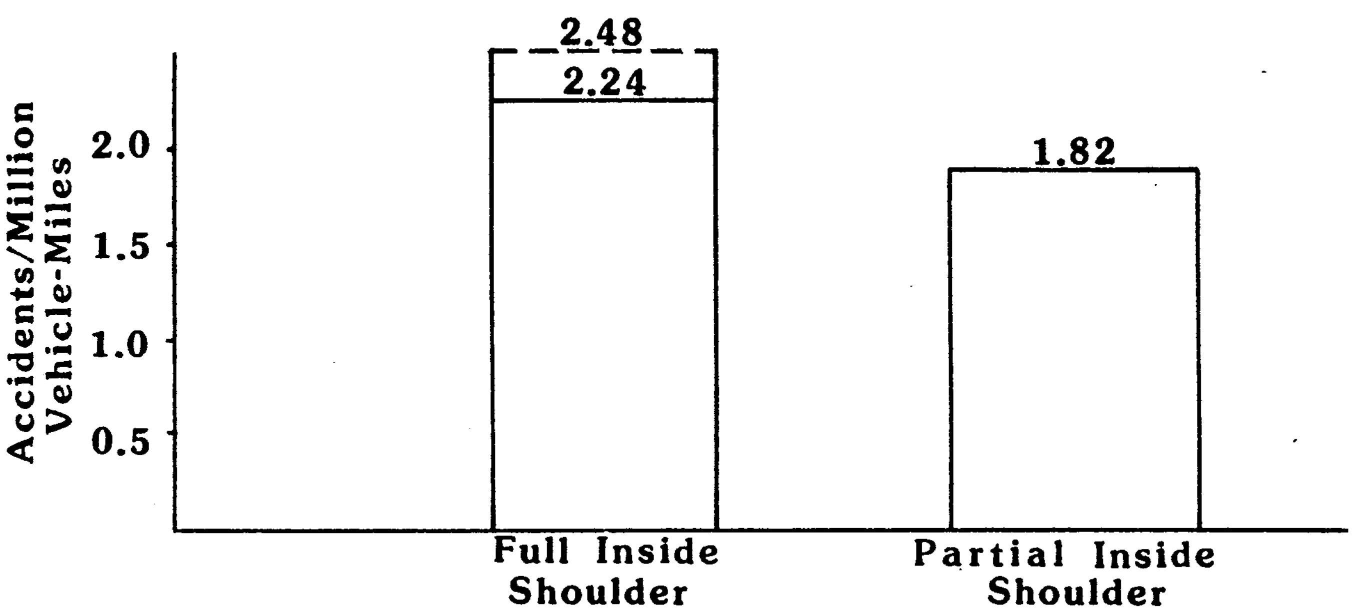


Figure 16. I-610 Overall Accident Rates

Adjusting for ADT increases makes the full inside shoulder rate go higher thus increasing the difference.

SH 286 and SH 358, Corpus Christi. The overall rate for the segment with full inside shoulders was 1.03 acc/mvm while the segment with no inside shoulders was 1.75 acc/mvm, as shown in Figure 17. Since these are two segments of different freeways it is obvious that their traffic comes from different populations. A two-means T-test indicates a significant difference between the two segments, as shown in Table 9. The segment with partial inside shoulders had a higher accident rate.

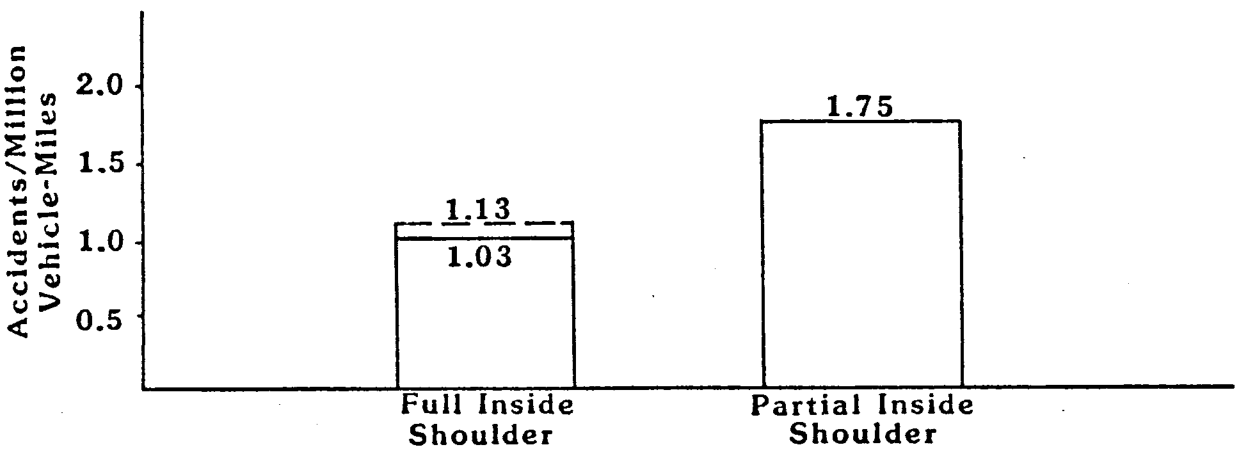


Figure 17. SH 286 and SH 358 Overall Accident Rates

The partial inside shoulder section is more congested with a peak hour volume estimated at 1,980 vehicles per lane per hour as compared to only 1,620 vehicles per lane per hour for the full shoulder section. Adjusting for ADT reduces the difference by increasing the full inside shoulder rate to 1.13 acc/mvm. However, the difference remains statistically significant. As will be shown later, the differences do not appear to be attributable to the lack of full inside shoulders.

Analysis By Lane Location on Cross Section

The analysis of overall accident rates can only be considered meaningful if the accidents can be attributed to the absence of shoulders. Accident location, especially left shoulder or left lane rates, would likely be higher if the lack of a left shoulder was the cause of increased accidents. Likewise, if the study sections are comparable, then right lane and right shoulder accidents would not likely be different between sections. One might expect some possible increase in middle lane accidents due to no left shoulder; however, the effect should not be nearly as great as the left shoulder or left lane area.

SH 183, Dallas. Figure 18 shows accident rates and distribution by lane for the SH 183 segments operating with full inside shoulders and with no inside shoulders. The segment operating with full inside shoulders has an accident rate at the inside shoulders of 0.17 acc/mvm, while the segment operating without inside shoulders has an accident rate at the inside shoulders of 0.24 acc/mvm. The difference in rates observed is small and not significant. Looking at the inside lane rates, the full inside shoulder segment has a 0.12 accident rate while the no shoulder segment has 0.26 acc/mvm. The difference of 0.14 acc/mvm is significant at the 0.05 level, indicating a higher accident rate for the inside lane of the segment operating without inside shoulders.

The outside lane also shows a high mean difference but the statistical test is not significant. No other lane location stands out as significant. Table 10 shows T-tests for the difference in accident rates by lane location. As may be observed, the probability of T being greater in absolute value is under 0.05 only for the inside lane. Each test has only 4 samples, resulting in a weak test. One cannot conclude that the SH 183 section without inside shoulders has a higher accident rate than the full shoulder section, given that we demonstrated earlier that ADT effects can reasonably be the case of the differences. Unfortunately, we do not have a means to adjust for ADT on a per lane basis. However, looking at Table 11, it can be seen that the

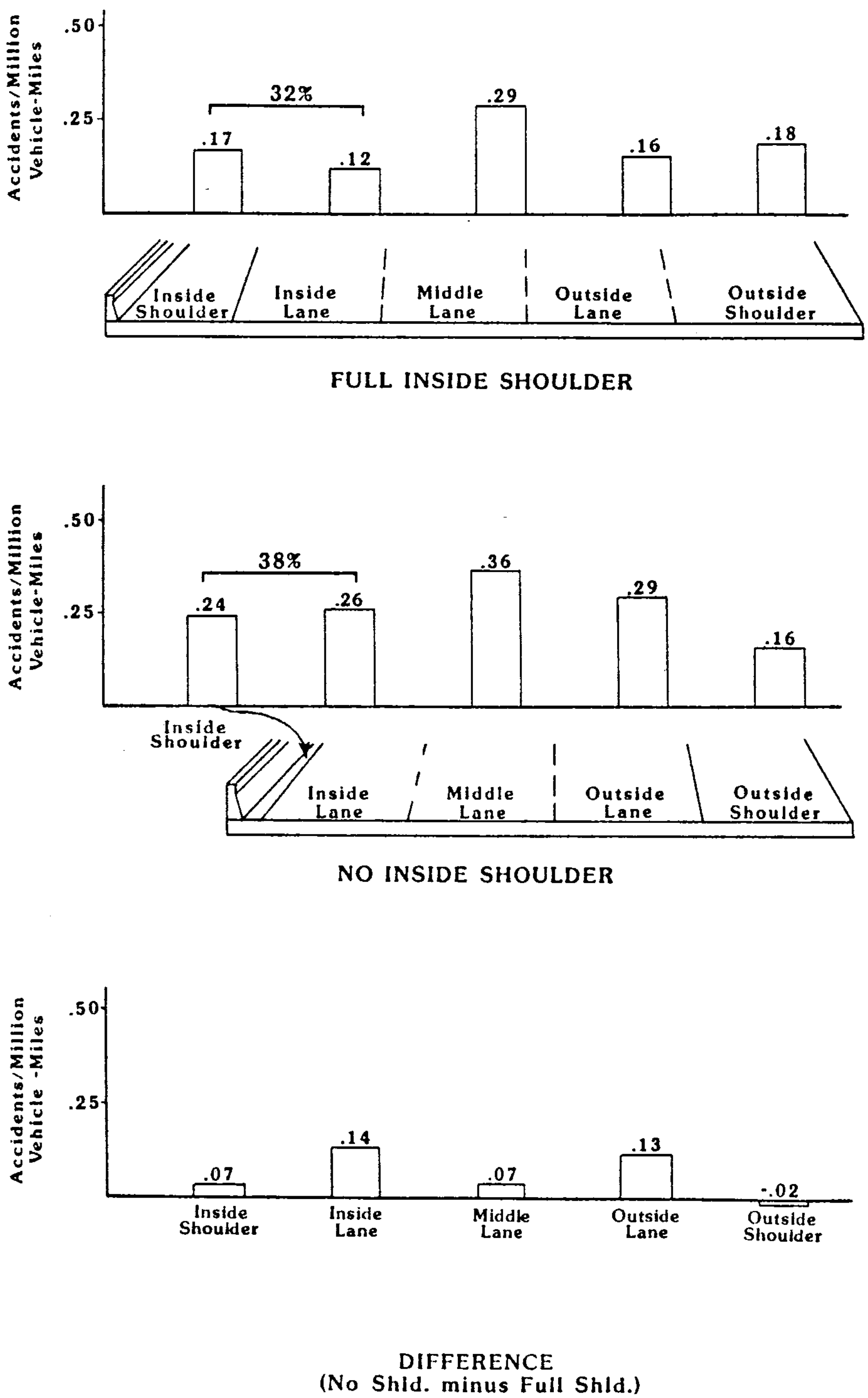


Figure 18. SH 183 Accident Rates by Lane

Table 11: SH 183 Test of Significance by Location of Accident

(No Shoulder minus Full Shoulder)

Location of Accident	Samples[1]	Mean Difference	Standard Error of Mean Diff.	T-Value	Probability of[2] Greater |T|
Inside Shoulder	4	0.072	0.042	1.72	0.18
Inside Lane	4	0.135	0.026	5.26	0.013*
Middle Lane	4	0.074	0.030	2.50	0.098
Outside Lane	4	0.128	0.054	2.36	0.10
Outside Shoulder	4	-0.022	0.057	-0.39	0.72

[1]Each sample provides the accident rate difference in one year.

[2]One asterisk (*) statistically means significant at the 0.05 level, and two asterisks (**) statistically mean very significant at the 0.01 level.

outside lane accidents increased nearly as much as the inside lane accidents, although the difference is not statistically significant. The results of the analysis of this section are not clear. Only in the context of other findings and experiences, it is reasonable to conclude that the differences may be unrelated to the absence of a left shoulder.

I-30, Dallas. Figure 19 displays the accident rate distribution for the selected I-30 segments operating with full inside shoulders and with no inside shoulders. The segment operating with full inside shoulders has an inside shoulder rate of 0.11 acc/mvm compared to 0.26 for the segment with no inside shoulders. The difference observed of 0.15 acc/mvm is significant at the 0.05 level, reflecting higher accident rates for the segment with no inside shoulders. Table 12 shows the statistical results. Comparing the inside lanes, the mean difference observed is 0.10 acc/mvm and is not statistically significant.

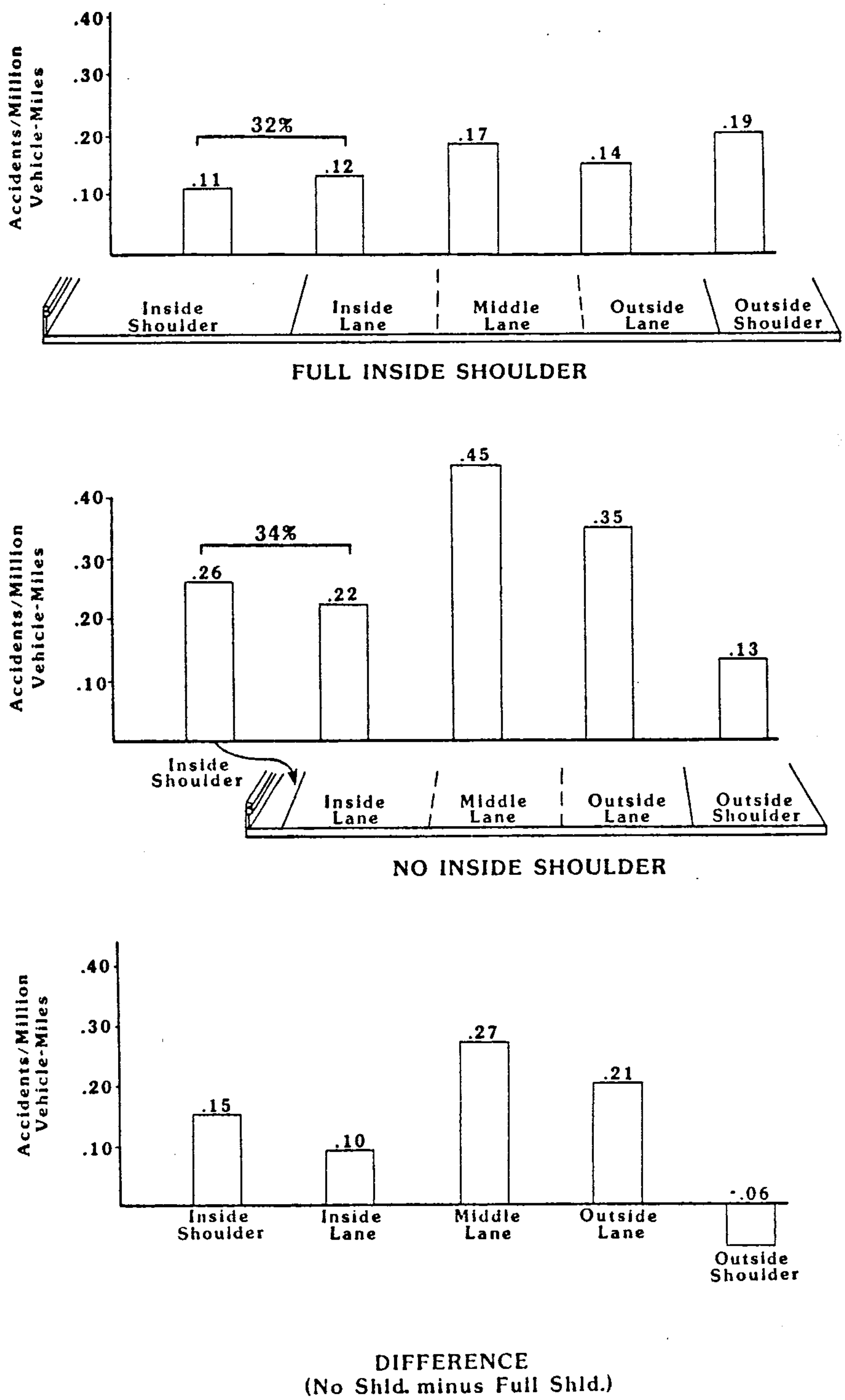


Figure 19. I-30 Accident Rates by Lane for Full versus No Inside Shoulders

Table 12. I-30 Test of Significance by Location of Accident

(No Shoulder minus Full Shoulder)

Location of Accident	Samples[1]	Mean Difference	Standard Error of Mean Diff.	T-Value	Probability of[2] Greater |T|
Inside Shoulder	4	0.149	0.034	4.33	0.02*
Inside Lane	4	0.102	0.049	2.11	0.135
Middle Lane	4	0.273	0.034	8.14	0.004**
Outside Lane	4	0.207	0.058	3.54	0.048*
Outside Shoulder	4	-0.065	0.035	-1.87	0.16

[1]Each sample provides the accident rate difference in one year.

[2]One asterisk (*) statistically means significant at the 0.05 level, and two asterisks (**) statistically mean very significant at the 0.01 level.

The middle lane of the segment with no inside shoulders had a much higher rate than the middle lane of the segment with full inside shoulders; it was significant at the 0.01 level. The rate was 0.45 acc/mvm for the segment with no inside shoulders and 0.22 acc/mvm for the segment with full inside shoulders. Figure 19 shows the above rates and the difference of 0.27 acc/mvm. There is no apparent cause for such a difference.

The outside lanes of the segment with no inside shoulders also had a higher rate than the same lanes of the segment with full inside shoulders, significant at the 0.05 level. Figure 16 shows the respective rates and the difference of 0.21 acc/mvm. There is no apparent reason for this difference, but ramp weaving may be a factor.

It would appear that the difference in accidents between sections is the result of differences in traffic and roadway factors in general given that significant differences in accident rates occur at several cross section locations.

Figure 20 shows I-30 accident rates by lane location for the segment with full inside shoulders and for the segment with partial inside shoulders.

Table 13 shows the T-tests for each lane location and shows that none is significantly different. From the T-tests it can be inferred that lane accident rates within the segment with partial inside shoulders are not different from those in the segment with full inside shoulders.

Table 13. I-30 Test of Significance By Location of Accident

(Partial Shoulder minus Full Shoulder)

Location of Accident	Samples[1]	Mean Difference	Standard Error of Mean Diff.	T-Value	Probability of[2] Greater |T|
Inside Shoulder	4	-0.038	0.024	-1.62	0.20
Inside Lane	4	-0.025	0.048	-0.51	0.65
Middle Lane	4	0.051	0.036	1.40	0.26
Outside Lane	4	-0.070	0.028	-2.52	0.09
Outside Shoulder	4	-0.011	0.012	-0.94	0.42

[1]Each sample provides the accident rate difference in one year.

[2]One asterisk (*) statistically means significant at the 0.05 level, and two asterisks (**) statistically mean very significant at the 0.01 level.

From Figure 20, the inside shoulder of the segment with partial inside shoulders has a rate of 0.07 acc/mvm, compared to 0.11 for the segment with full inside shoulders. The inside lane of the segment operating with partial inside shoulders has a rate of 0.10 acc/mvm compared with 0.12 for the segment with full inside shoulders. The partial shoulder section appears to function as well as the full shoulder section.

US 59, Houston. Figure 21 shows accident rate distributions for the two segments operating before with full inside shoulders and after with partial inside shoulders. The segment with full inside shoulders has an inside shoulder rate of 0.14 acc/mvm, while the segment with partial inside shoulders has a rate of 0.22 acc/mvm for a difference of 0.08. This is not a significant difference, as shown in Table 14. The inside lane difference is even smaller at 0.01 acc/mvm.

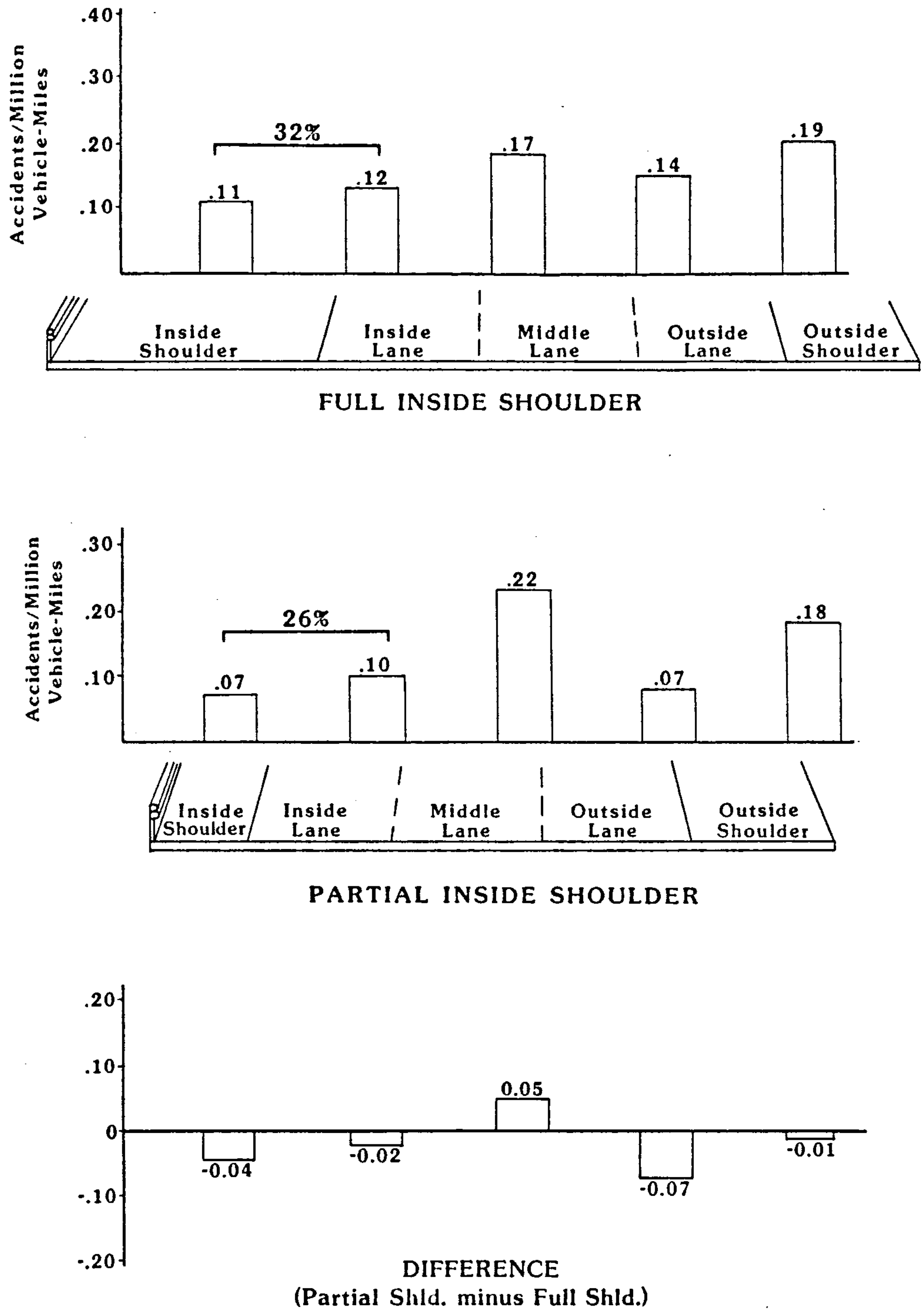


Figure 20. I-30 Accident Rates by Lane for Full vs. Partial Inside Shoulder

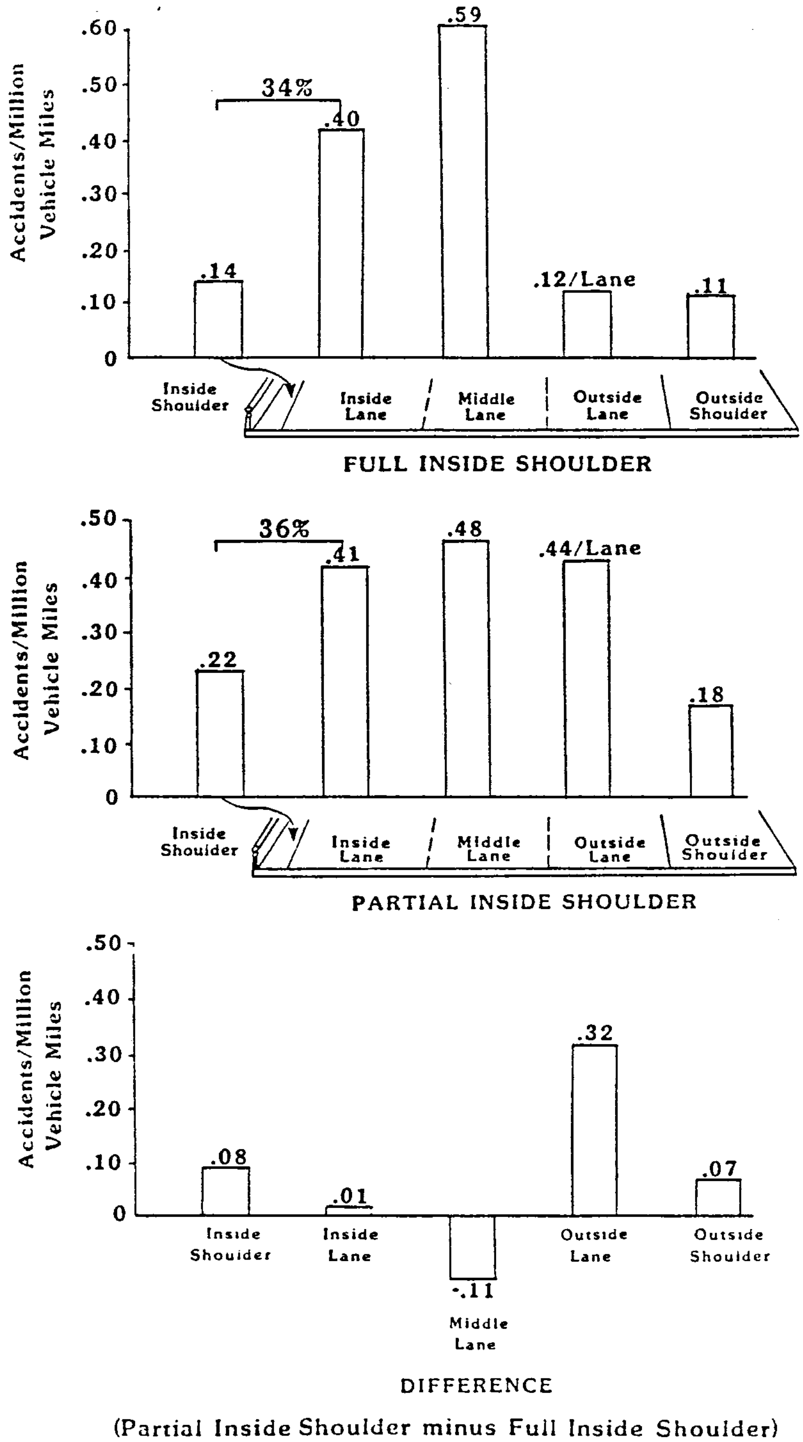


Figure 21. US 59 Accident Rates by Lane

Table 14. US 59 Test of Significance by Location (Partial Shoulder versus Full Shoulder)

Location of Accident	Inside Shoulder	Samples	Mean	Standard Error	T-Value	Probability Greater 1T1
Inside Shoulder	Partial	5	0.218	0.058	1.23	0.26
	Full	5	0.143	0.019		
Inside Lane	Partial	5	0.412	0.051	0.13	0.90
	Full	5	0.405	0.016		
Middle Lane	Partial	5	0.477	0.055	-1.76	0.12
	Full	5	0.590	0.033		
Outside Lanes/	Partial	5	0.455	0.067	4.6	0.008**
/Lane[3]	Full	5	0.123	0.018		
Outside Shoulder	Partial	5	0.182	0.018	3.29	0.011*
	Full	5	0.112	0.011		

[1]Each sample provides the accident rate for one year.

[2]One asterisk (*) statistically means significant at the 0.05 level, and two asterisks (**) statistically mean very significant at the 0.01 level.

[3]The number of outside lanes is different on the two sections, so the analysis is performed on a per lane basis.

The only significant differences are found on the outside lane and outside shoulders. The segment with full inside shoulders has a rate of 0.11 while the section with no inside shoulders shows a rate of 0.18 for a difference 0.07. The outside lane for the segment provided with full inside shoulders had a rate per lane of 0.12 as compared with a rate of 0.45 for the partial shoulder section. These differences would not be related to the less than full width inside shoulder.

I-610, Houston. Figure 22 shows accident rate distribution for before and after on this segment. The inside shoulder rate before improvements to take inside shoulders to add capacity was 0.25 acc/mvm. After improvements,

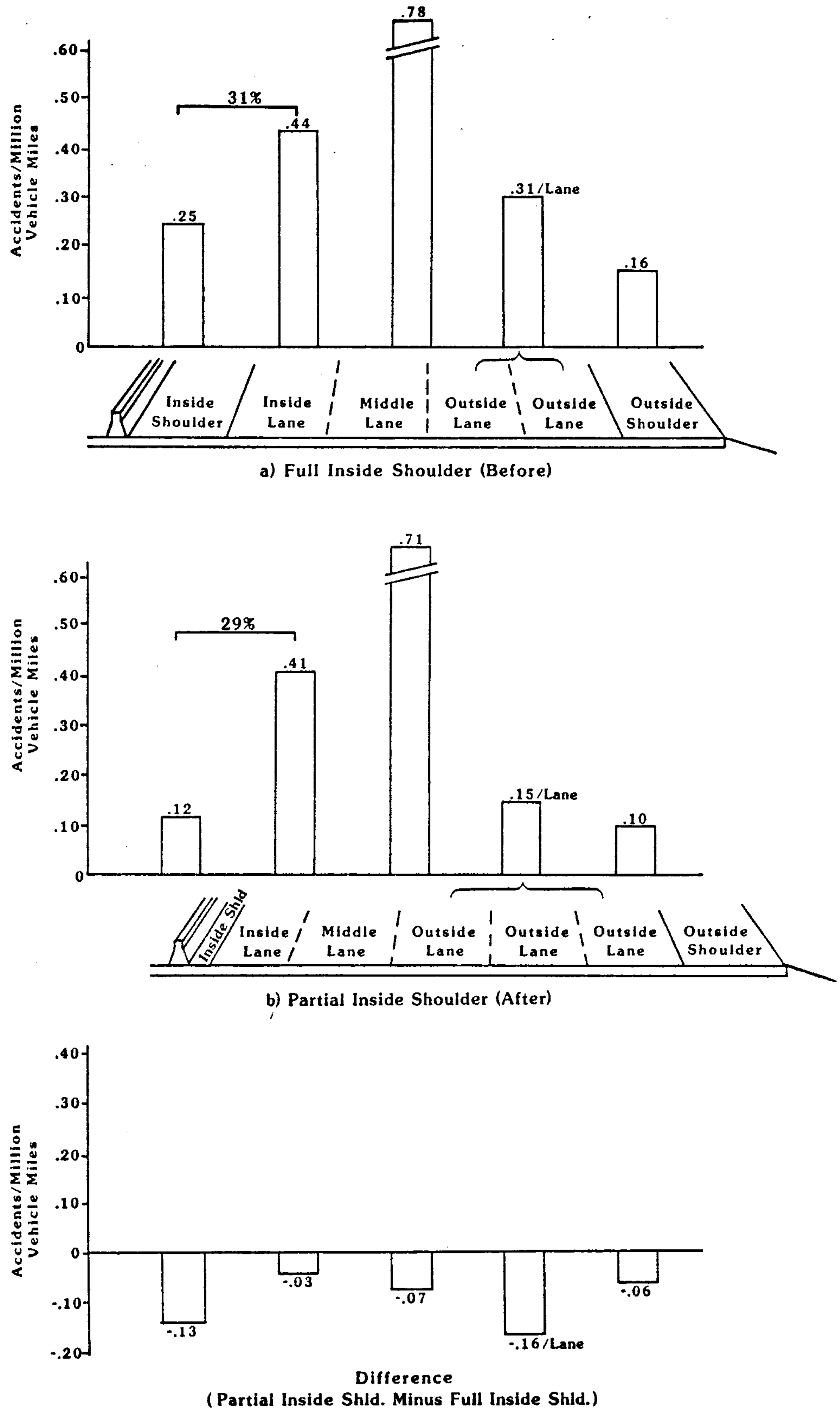


Figure 22. I-610 Accident Rates by Lane

it went down to 0.12 acc/mvm or a drop of 0.13. This is significant at the 0.05 level, as shown in Table 15. The inside lane difference is smaller, a

Table 15. I-610, Houston Test of Significance by Location

(Partial Shoulder minus Full Shoulder)

Location of Accident	Inside Shoulder	Samples[1]	Mean	Standard Error	T	Probability of Greater T [2]
Inside Shoulder	Full	4	0.250	0.037	-3.46	0.03*
	Partial	4	0.117	0.009		
Inside Lane	Full	4	0.443	0.147	-0.22	0.83
	Partial	4	0.406	0.087		
Middle Lane	Full	4	0.779	0.059	-0.69	0.52
	Partial	4	0.711	0.079		
Outside Lanes	Full	4	0.307	0.013	-8.87	0.001**
/Lane[3]	Partial	4	0.148	0.012		
Outside Shoulder	Full	4	0.158	0.024	-1.87	0.11
	Partial	4	0.100	0.021		

[1]Each sample provides the accident rate for one year.

[2]One asterisk (*) statistically means significant at the 0.05 level, and two asterisks (**) statistically mean very significant at the 0.01 level.

[3]The change from 4 directional to 5 directional lanes requires that the outside lanes be analyzed on a per lane basis.

reduction of only 0.03 acc/mvm and is not significant. Combined, the inside shoulder and inside lane accidents of the segment with full shoulders add to 31 percent of all period accidents, and to 29 percent of all period accidents after the full inside shoulders were eliminated. The above indicates that the removing of the inside shoulders to add capacity by providing inside lanes reduced accident rates along the median related lanes.

It should be noted that all other lanes went down in accident rates, although only the outer lanes are significant. The outside lane rate decreased from 0.31 acc/mvm to 0.15 acc/mvm or 52 percent. The analysis of outside lanes must be qualified by the need to adjust outside lane rates due to the variable number of lanes before and after. This adjustment is necessary because all lanes except the left lane and the adjacent lane (inside lane by definition) are considered outside lanes on the accident reports. These particular improvements were made to eliminate a bottleneck on this circumferential freeway and by doing so, the capacity and the ADT increased substantially. Based on the above it may be inferred that partially removing the inside shoulder helped to bring accident rates down without reducing safety along the median.

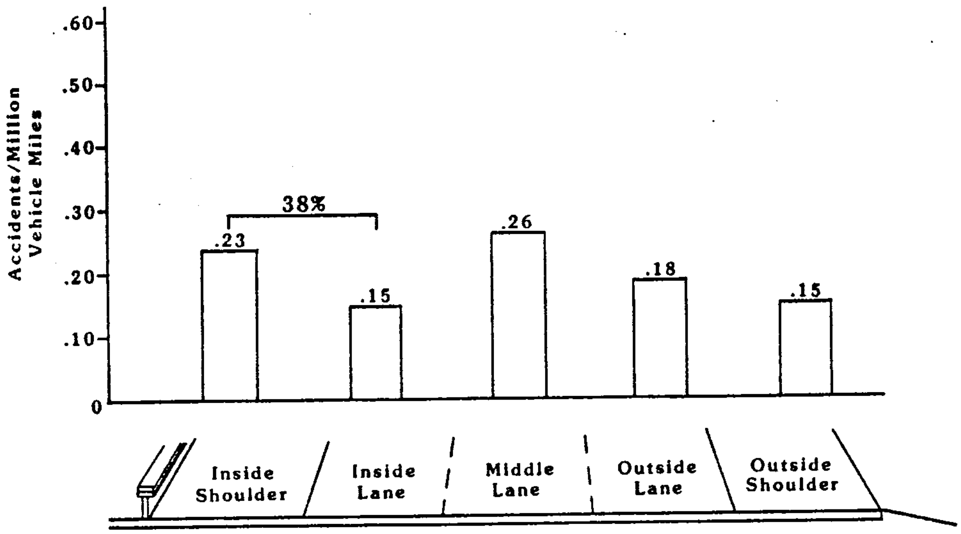
SH 286 and SH 358, Corpus Christi. Figure 23 shows accident rate distribution for these two segments, SH 286 with full inside shoulders and SH 358 with partial inside shoulders. The segment with full inside shoulders has a slightly higher inside shoulder rate at 0.23 acc/mvm, while the segment with partial inside shoulders has an inside shoulder rate of 0.18 acc/mvm. This 0.05 difference is not a significant, as observed in Table 16.

Table 16. SH 286 and SH 358, Corpus Christi Test of Significance by Location (Partial Shoulder minus Full Shoulder)

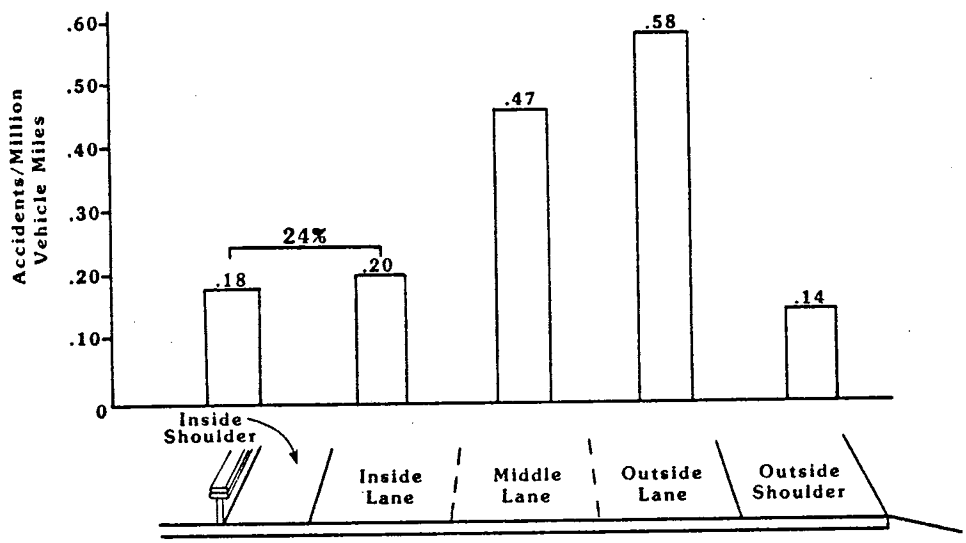
Location	Inside Shoulder	Samples[1]	Mean	Standard Error	T-Value	Probability of[2] Greater T
Inside Shoulder	Full	4	0.227	0.024	-1.09	0.32
	Partial	4	0.183	0.032		
Inside Lane	Full	4	0.146	0.035	1.50	0.18
	Partial	4	0.203	0.015		
Middle Lane	Full	4	0.261	0.056	2.92	0.03*
	Partial	4	0.474	0.046		
Outside Lane	Full	4	0.184	0.027	6.92	0.0005**
	Partial	4	0.578	0.050		
Outside Shoulder	Full	4	0.153	0.011	-0.56	0.59
	Partial	4	0.139	0.020		

[1]Each sample provides the accident rate for one year.

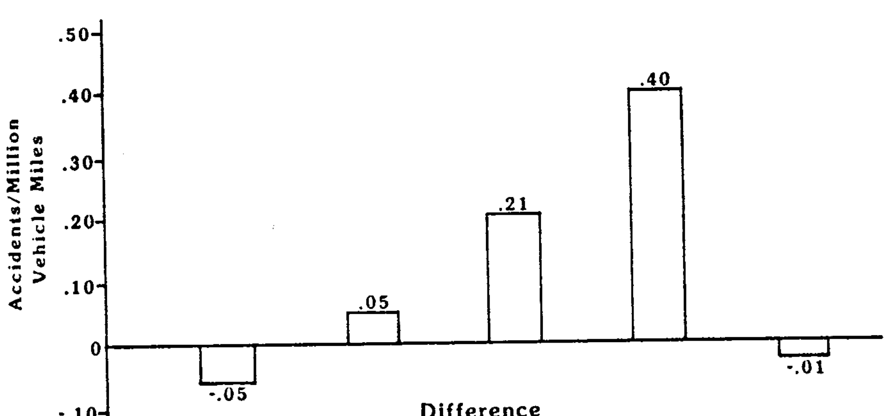
[2]One asterisk (*) statistically means significant at the 0.05 level, and two asterisks (**) statistically mean very significant at the 0.01 level.



Full Inside Shoulder (SH 286)



Partial Inside Shoulder (SH 358)



Difference
(Partial Inside Shld.minus Full Inside Shld.)

Figure 23. SH 286 and SH 358 Accidents Rates by Lane

The inside lane difference is not significant and of similar magnitude as that of the inside shoulders but reversed. Overall, the inside shoulders and lanes added have about the same accident rate for both segments.

Significant differences in accident rates are found at the middle and outside lanes (see Table 15). Together these account for 0.61 acc/mvm or 85 percent of the overall difference in accident rates. The reason for the much higher rates in the middle and outside lanes of the segment with the partial inside shoulders is not known, but accidents along the median are not directly contributing to the significant difference in overall segment rates. It would appear that the differences in overall accident rates are not shoulder related. It is likely that the difference in accidents is related to the difference in traffic conditions on the two segments. As indicated earlier, the partial shoulder section operates near capacity with an estimated peak hour volume of 1,980 vehicles per lane per hour. The partial shoulder section operates at a higher level-of-service, with the peak hour volume estimated to be 1,620 vehicles per lane per hour.

Two cases have been compared where freeway segments operate with full inside shoulders and with no inside shoulders. These cases, SH 183 and I-30 in Dallas, had significantly higher rates in one of the median related lanes (inside shoulders or inside lanes) of the segment with no inside shoulders. The cause of these differences is possible ADT effects in the SH 183 case and by other traffic factors in the I-30 case.

Four cases present freeways with partial inside shoulders versus those with full inside shoulders. The I-610 case in Houston is a before and after study and should not be directly compared with the other two cases. The I-610 case is consistent with other before and after studies (and also consistent with the California analysis which follows). I-30 in Dallas, US 59 in Houston and SH 286/SH 358 in Corpus Christi provide an interesting view of accident distribution. In terms of median related accident rates the segments with partial inside shoulders have about the same or slightly lower rates, than the segments with full inside shoulders.

The general conclusion based on the limited Texas data is that partial inside shoulders (as little as 3 ft. and no more than 6 ft.) appear to be as effective as full shoulders. No left shoulder section (2 ft. or less) results are not as definitive in that some judgment is required in interpreting the results. It is reasonable to conclude that traffic factors (primarily congestion) are the cause of accident rate differences. In the SH 183 case, the effects of ADT can be demonstrated. In the case of I-30, potential congestion effects do not appear to explain accident rate differences. However, in the I-30 case, accident rate differences are distributed across the cross section to such an extent that other traffic or roadway factors can be reasonably speculated to be a primary cause. These conclusions are consistent with the analysis of the California data presented later in the report.

Accident Severity

Another very important issue on freeway safety is the level of damages or severity associated with accidents. The availability of an inside shoulders also may affect the severity of accidents. For example, if a car stalls on the inside lane of a freeway where there is no shoulder to park the vehicle following may impact the stopped car. The following analysis suggests that changes in severity are not taking place. In this section freeway segments are compared based on the severity of accidents. The DPS defines severity in five categories. These are fatal, incapacitating injury, non-incapacitating injury, possible injury and non-injury.

A convenient way to investigate the severity of accidents is to determine the percent of each segment accidents that falls under each category. Percentages are obtained by dividing the number of accidents in each category for a given segment by the total accidents in that segment and multiplying by one hundred. Segments of the same freeway or case are then compared to detect any abnormalities that can be attributed to the availability or lack of inside shoulders. Emphasis is placed on severe accidents, those resulting in fatal and incapacitating injuries, since these have a greater social and economic cost. Bar charts pairing segments have been used to graphically describe accident distribution by severity for each case studied.

Severity Distributions. Figures 24-29 show the cases investigated comparing segments with full inside shoulders against those with partial or no inside shoulders.

On SH 183 (Figure 24) the two segments are very similar in all categories. Fatalities constitute less than half a percent while incapacitating accidents are about six percent. These two categories combined, herein defined as serious accidents, add to 6.8 and 5.8 percent for the full inside shoulder and the no inside shoulder segments, respectively. Non-incapacitating, possible injuries and non-injury categories constitute the balance. The non-injury accidents, commonly called "property damage only" are well over half of all accidents.

On I-30 (Figure 25), fatalities and incapacitating accidents add to 8.9 percent on the segment with full inside shoulders and to only 5.1 percent in the segment with no inside shoulders. Differences may be significant but there is insufficient data for a more rigorous statistical analysis. However, like SH-183, serious accidents are a lower percent of all segment accidents on the segment operating with no shoulders.

I-610 (Figure 26) shows the same relationship. Fatal accidents are slightly higher on the segment with no inside shoulder, but serious accidents are a lower percent of all segment accidents (in this case, the same segment but before and after). The I-30 (Figure 27) serious accidents on the segment with full inside shoulders add to 8.9 percent while the segment with partial inside shoulders show 7.1 percent. In Corpus Christi (Figure 28), the segment with full inside shoulders reflects 5.5 percent of all accident being serious while on the segment with the partial inside shoulders this percentage adds to 3.4.

Looking at US 59 (Figure 29), fatalities are slightly higher for the section with partial inside shoulders, but combined serious accidents are a lower percent. That is, they add to 4.4 percent on the segment with full inside shoulders and to 4.0 percent for the segment with partial inside shoulders.

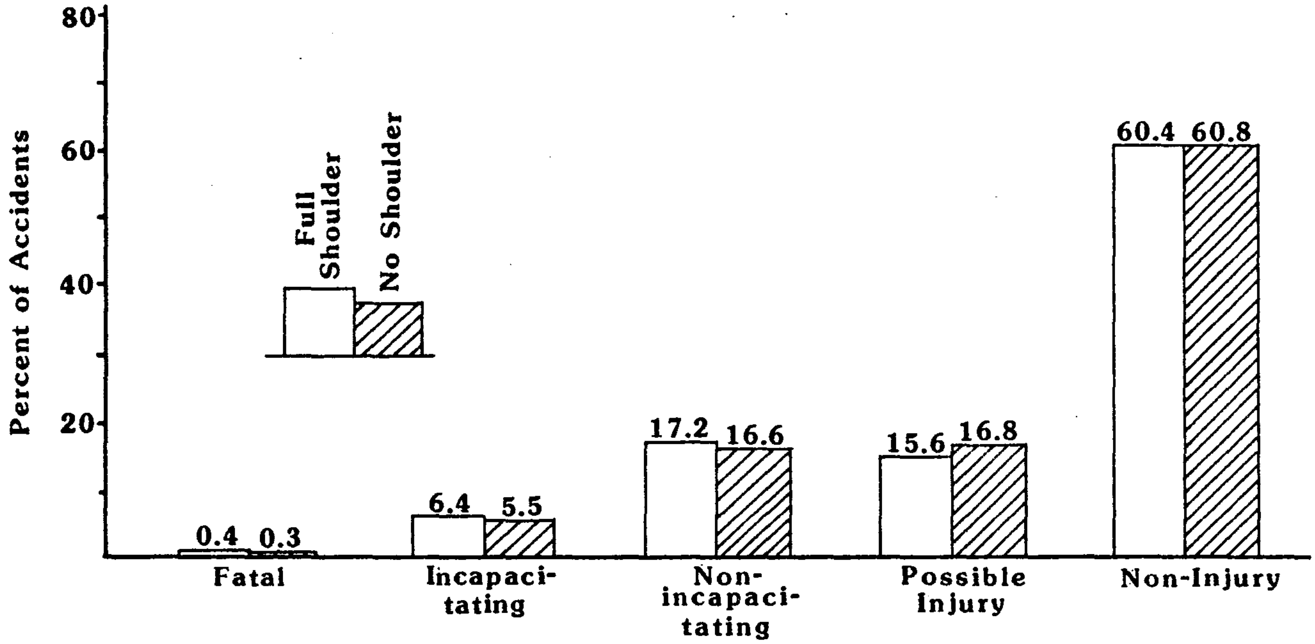


Figure 24. SH 183 Severity as a Percent of Segment Accidents, Dallas

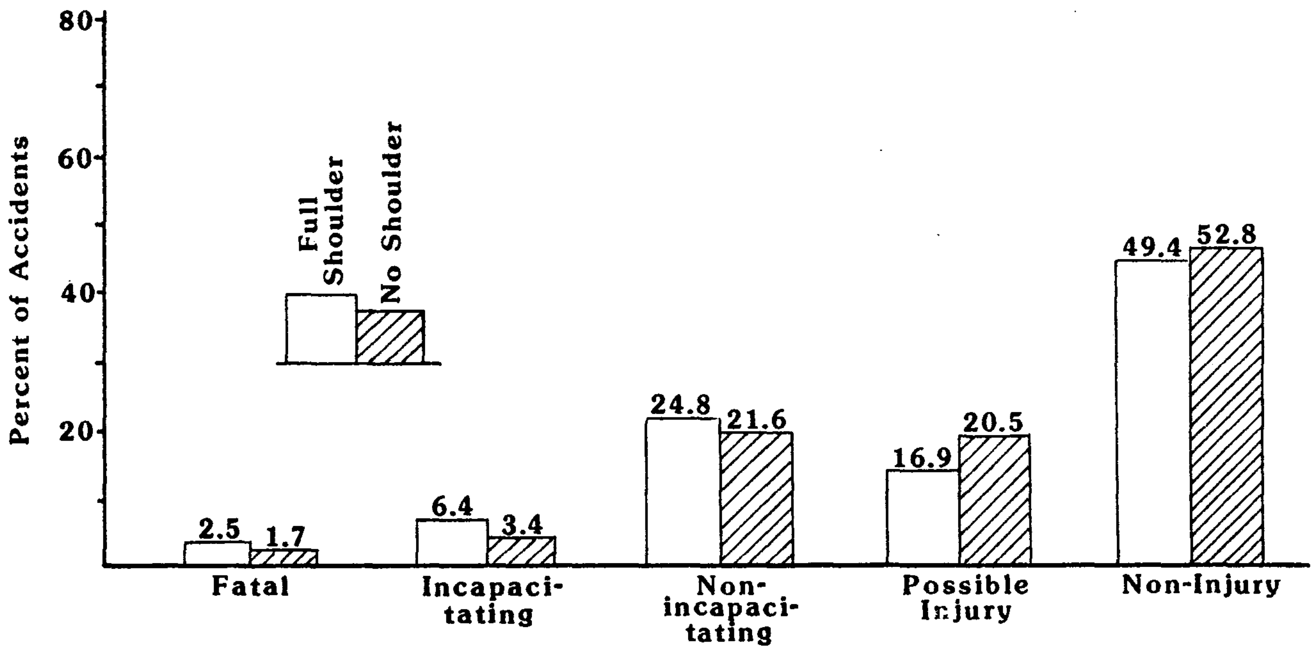


Figure 25. I-30 Severity as a Percent of Segment Accidents, Dallas

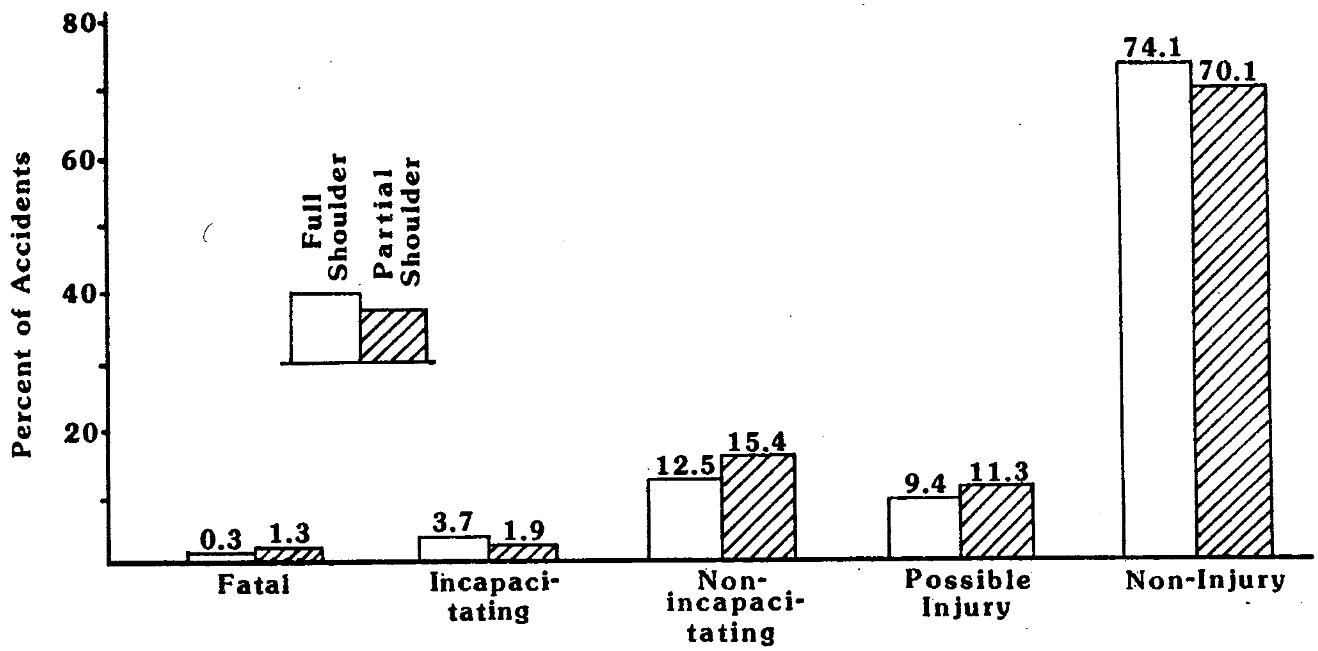


Figure 26. I-610 Severity as a Percent of Segment Accidents, Houston

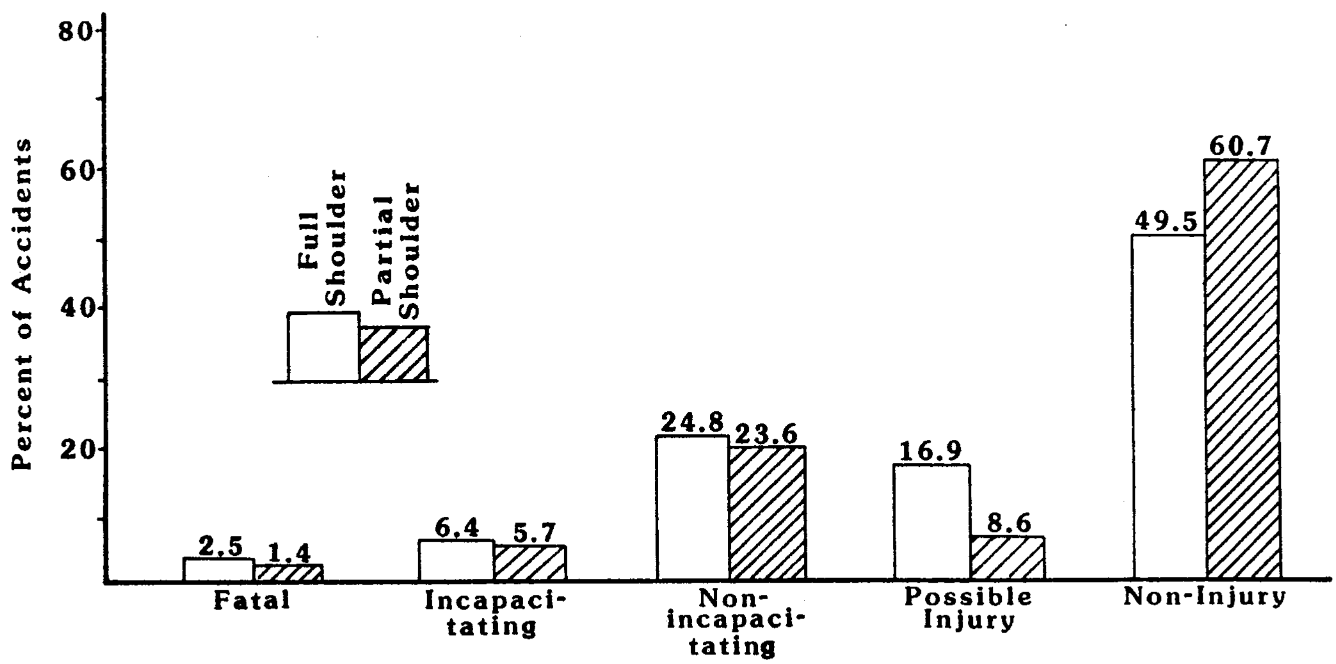


Figure 27. I-30 Severity as a Percent of Segment Accidents, Dallas

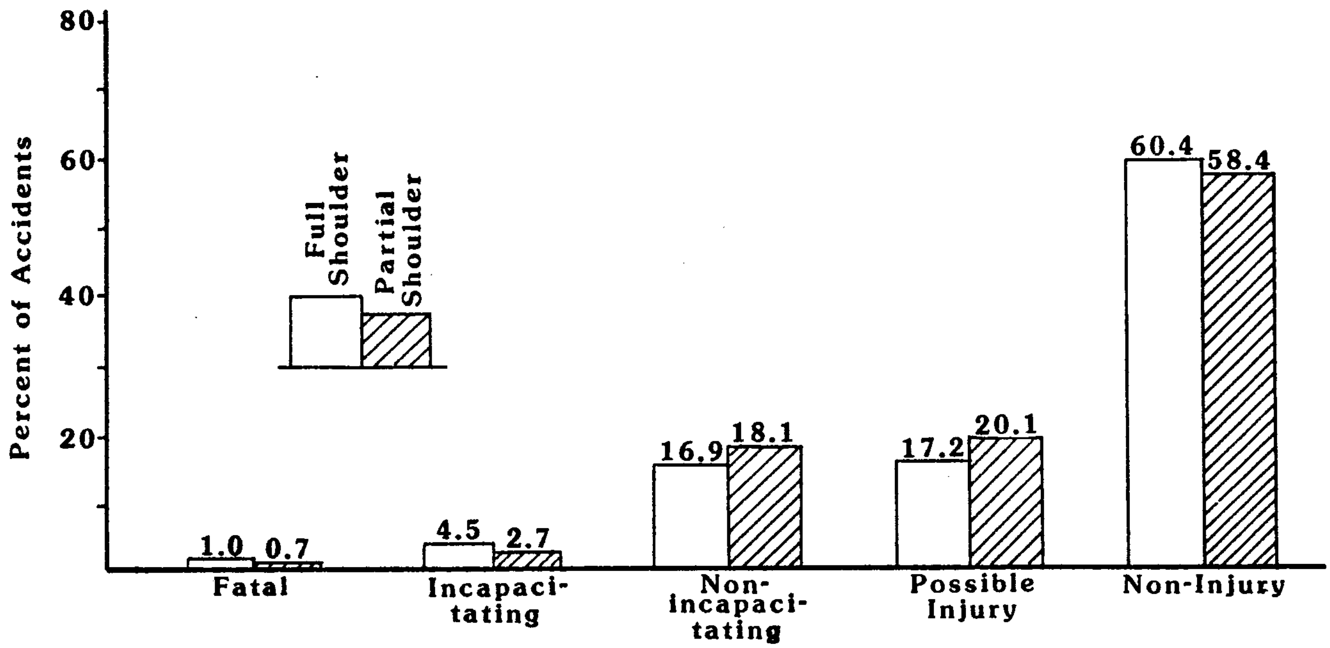


Figure 28. SH 286 and SH 358 Severity as a Percent of Segment Accident, Corpus Christi

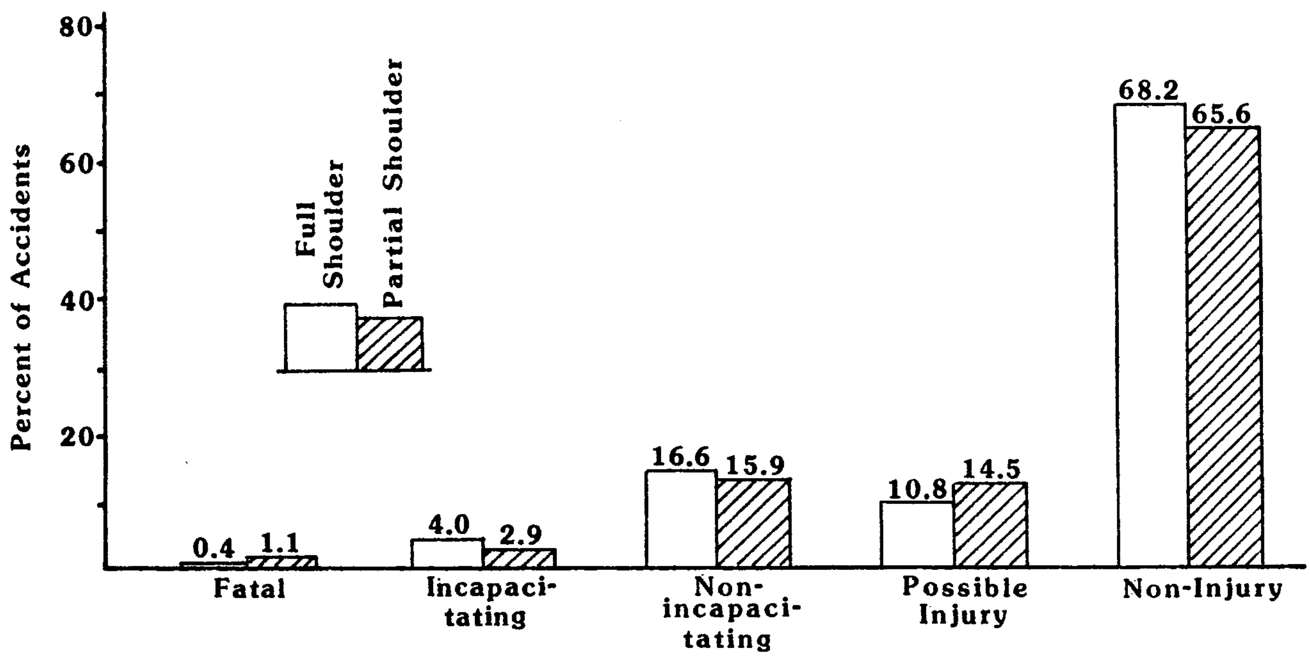


Figure 29. US 59 Severity as a Percent of Segment Accidents, Houston

The above perspective, although simplistic, indicates that partial or no inside shoulders do not have a negative effect on the distribution of serious accidents. It is likely that serious accidents are a small percentage of total accidents because the sections with higher accident rates are the result of congestion caused accidents. A more precise way of looking at severity is based on rates, but this method also has some limitations, specifically the variability introduced by the use of ADT. The percentage method used above eliminates that drawback. Severity rates are presented in the next section.

Severity Rates. Severity rates, based on the ratio of accidents to vehicle miles of travel, allow for direct comparisons between segments of the same freeway with different shoulder treatments. Figure 30 displays the accident rate by severity category for the segments with and without inside shoulders on SH 183. The number of fatal accidents is less than 0.005 per million vehicle miles in either segment. Serious accidents, incapacitating injuries together with fatalities, constitute 0.063 acc/mvm on the segment with full inside shoulders and 0.007 acc/mvm on the segment with no inside shoulders. Thus, the segment with no inside shoulders shows a rate about 22 percent higher. From Figure 30 it is evident that the majority of accidents are non-serious, but the segment operating with no inside shoulders shows the higher rates. Looking at Figure 31, the difference in accident rates between the segment with full inside shoulders and that with no inside shoulders can be seen. Ninety-six percent of the difference in accident rates between those segments is attributed to non-serious accidents. Serious accidents contribute .014 acc/mvm, or about 4 percent of a total difference of 0.379 acc/mvm.

Figure 32 presents accident severity rates for I-30. Fatal accidents are higher on the segment with no inside shoulders; however, serious accidents are not that different. Serious accidents add to 0.066 acc/mvm on the segment with full inside shoulders and to 0.072 on the segment with no inside shoulders. The rate of the segment with no inside shoulders is about 8 percent higher. Figure 33 portrays the difference for all severity categories. Over 99 percent of the difference is attributed to non-serious

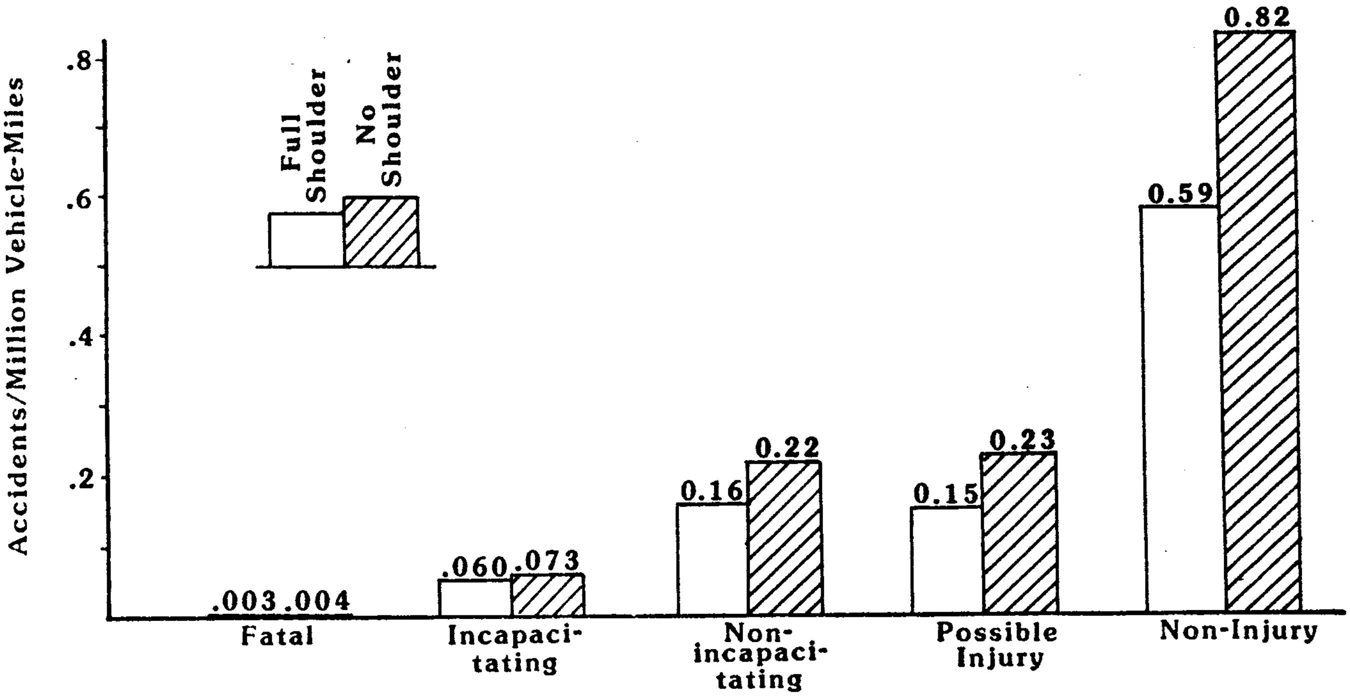


Figure 30. SH 183 Overall Accident Severity Rates by Category

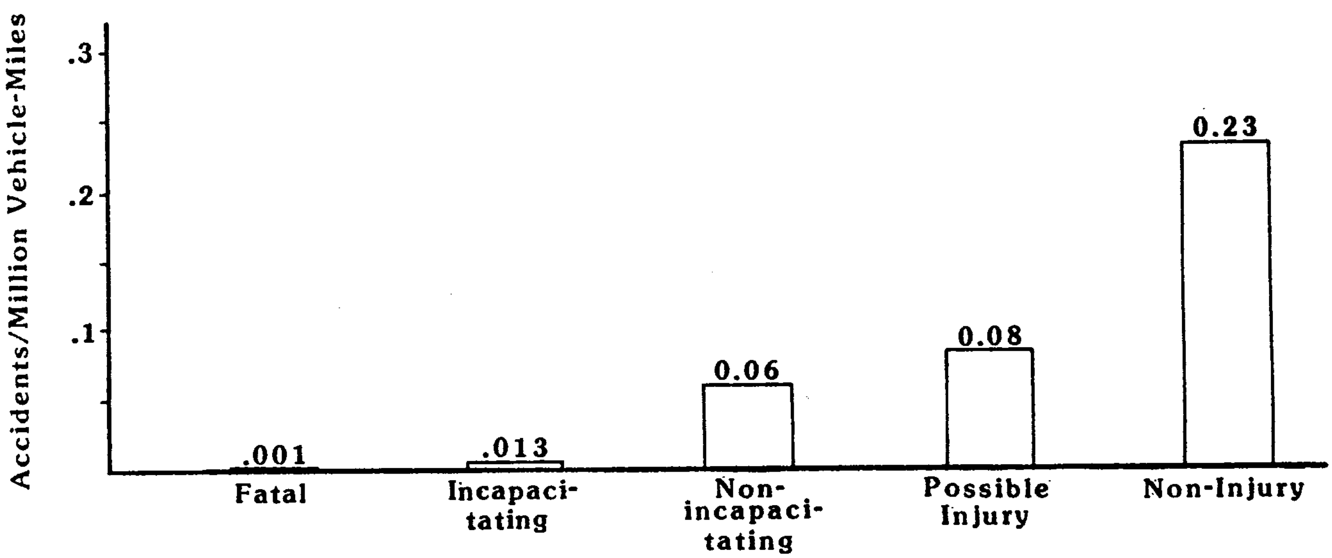


Figure 31. SH 183 Severity Rates, by Segment No Shoulder minus Full Shoulder

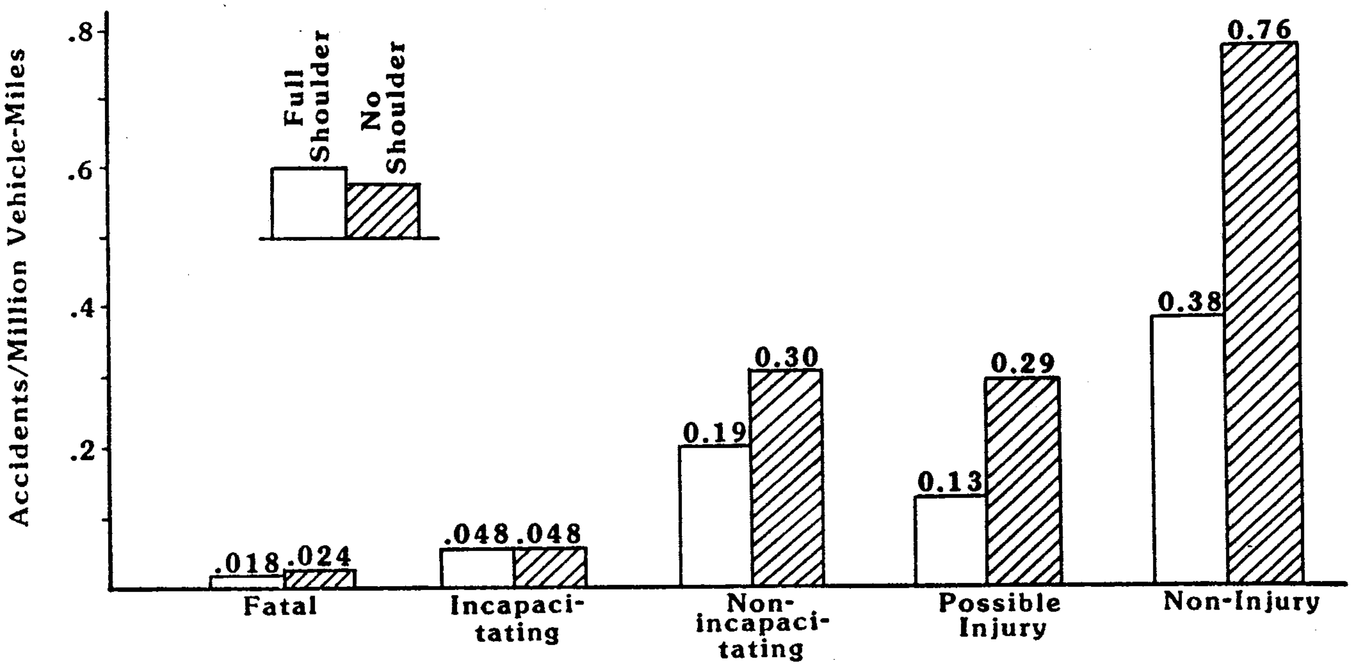


Figure 32. I-30 Overall Accident Severity Rate

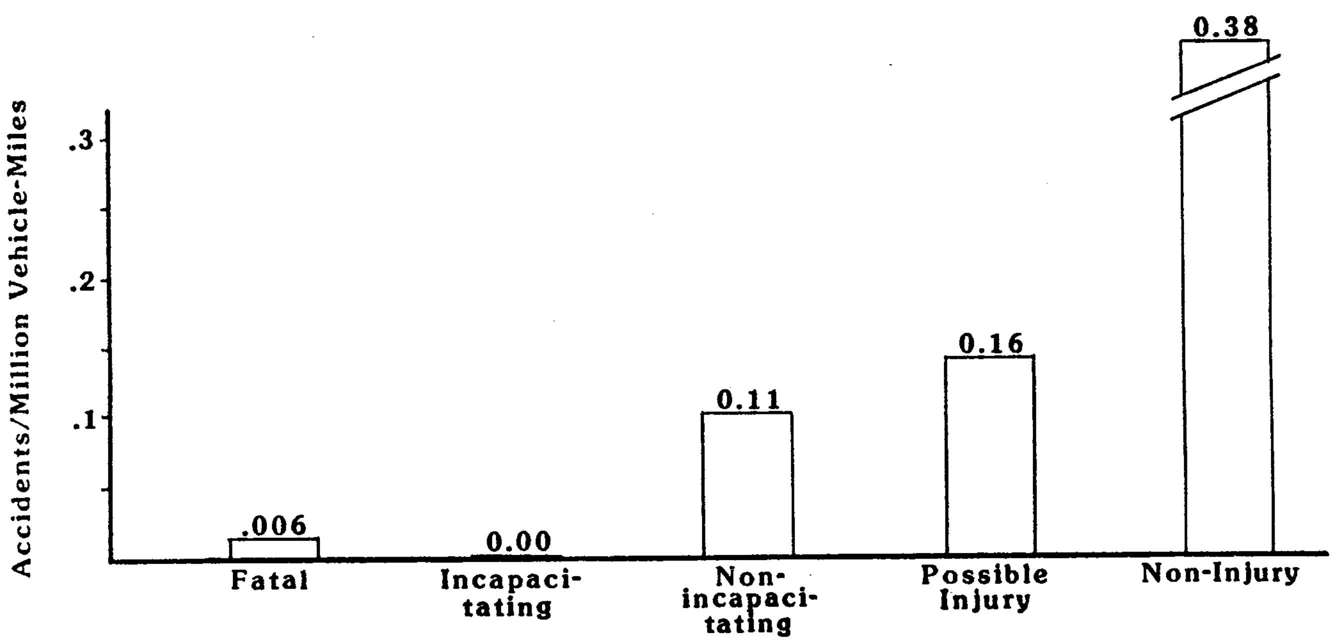


Figure 33. I-30 Severity Rate Differences Between Segments No Shoulder minus Full Shoulder

accidents since serious accidents contribute only .006 acc/mvm out of a total difference of 0.769.

Severity rates for I-610 are shown in Figure 34. Once more, fatal accidents are shown to occur at a higher rate on the segment with no inside shoulders. Yet, in this case there is a considerable difference in serious accident rates. Serious accidents add to 0.091 acc/mvm on the segment with full inside shoulders and to 0.058 acc/mvm on the segment with no inside shoulders. The serious accident rate of the segment with full inside shoulders is 57 percent higher. Figure 35 portrays the differences in more detail. Notice that most of the difference is due to non-serious accidents, in specific to the non-injury category.

Figure 36 presents accident severity rates for I-30. Fatal accident rates decline (see Figure 37) with the use of partial inside shoulders. Other categories also decline. Serious accident rates add to 0.066 acc/mvm on the segment with full inside shoulders and to 0.045 acc/mvm on the segment with the partial inside shoulders. The serious accident rate of the segment with partial inside shoulders is about 32 percent lower, and this may be significant. Also, the reduction in serious accident rate contributes 0.021 acc/mvm out of a total of 0.111 or 19 percent of the total difference.

Severity rates for SH 286 and SH 358 are shown in Figure 38. Fatal accidents slightly increase with the use of partial inside shoulders. As will be shown later, this is due to only one more fatal accident. Serious accidents add to 0.057 acc/mvm on the segment with full inside shoulders and to 0.058 acc/mvm on the segment with partial inside shoulders. The difference is very small and negligible. Looking at Figure 39, the nature of the accident rate increase that makes the segment with partial inside shoulders significantly higher can be easily discerned, that is, non-serious accidents.

Severity rates for US 59 are shown in Figures 40 and 41. Fatal accidents are higher for the segment with no inside shoulder than for the segments with full inside shoulders. Nevertheless, both segments have the same

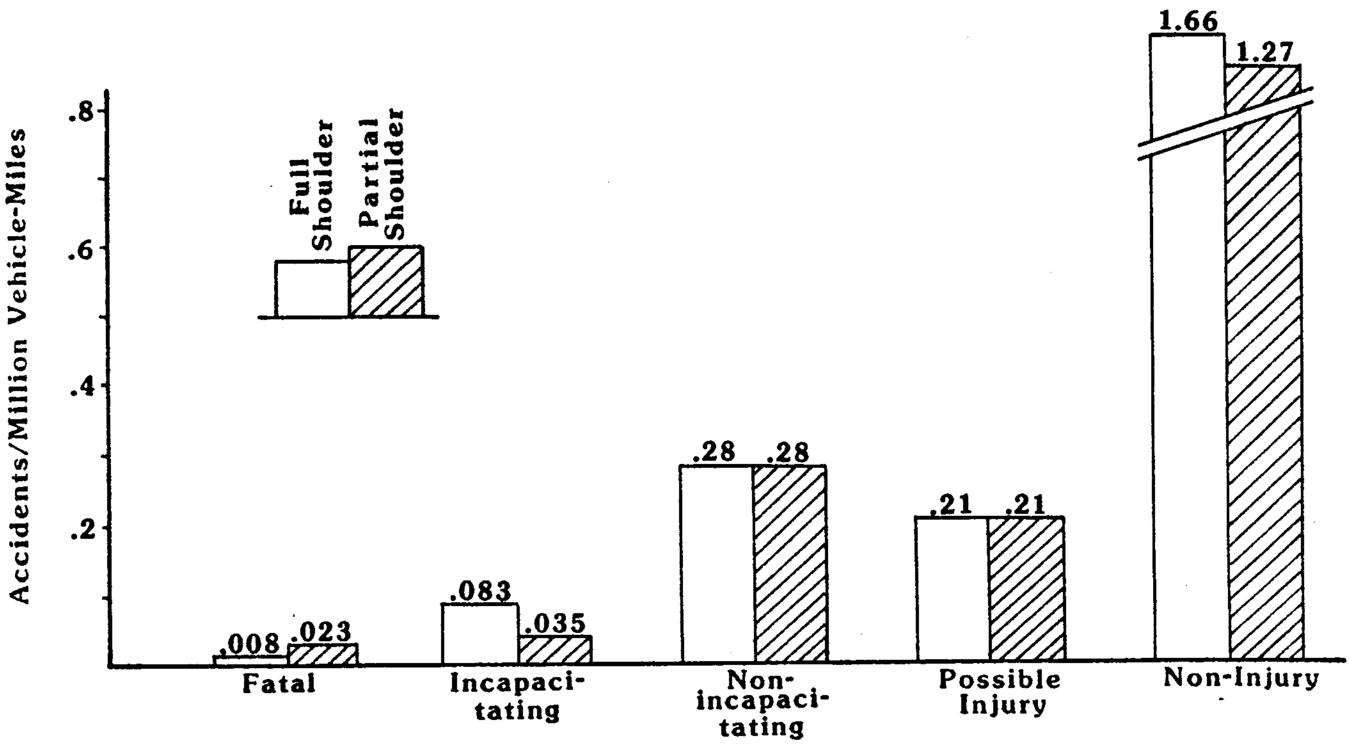


Figure 34. I-610 Overall Accident Severity Rates by Category

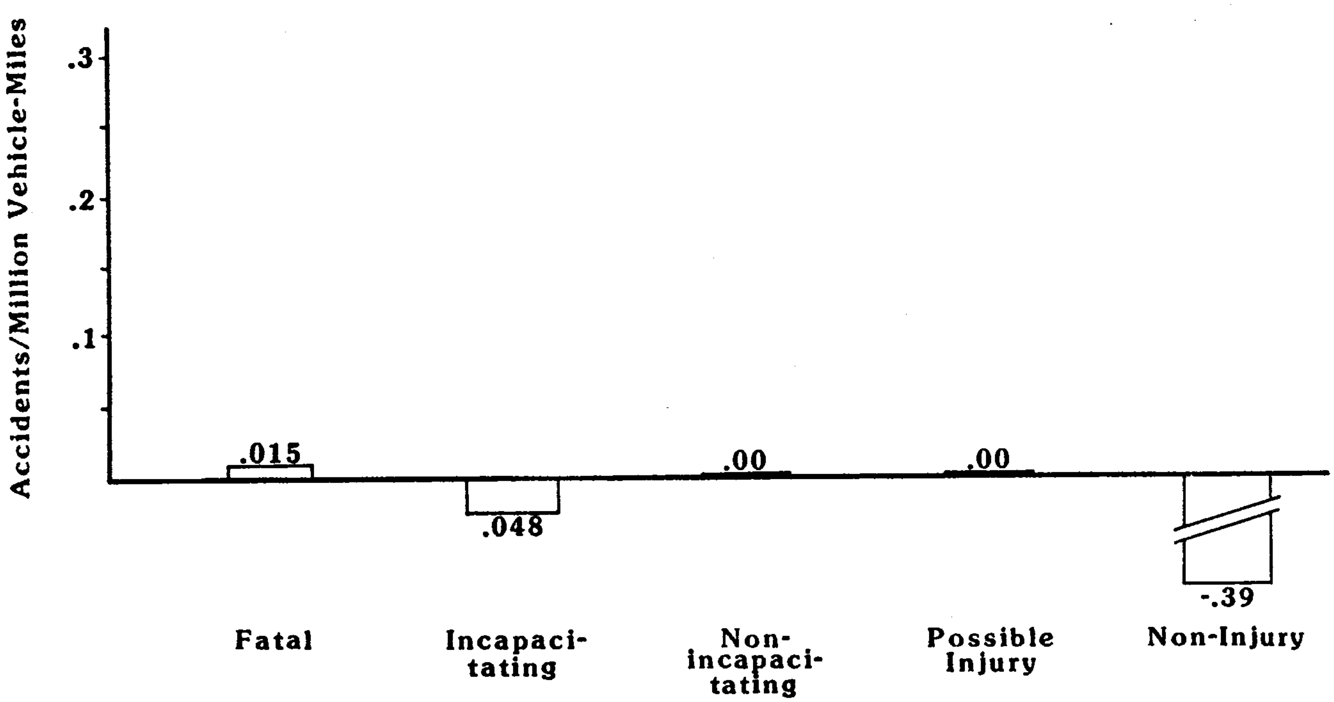


Figure 35. I-610 Severity Rate Differences Between Segments
Partial Shoulder minus Full Shoulder

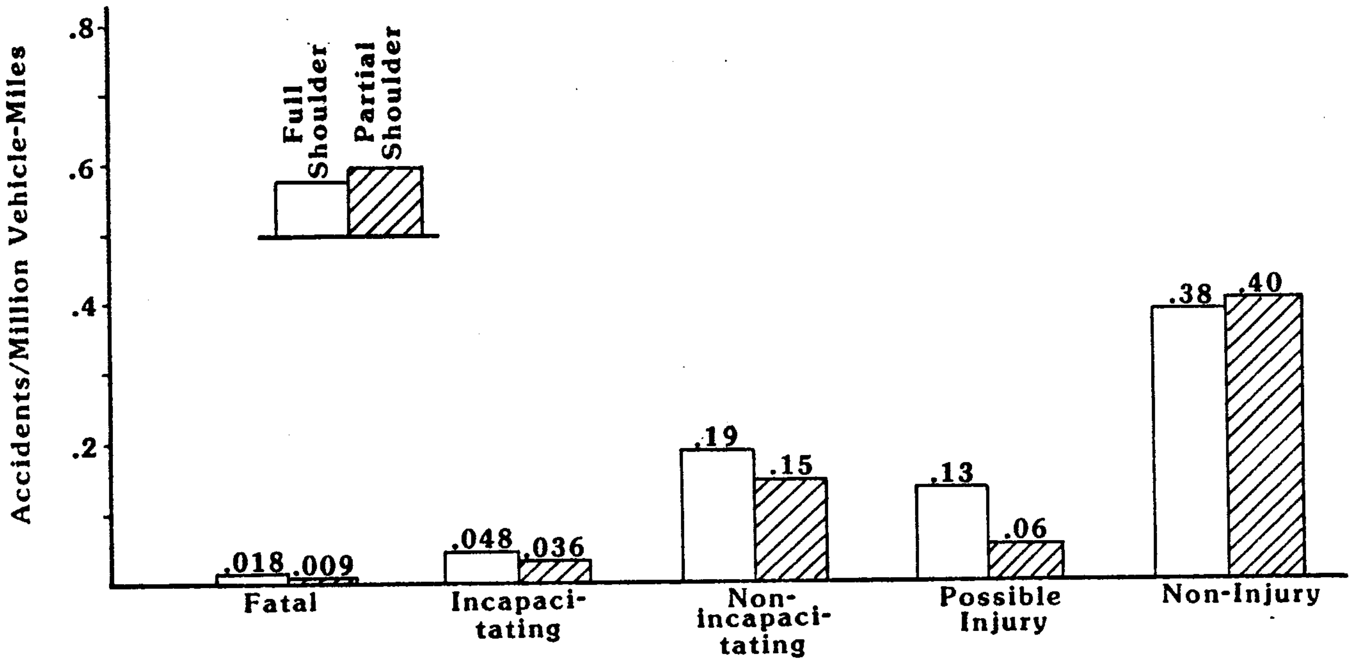


Figure 36. I-30 Overall Accident Severity by Category

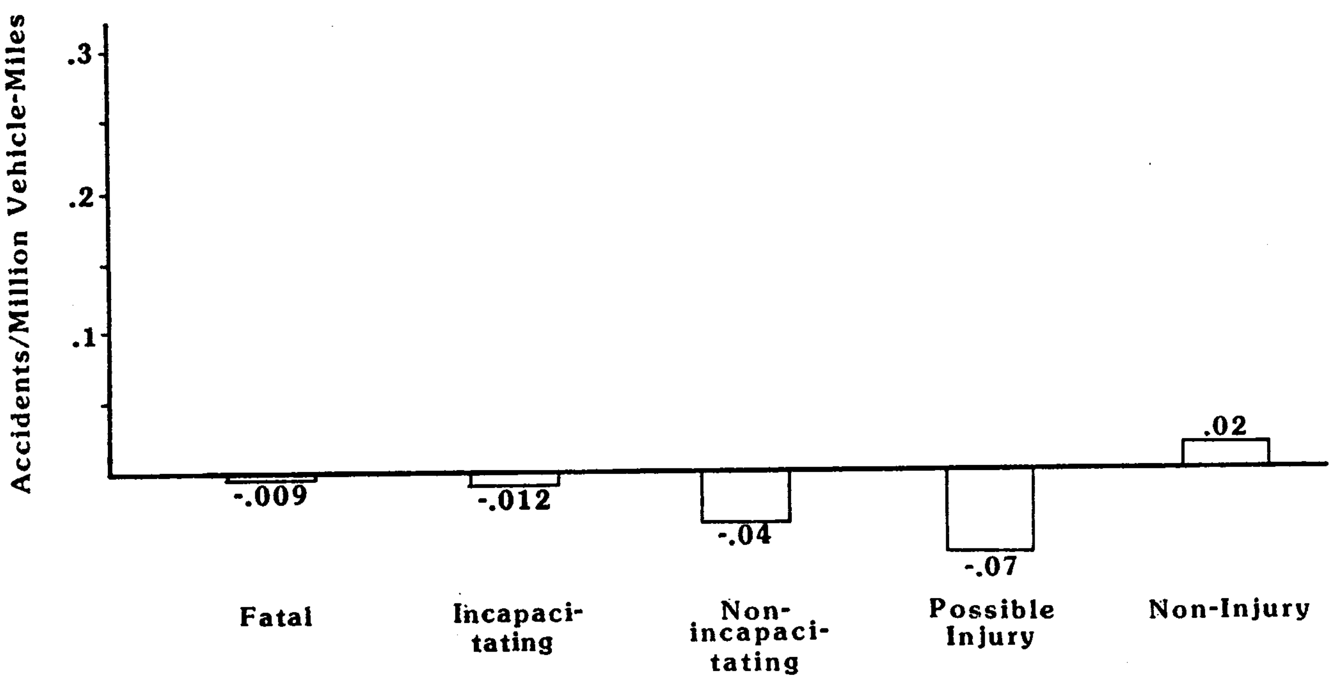


Figure 37. I-30 Accident Severity Differences Between Segments
Partial Shoulder minus Full Shoulder

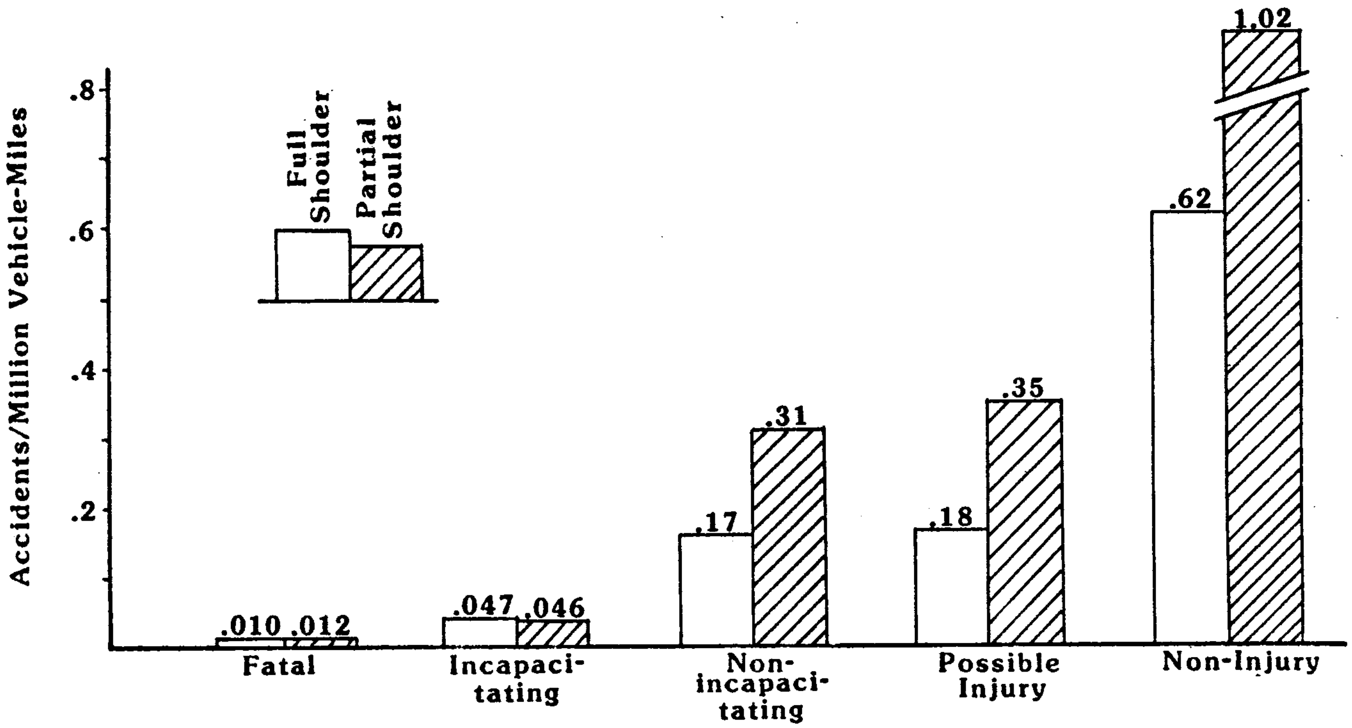


Figure 38. SH 286 and SH 358 Accident Severity Rates by Category

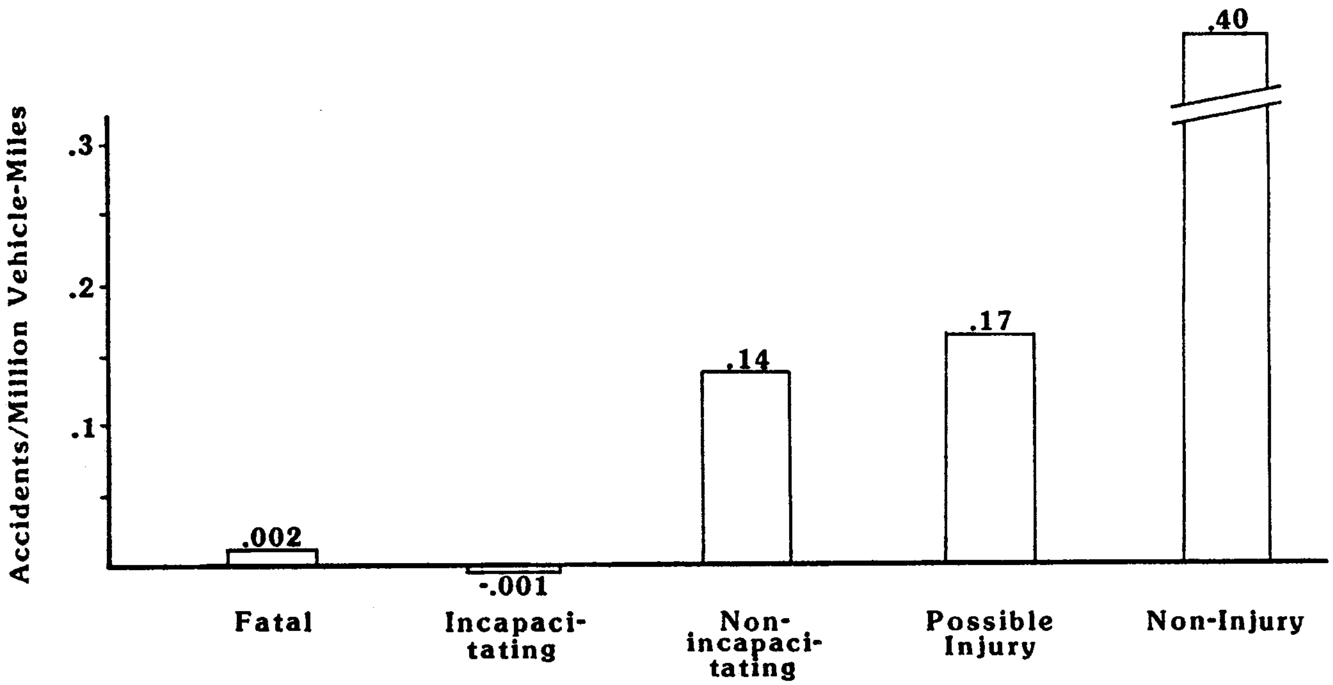


Figure 39. SH 286 and SH 358 Accident Severity Differences Partial Shoulder minus Full Shoulder

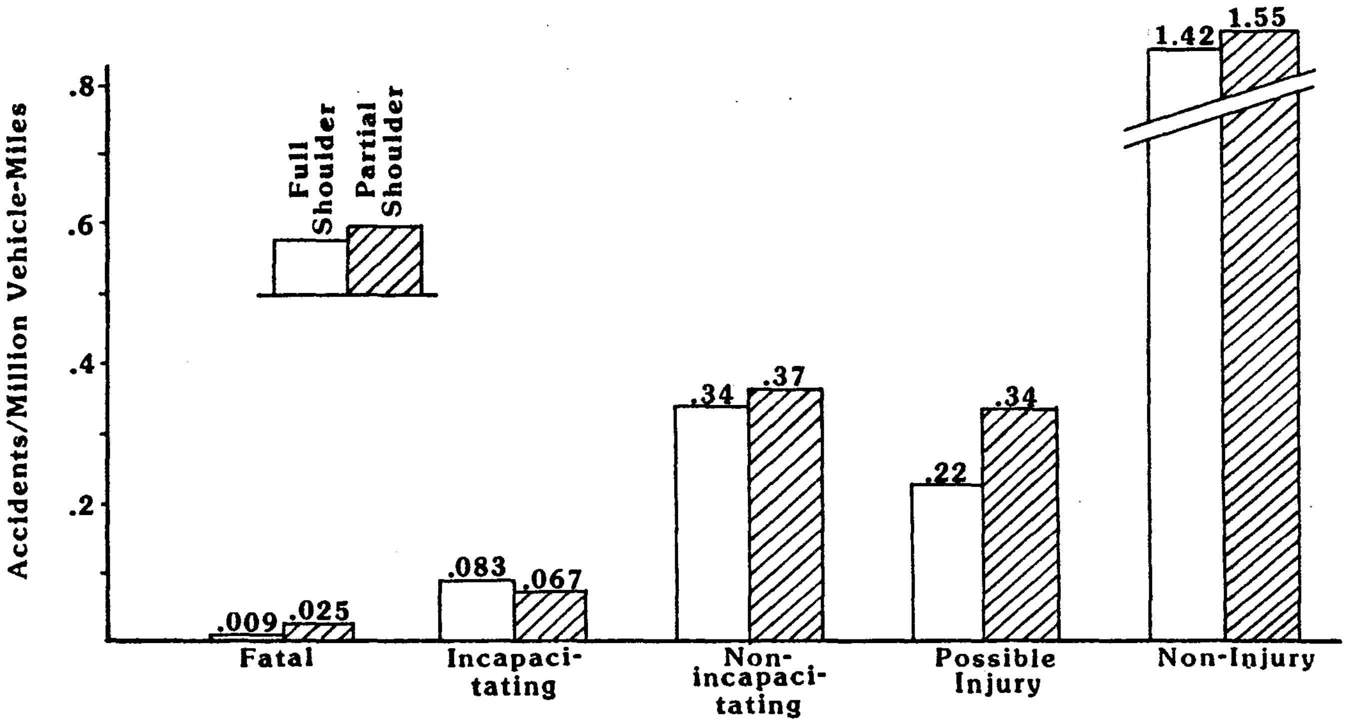


Figure 40. US 59 Accident Severity Rates by Category

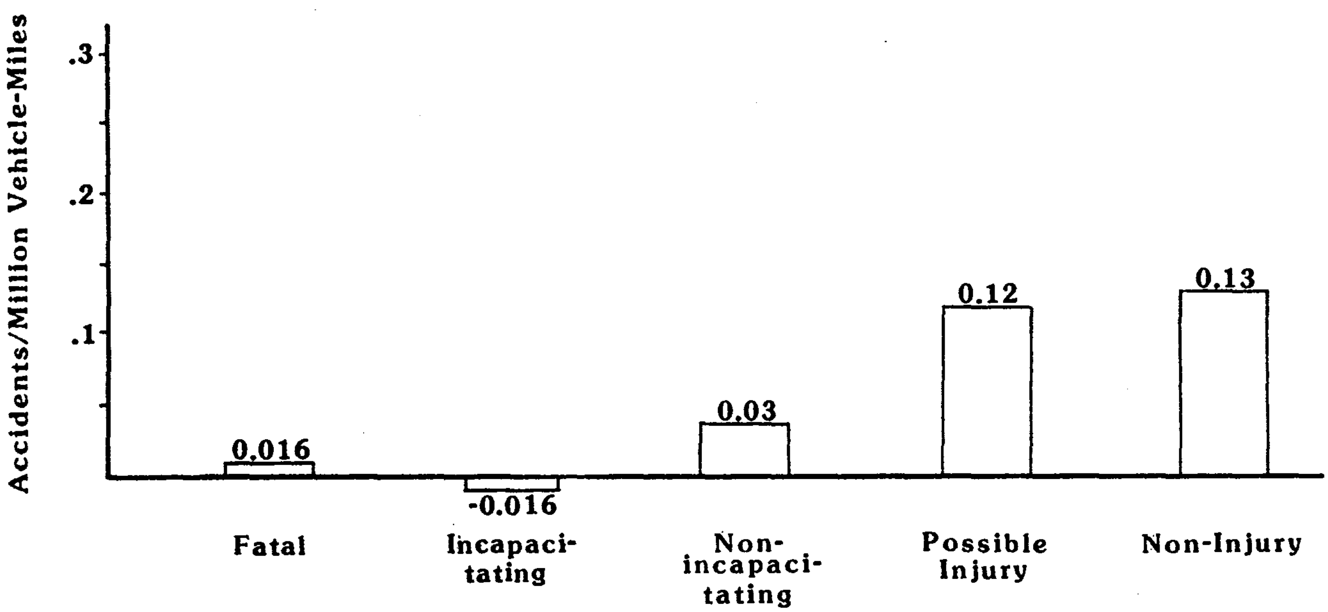


Figure 41. US 59 Accident Severity Rate Differences No Shoulder minus Full Shoulder

rate of serious accidents, 0.092 acc/mvm. Since there is no difference, serious accidents do not contribute to the difference in accident rates.

Accident severity rates seem to indicate that fatalities and incapacitating injuries are independent of conclusions drawn on the safety of inside shoulders based on overall accidents. Based on this analysis it seems likely that serious accidents are independent of the presence of inside shoulders. However, severe accidents are rare event within the study segments, and the few observations available from DPS files do not permit more powerful statistical tests. An analysis of accident rates by severity of accidents occurring solely on the inside shoulder and inside lane would be desirable but the number of reported accidents is very limited. Nevertheless, further understanding of those subcategories may be gained by looking at the frequency of selected type accidents.

Infrequent Accidents By Lane

To understand the nature of specific accident types such as those involving pedestrians, it is desirable to break down observations by lane and severity. Unfortunately, the more the accidents are subdivided, the fewer the number of recorded accidents, and the fewer the number of samples that can be obtained to perform statistical analyses. Tables 17 through 21 present the frequency of accidents involving pedestrians, parked cars or resulting in fatalities. Segment observations are summarized for the selected period of time by each shoulder treatment.

Several subjective generalizations can be made looking at these tables as a group. First, in each group there are many empty cells or lack of accident observations. Most are shown as single digit observations reflecting five or less accidents. For obvious reasons, little can be done to perform rigorous statistical tests. Second, except for accidents involving parked vehicles on outside shoulders, lane location seems random, and the effect of any particular shoulder treatment is unpredictable based on available observations. Third, when inside shoulders and inside lanes are combined, more observations of these "rare" type accidents show up for full inside shoulder segments than for no inside shoulder segments (13 against 8).

Table 17. SH 183 Infrequent Accidents (1980-1983)

Location of Impact	Pedestrian Shoulders[1]		Parked Vehicle Shoulders		Fatal Shoulders	
	Full	None	Full	None	Full	None
Inside Shoulder	--	--	1	--	--	--
Inside Lane	--	1	--	--	Location	1
Middle Lane	--	4	--	--	Not	--
Outside Lane	--	1	1	1	Given	--
Outside Shoulder	--	--	13	17	--	1
TOTAL	0	6	15	18	1	2

[1]"Shoulders" refers to the segment studies. "Full" have inside shoulders 8 or more ft. wide. "None" have inside shoulders 0 to 2 ft. wide.

Table 18. I-30 Infrequent Accidents (1980-1983)

Location of Impact	Pedestrian Shoulders[1]			Parked Vehicle Shoulders			Fatal Shoulders		
	Full	Partial	None	Full	Partial	None	Full	Partial	None
Inside Shoulder	1	--	--	2	--	--	2	--	--
Inside Lane	--	--	--	--	--	--	1	1	--
Middle Lane	--	1	1	--	--	--	2	--	1
Outside Lane	--	--	1	--	--	--	--	--	--
Outside Shoulder	--	--	1	16	7	5	--	1	2
TOTAL	1	1	3	18	7	5	5	2	3

[1]"Shoulders" refers to the segment studied. "Full" have inside shoulders 8 or more ft. wide. "None" have inside shoulders 0 to 2 ft. wide. "Partial" have inside shoulders 3 to 7 ft. wide.

Table 19. SH 286 and SH 358 Infrequent Accidents (1980-1983)

Location of Impact	Pedestrian Shoulders[1]		Parked Vehicle Shoulders		Fatal Shoulders	
	Full	Partial	Full	Partial	Full	Partial
Inside Shoulder	--	--	--	1	3	--
Inside Lane	--	2	--	1	--	--
Middle Lane	--	--	1	1	--	--
Outside Lane	--	2	--	1	--	3
Outside Shoulder	--	1	5	5	--	1
TOTAL	--	5	6	9	3	4

[1]"Shoulders" refers to the segment studied, in this case SH 286 with full inside shoulders and SH 358 with partial inside shoulders. "Full" have inside shoulders 8 or more ft. wide. "Partial" have inside shoulders 3 to 7 ft. wide.

Table 20. I-610 Infrequent Accidents (1980-1983)

Location of Impact	Pedestrian Shoulders[1]		Parked Vehicle Shoulders		Fatal Shoulders	
	(Before) Full	(After) Partial	(Before) Full	(After) Partial	(Before) Full	(After) Partial
Inside Shoulder	--	--	3	--	--	1
Inside Lane	--	2	--	--	--	2
Middle Lane	--	--	--	--	1	--
Outside Lane	--	1	--	--	--	1
Outside Shoulder	--	1	6	4	--	--
TOTAL	--	4	9	4	1	4

1"Shoulders" refers to the segment studied, in this case the same segment of I-610 before or after improvements. "Full" have inside shoulders 8 or more ft. wide. "None" have inside shoulders 0 to 2 ft. wide.

Overall, these tables confirm the random nature of this type of accident rather than to support any previous expectation. The exception is the higher occurrence of parked car accidents on the outside shoulders and, even here, the limited number of observations precludes more powerful tests.

Summary of Inside Shoulder Accident Evaluation

The analysis of the study locations suggests that traffic factors and to some extent roadway (other than shoulder) factors are contributing to the accident differences. The findings can be most strongly stated in terms of what is not occurring. There is no evidence of any patterns that conclusively support the notion that the lack of inside shoulders contribute to increased accidents.

Table 21. US 59 Infrequent Accidents (1980-1984)

Location of Impact	Pedestrian Shoulders[1]		Parked Vehicle Shoulders		Fatal Shoulders	
	Full	Partial	Full	Partial	Full	Partial
Inside Shoulder	--	--	2	--	--	--
Inside Lane	--	--	--	--	1	1
Middle Lane	1	1	--	--	--	3
Outside Lane	1	--	--	--	1	--
Outside Shoulder	1	--	7	5	1	--
TOTAL	3	1	9	5	3	4

[1]"Shoulders" refers to the segment studied. "Full" have inside shoulders 8 or more ft. wide. "Partial" have inside shoulders 3 to 7 ft. wide.

The analysis of infrequent accidents also suggests that no pattern of severe accidents can be attributed to the absence of left shoulders. Increases in accidents that so occur (for whatever reason) are not of the serious type. This finding is also consistent with the notion that accident differences that occur are primarily traffic related. That is, the result of more congested operation.

The judgments made here could be considered speculative if it were not for the extensive experience with shoulder removals presented later in the report. The data presented here indicates the lack of a clearly definable problem attributable to the absence of a left shoulder.

THE CALIFORNIA EXPERIENCE WITH SHOULDER REDUCTION PROJECTS

California has been using shoulders to increase the capacity of freeway segments since the early 1970's. Some of these were the subject of previous reports (14, 15, 16, 17). This evaluation of freeway segments in California is done in coordination and cooperation with the California Department of Transportation (CALTRANS). This study was successful in drawing supportable conclusions because CALTRANS and the Department were concerned about finding an answer to the shoulder safety issue.

Freeway segments that went from full shoulders to reduced shoulders were selected for a before-and-after accident analysis. Most cases studied involved inside shoulders; some involve outside shoulders. The segments studied are located in the Los Angeles, San Francisco and San Diego urbanized areas.

The various cases have been grouped into those where part or all of the width of inside shoulders have been taken as a travel lane and those with outside shoulder treatments. Since shoulder treatments may have an effect on upstream and downstream accidents, some of the sites immediately adjacent were also investigated. It can be surmised that, when the capacity of a segment is increased to remove a bottleneck, the site upstream may experience an accident reduction if it was experiencing congestion from a downstream bottleneck. When possible, the site downstream of the study section was also evaluated to determine if accidents were increased due to the creation of a downstream bottleneck. Likewise, sections upstream of study sections were evaluated for possible benefits due to reduced downstream congestion.

Computerized accident files recorded by the California Highway Patrol and maintained by the California Department of Transportation have been used as the principal source of accident data. Years 1974 through 1984 were available for analysis. Variables used to select each accident included mainlane accidents only (thus excluding ramps), direction traveled and others required to identify the segment. The above data was processed using the

Statistical Analysis System (SAS) programs to summarize segment accidents, calculate accident rates, and to compare rate differences by using a two-means T-test. Histograms of accidents recorded each tenth of a mile along each segment also were printed to detect any abnormalities between before and after conditions.

It should be noted that the analysis of accidents is limited by the available number of study sites and their location. Statistical analysis is used as a tool to aid in the analysis. The limited number of sites available and their location makes more powerful statistical testing with control cases infeasible. Nevertheless, the preponderance of evidence supported by the statistical techniques available supports informed judgments concerning the appropriateness of certain actions.

Inside Shoulder Treatments

Characteristics of Segments Studied

Segments where inside shoulders were removed to use as a travel lane are shown in Table 22. Of the 12, seven are located in Los Angeles County, and one each in Orange, Marin, Alameda, Contra Costa and San Diego Counties. Many of these segments are under one mile in length and, except for I-405, all continuous subsegments are under two miles. The I-10 segments are each the sum of eastbound and westbound subsegments in order to provide enough accidents for statistical analysis.

Prior to restriping each segment had a full inside shoulder which was later used as a travel lane. For study purposes shoulders two-ft. wide or narrower are considered as "no shoulder", those three to seven-ft. wide are considered "partial shoulder", and those eight or more ft. are considered "full shoulder". Thus, there were six cases with no inside shoulders and six with partial inside shoulders after restriping. Full right shoulders are provided in all cases except for I-580 where the right shoulder previously used as an auxiliary lane was turned into a permissive (peak period) lane after restriping, and the two I-10 cases where the right shoulder was restored by removal of the left shoulder.

Table 22. Characteristics of California Freeways Where Inside Shoulders Were Removed

Route and County	Beg. Mile Post	Length, Direction	Period	Cross Section: Left Shoulder	Cross Section: Main Lanes	Cross Section: Right Shoulder	ADT	Peak Hour Volume	Vehicles per Lane[1]
1. I-5	36.65	1.34mi.,	Before	10'	4-12'	10'	119,500	11,300	1,700
Los Angeles		SB	After	3'	5-11'	10'	133,200	12,380	1,490
2. I-5	37.80	0.69mi.,	Before	10'	4-12'	10'	119,500	11,300	1,700
Los Angeles		NB	After	3'	5-11'	10'	133,200	12,380	1,490
3. I-10	9.35E	1.41mi.,	Before	10'	5-11'	2'	205,300	16,030	1,920
Los Angeles	9.40W	EB, WB	After	2'	5-11'	10'	219,800	17,430	2,090
4. I-10	11.22E	2.28mi.,	Before	10'	5-11'	2'	227,300	18,500	2,220
Los Angeles	11.21W	EB, WB	After	2'	5-11'	10'	218,800	18,030	2,160
5. CA-22	5.82	3.25mi.,	Before	10'	3-12'	8'	123,700	10,990	2,200
Orange		WB	After	2'	3-11'	8'	168,700	12,600	1,890
					+11'AL[2]				
6. CA-60	15.16	0.68mi.,	Before	10'	4-12'	8'	121,300	11,820	1,770
Los Angeles		EB	After	3'	5-11'	8'	112,000	11,450	1,370
7. US-101	16.13	0.67mi.,	Before	8'	4-12'	10'	237,700	18,230	2,730
Los Angeles		NB	After	3'	5-11'	10'	265,300	20,500	2,460
8. I-405	30.17	7.72mi.,	Before	10'	4-12'	10'	167,500	13,480	2,020
Los Angeles		NB	After	3'	5-11'	10'	201,300	16,630	2,000
9. US-101	14.80	0.31mi.,	Before	8'	3-12'	10'	97,800	10,740	2,150
Marin		SB	After	2'	4-11'	8'	106,000	11,600	1,740
10. I-580	42.74	0.61mi.,	Before	8'	4-12'	0'	161,800	15,350	1,840
					+10'AL[2]				
Alameda		EB	After	1'	5-11'	0'	166,900	15,830	1,580
					+10'PL[3]				
11. I-680	17.90	0.38mi.,	Before	10'	3-12'	10'	122,000	13,450	2,690
Contra Costa		SB	After	2'	4-11'	10'	133,000	14,670	2,200
12. CA-94	5.09	1.13mi.,	Before	8'	4-12'	8'	90,500	10,500	1,580
San Diego		EB	After	3'	5-11'	3'	106,800	12,250	1,470

[1]Estimated (peak hour volume times 0.6 divided by number of directional lanes).

[2]AL = Full time auxiliary lane.

[3]PL = Part time auxiliary lane.

The average daily traffic (ADT) shown in Table 22 is a composite of the period covered before or after restriping. The ADT is close to or above 100,000 vehicles per day for all segments. The ADT and peak hour traffic were obtained from the respective yearly Traffic Volumes on California State Highways (18) published by the California Department of Transportation. Vehicles per lane is an estimate based on peak hour traffic multiplied by 0.6 to account for the peak direction traffic and divided by the number of mainlanes available along each segment.

Procedure

Overall accident rates have been calculated to compare a freeway segment prior to restriping with the same segment after restriping. Accidents are first summed for each quarter or semester, (6 months), as appropriate, to obtain good samples (cells). Sample accidents are divided by vehicle-miles to calculate accidents per million vehicle-miles. Once this is done for the period before and the period after restriping, both periods are compared using a two-means T-test. As designed, this test helps determine if the rate, after restriping, is higher or lower than before restriping and if such difference is statistically significant.

Overall accident rates include accidents classified as highway type only, and exclude those regarded as intersection or ramp. Accidents are grouped by direction of travel on the freeway. The ADT used to obtain rates is bidirectional and is therefore divided by two for analysis. Segment accidents are then plotted by direction every tenth of a mile. This is used to check any abnormalities such as exceedingly high accident locations and shifts along the freeway as capacity is increased.

Segment Comparisons

Table 23 shows accident rates for each case previously described in Table 22. Means (rates) are given for the period before and the period after restriping. Results of the T-test to determine how the after accidents compare with the before accidents also are included. These are the T-value,

Table 23. Overall Accident Rates on California Freeways Where Inside Shoulders Were Removed

Seg. No.	Freeway, County Length, Direction	Period	Samples[1]	Mean (Acc/MVM)	T-Value	Probability of[2] Greater |T|
1.	I-5, Los Angeles	Before 7/15-6/78	12	1.066	1.08	0.29
	(1.34 mi., SB)	After 7/79-6/82	12	1.288		
2.	I-5, Los Angeles	Before 7/75-6/78	6	1.178	-1.65	0.13
	(0.69 mi., NB)	After 7/79-6/82	6	0.784		
3.	I-10, Los Angeles	Before 1/76-12/79	16	0.764	-3.88	0.001**
	(1.41 mi., EB, WB)	After 1/81-12/84	16	0.417		
4.	I-10, Los Angeles	Before 1/76-12/79	16	1.859	-2.87	0.009**
	(2.28 mi., EB, WB)	After 1/81-12/84	16	1.241		
5.	CA-22, Orange	Before 1/77-6/80	14	0.829	-2.33	0.03*
	(3.25 mi., WB)	After 4/82-12/84	11	0.617		
6.	CA-60, Los Angeles	Before 1/79-6/81	5	0.905	-2.00	0.09
	(0.68 mi., EB)	After 1/83-12/84	4	0.683		
7.	US-101, Los Angeles	Before 1/79-12/81	12	0.789	-0.65	0.53
	(0.67 mi., NB)	After 10/82-12/84	9	0.685		
8.	I-405, Los Angeles	Before 1/74-3/75	5	0.793	2.90	0.01*
	(7.72 mi., NB)	After 4/77-12/79	11	1.058[3]		
9.	US-101, Marin	Before 1/80-6/82	5	0.649	-0.82	0.5
	(0.31 mi., SB)	After 1/83-12/84	4	0.422		
10.	I-580, Alameda	Before 1/79-9/81	11	1.964	-2.33	0.03*
	(0.61 mi., EB)	After 4/82-12/84	11	1.466[4]		
11.	I-680, Contra Costa	Before 1/80-12/81	4	1.066	-0.22	0.84
	(0.38 mi., SB)	After 7/82-12/83	3	1.015		
12.	CA-94, San Diego	Before 1/76-12/79	8	0.621	-0.69	0.50
	(1.13 mi., EB)	After 1/81-12/84	8	0.556		

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) means statistically significant at the 0.05 level, and two asterisks (**) means statistically significant at the 0.01 level.

[3]See text for explanation of increase.

[4]See text for description of project.

the probability that the T-value is greater in absolute value, and whether the test is statistically significant as identified by asterisks.

I-5, Los Angeles. Results of T-test on Segments 1 and 2 indicate that there was no significant difference in accident rates before and after restriping. The first segment, I-5 southbound, had 1.07 acc/mvm prior to restriping and 1.29 acc/mvm after. Figure 42 shows this relationship. Segment 1 was operating with a full inside shoulder, four mainlanes and a full outside shoulder prior to improvements. After restriping the segment had a partial inside shoulder (3-ft. wide), five mainlanes and a full outside shoulder. Table 22 outlines these physical characteristics.

The number of accident samples is good for Segment 1, where accident data for 12 quarters was available for before and after comparison. Accidents (observations) per sample were fair in that some samples had 5 or less observations per quarter. Frequency bar charts of accidents recorded within every tenth of a mile along this segment reflect higher rates at milepoints 36.8 and 37.5 after restriping. However, these increases are not large enough to change the before and after difference in accident rates to a statistically significant level. No shift in accident pattern toward the downstream end can be detected after improvements.

Segment 2, I-5 northbound, had 1.18 acc/mvm before restriping and 0.78 acc/mvm after. The accident rate went down but the difference is not statistically significant. Figure 43 shows this relationship. Geometric characteristics are similar to Segment 1; the principal treatment took an inside shoulder and turned it into an additional travel lane, leaving a partial inside shoulder (3-ft. wide).

The number of accident samples for the above segment are fair because they had to be grouped into six-month semesters, rather than quarters, due to the limited number of observations. Thus, accident samples also are fair with a few having five or less observations. Frequency bar charts are stable, with minor differences between before and after that may be attributed to sample variability, but with no statistical significance.

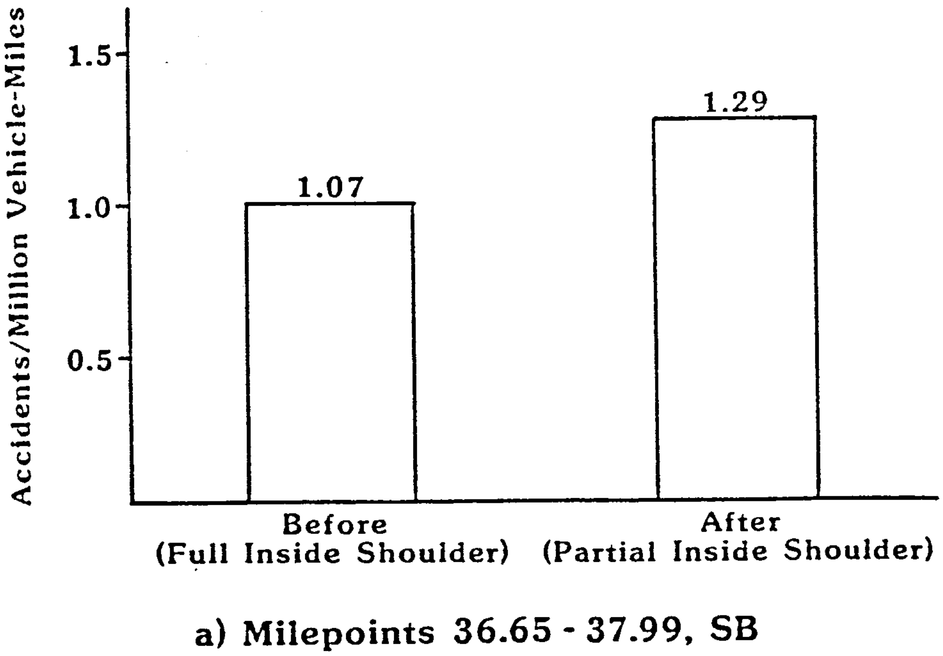


Figure 42. I-5 Southbound, Overall Accident Rates Before and After Changes in Left Shoulder

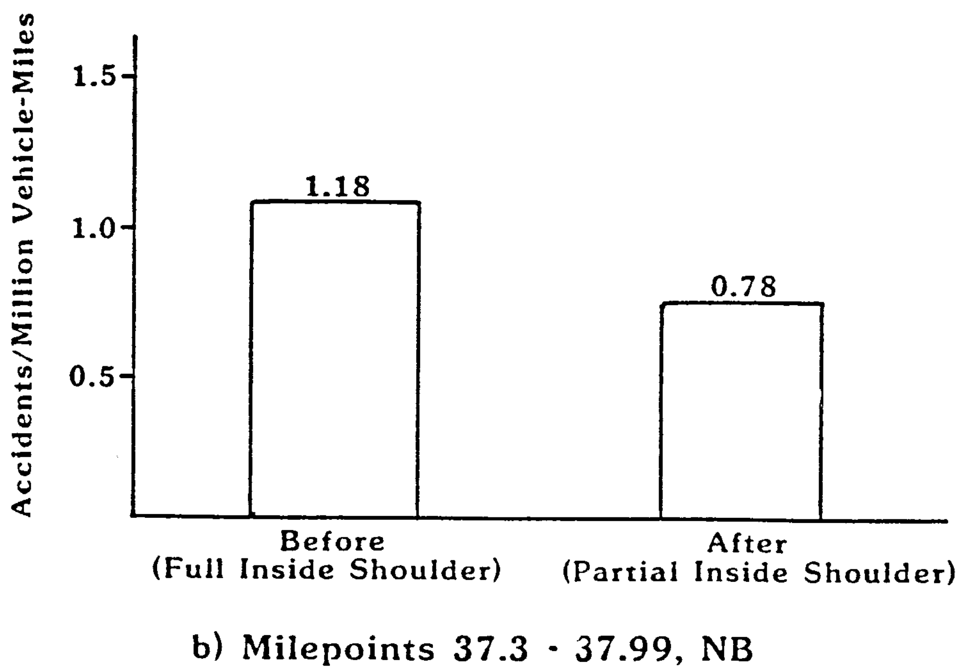


Figure 43. I-5 Northbound Overall Accident Rates Before and After Changes in Left Shoulder

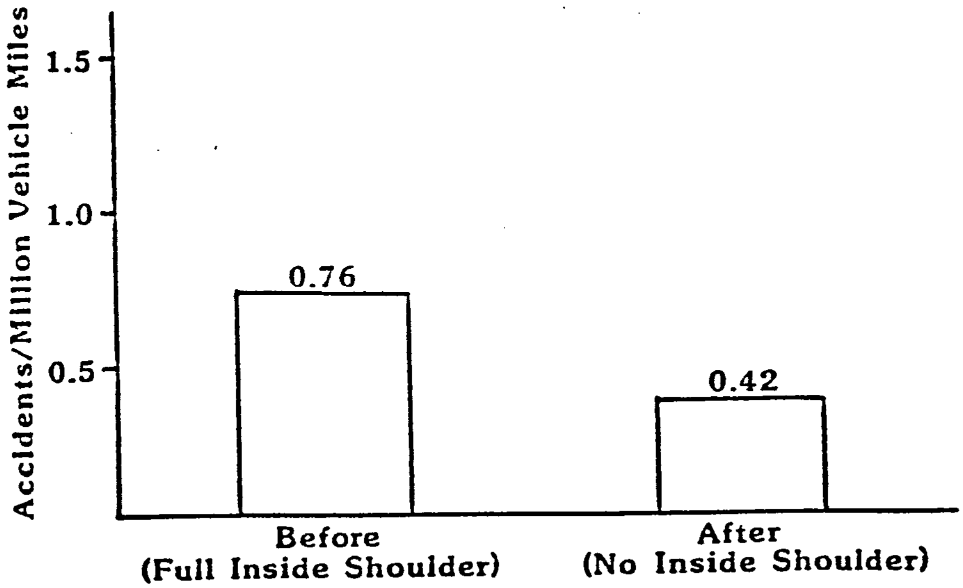
I-10, Los Angeles. The T-tests on Segments 3 and 4 show a significant decrease in each case. Segment 3, with a total length of 1.41 miles including eastbound and westbound subsegments, had 0.76 acc/mvm prior to restriping and 0.42 acc/mvm after. Initially, the segment was operating with full inside shoulders, five mainlanes, but no outside shoulder (2-ft. wide). Restriping shifted mainlanes toward the median, thus providing full outside shoulders but no inside shoulders and retaining the same number of lanes. Figure 44 graphically shows this rate relationship.

Statistically, segment 3 samples are fair although the number of samples, 16, for each period is good. The frequency bar chart reflects no abnormality nor considerable shift in pattern, even though accident reductions can be detected at specific milepoints.

Segment 4, 2.28 miles long including eastbound and westbound subsegments, experienced 1.86 acc/mvm before changes and 1.24 acc/mvm after; the accident rate went down, but the difference is statistically significant. Similar to Segment 3, the segment was operating with a full inside shoulder, five mainlanes and no outside shoulder in each direction, and restriping shifted lanes toward the median leaving no inside shoulder. About 55 percent of this segment is provided with an auxiliary lane between on-to-off ramps. Figure 45 also shows the above rate relationship.

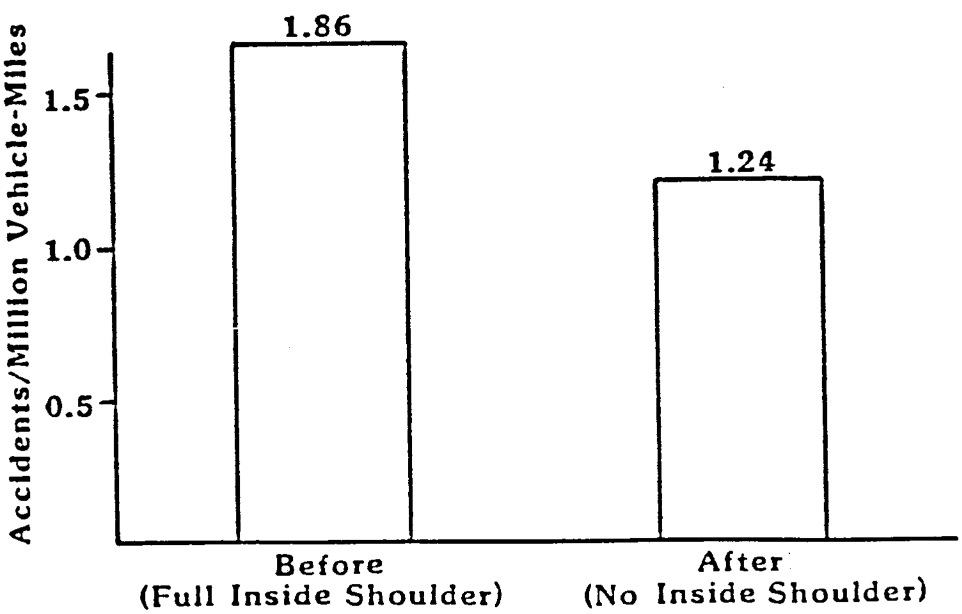
Samples are good in this case and so are their number. Total observations add to 1,157. Bar charts show accident reduction after restriping but no evident shift in pattern.

Segment 4 provides a good data base that permits analysis by lane. Table 24 presents T-tests performed for each lane. It can be noticed that all lanes experienced a reduction in accident rates even though only the inside lane experienced a statistically significant reduction. Inside shoulders and outside shoulders had too few observations to make meaningful comparisons. Test results are good even though only 74 percent of the overall segment accidents were recorded as happening in one of the designated lane locations and this reduces the number of observations available for



a) Milepoints 9.35 - 10.10, EB and Milepoints 9.40 - 10.06, WB

Figure 44. I-10 (Segment 3) Overall Accident Rates Before and After Changes in Left Shoulder



b) Milepoints 11.22 - 12.38, EB and Milepoints 11.21 - 12.33, WB

Figure 45. I-10 (Segement 4) Overall Accident Rates Before and After Changes in Left Shoulder

Table 24. I-10 T-test by Lane, Los Angeles

Accident Location	Period	Samples[1]	Mean	T-Value	Probability of[2] Greater T
Inside Shoulder	Before	1			
	After	0	Unreliable data, too few observations		
Inside Lane	Before	16	0.164	-2.10	0.05 *
	After	16	0.100		
Middle Lanes	Before	16	0.109	-1.9	0.07
	After	16	0.085		
Outside Lane	Before	16	0.171	-1.46	0.15
	After	16	0.133		
Outside Shoulder	Before	5			
	After	5	Unreliable data, too few observations		

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) statistically means significant at the 0.05 level and two asterisks (**) means very significant at the 0.01 level.

testing. Taking away the inside shoulder did not increase median related accidents.

Overall, the above two segments show a significant reduction in accident rates at the 0.01 level. The analysis of these two I-10 segments is an important indicator of the relative significance of right versus left shoulders. It is apparent that the right shoulder is more important than the left shoulder since the switch from left shoulder only to right shoulder only produced a very significant reduction in accidents. Inside shoulder removals appear preferable to right shoulder removals.

CA-22, Orange. A T-test on Segment 5 indicates a significant reduction in accident rates at the 0.05 level. This segment had 0.83 acc/mvm before restriping and 0.62 acc/mvm after restriping. Figure 46 illustrates these rates for visual comparisons. Restriping was done to add an auxiliary lane between on-to-off ramps without taking the right shoulder. Initially there was a full inside shoulder, three mainlanes and a full outside shoulder. After restriping there was no inside shoulder (2-ft. wide), three narrower mainlanes (11-ft. wide), an auxiliary lane between on-to-off ramps and a full outside shoulder. Between off-to-on ramps the auxiliary lane was striped off.

Samples are good in number as well as in observations per sample. The frequency bar chart reflects no major abnormality nor considerable shift, even though accidents about midpoint milepoint 7.8 were reduced by more than 50 percent. The latter can be the result of a bottleneck relief. There are not enough observations for an analysis by lane.

CA-60, Los Angeles. The T-test on Segment 6 shows a non-significant reduction in accident rates. This short, 0.68 mile segment, had 0.90 acc/mvm before restriping and 0.68 acc/mvm after. Figure 47 illustrates these rates. This segment was initially provided with a full inside shoulder, four main-lanes and a full outside shoulder. After restriping, a partial (3-ft. wide) inside shoulder was left, five mainlanes and the full outside shoulder.

Statistically, samples are poor in number and in observations per sample. The frequency bar chart reflects a reduction in accidents around milepoint 15.5, suggesting a bottleneck relief as a result of the added capacity. However, observations are limited and inferences are not possible.

US-101, Los Angeles. The result of the T-test on Segment 7 shows a non-significant reduction in accident rates. The segment had 0.79 acc/mvm before restriping to add a lane and 0.68 acc/mvm after. Figure 48 shows these rates. Initially there was a full inside shoulder, four mainlanes and a full outside shoulder. Restriping made a partial (3-ft. wide) inside shoulder, five narrower lanes, and the full outside shoulder remained as before.

Samples are good in number but fair in observations per sample. Bar charts suggest that a bottleneck about milepoint 16.2 may have been cleared but there is no observable shift in accident pattern.

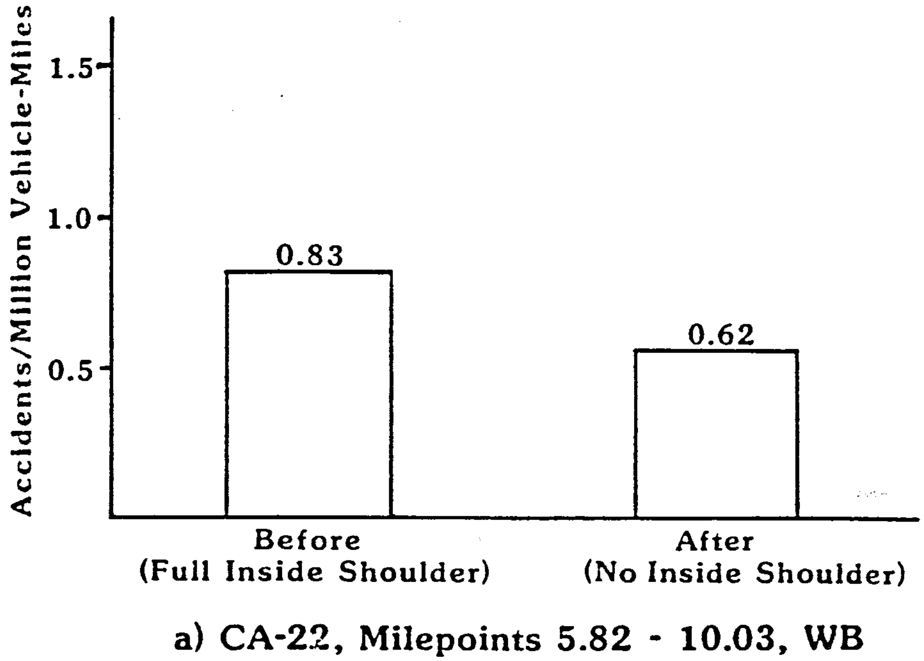


Figure 46. CA-22 Overall Accident Rates Before and After Changes in Left Shoulder

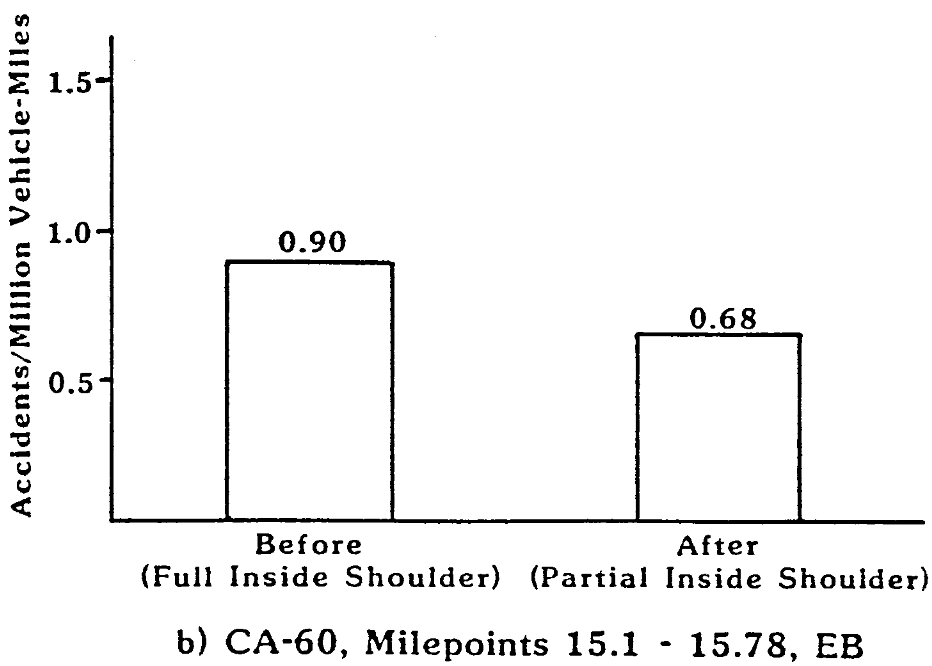
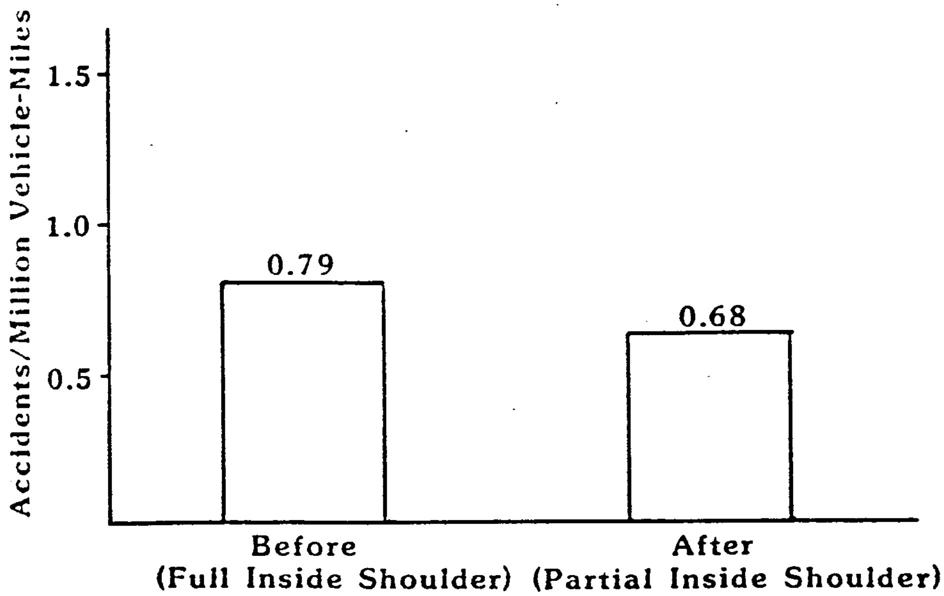
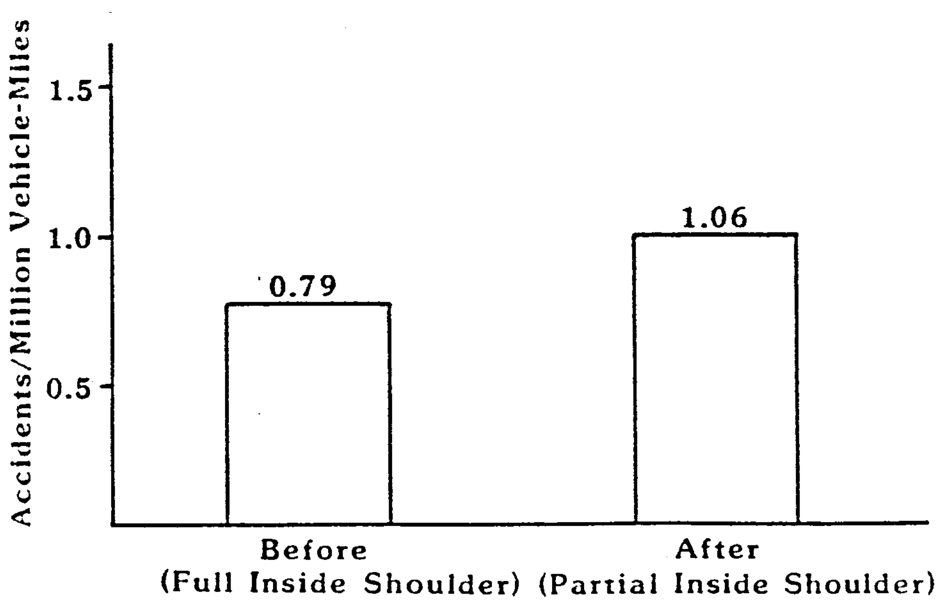


Figure 47. CA-60 Overall Accident Rates Before and After Changes in Left Shoulder



a) US-101, Milepoints 16.13 - 16.80, NB

Figure 48. US 101, Los Angeles, Overall Accident Rates Before and After Changes in Left Shoulder



b) I-405, Milepoints 30.17 - 38.75, NB

Figure 49. I-405 Overall Accident Rates Before and After Changes in Left Shoulder

I-405, Los Angeles. Results of the T-test on Segment 8 indicate a significant increase in accident rates. This long segment, 8.58 miles, experienced 0.79 acc/mvm before restriping and 1.06 acc/mvm after. Figure 49 shows this relationship. Initially this segment had a full inside shoulder, four mainlanes and a full outside shoulder. After restriping it was provided with a partial (3-ft. wide) inside shoulder, five mainlanes and retained the same full outside shoulder. Two short subsegments have an auxiliary lane between on-to-off ramps in addition to the five mainlanes and full outside shoulder. The additional lane was initially intended to be an HOV lane, but was opened as a mixed-flow lane due to the Santa Monica diamond lane controversy.

Samples before restriping are only five, and this is less than desirable. Yet, observations are very good adding to 1,185 and giving each sample a very stable number. The after restriping accident rates are significantly higher at the 0.05 level. Examining the frequency bar charts provides a clue to these differences. There is a shift in accidents downstream, or toward the north end of this freeway segment. This is measurable by determining the percent of all accidents that occurred in the last quarter segment before restriping to compare with the percent after restriping. Before restriping, 16 percent of all accidents occurred along the last quarter length of this segment (2.1 miles); after restriping, 48 percent of all accidents occurred within that subsegment.

The good accident data base allows detailed lane analysis. Table 25 presents T-tests performed for each lane. The inside and the outside lanes experienced a non-significant reduction in accident rates after restriping. The inside and outside shoulders had too few accidents for this kind of analysis. On the other hand, middle lanes experienced a very significant increase in accident rates going from 0.046 acc/mvm before restriping to 0.078 acc/mvm after. This change is significant at the 0.01 level. A histogram of accident frequency by lane at each tenth of a mile shows a high peak as traffic approaches the US 101 exit ramps.

Dividing the whole I-405 segment into three subsegments, each 2.9 miles long, allows investigation of the shift observed in the histograms. An upstream, an intermediate and a downstream subsegment each show a different accident pattern. The upstream subsegment went down very significantly from 1.22 acc/mvm to 0.84 acc/mvm. The intermediate subsegment increased slightly, non-significantly, from 0.57 acc/mvm to 0.66 acc/mvm. The downstream subsegment almost tripled from 0.60 acc/mvm to 1.68 acc/mvm. Table 26 shows the above rates with more detail. It can be inferred that a safety problem was introduced in the third subsegment.

Data limitations preclude extensive partitioning of all lanes and subsegments. However, analysis was made of types of collisions in the middle lanes of the downstream subsegment. The rear-end collisions averaged 0.028 acc/mvm before improvements and 0.197 acc/mvm after. This represents close to a seven fold increase that is statistically significant. Sideswipes increased but not significantly. Table 27 shows the middle lane rear-end accidents and rates of this downstream subsegment. Examination of the individual accident records also indicated an over-representation of pm peak period accidents.

Based on the above, it can be inferred that taking the inside shoulder in the first two subsegments of I-405 was not detrimental to safety. This action improved accident rates in the first subsegment. The downstream subsegment experienced an increase in accident rates; however, the inside lane and shoulder had no influence in that change. Midlane weaving prior to the exit at the US-101 ramp, which has inadequate capacity, seems to be the main reason behind the increase. This condition significantly increased midlane rear-end accidents on the downstream subsegment. The inside lane accident rate of this subsegment decreased. Therefore, the partial inside shoulder was not the cause of increased accidents.

It should be noted that the project was originally intended to be an HOV lane. However, it was implemented as a mixed flow lane. As a mixed flow lane, it resulted in a lane balance problem at its terminus. Essentially the 5-lane section increased capacity downstream of the I-10 (Santa Monica) interchange (the beginning of the project). This increased input volumes and reduced congestion in the first segment. The increased volume overloaded the downstream segment which had very little before congestion due to lane

Table 25. I-405 T-test by Lane, Los Angeles

Accident Location	Period	Sample[1]	Mean	T-Value	Probability of Greater T[2]
Inside Shoulder	Before		Unreliable data, too few observations		
	After				
Inside Lane	Before	5	0.067	-1.18	0.26
	After	11	0.054		
Middle Lanes /Lane[3]	Before	5	0.046	4.34	0.01**
	After	11	0.078		
Outside Lane	Before	5	0.129	-0.16	0.88
	After	11	0.126		
Outside Shoulder	Before		Unreliable data, too few observations		
	After				

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) means significant at the 0.05 level and two asterisks (**) means very significant at the 0.01 level.

[3]The number of inside lanes changes from 2 before to 3 after so the analysis is performed on a per lane basis.

Table 26. I-405 T-test by Subsegment

Subsequent Location	Period	Samples[1]	Mean	T-Value	Probability of Greater T[2]
Upstream	Before	5	1.221	-4.23	0.001**
	After	11	0.835		
Intermediate	Before	5	0.573	0.93	0.37
	After	11	0.664		
Downstream	Before	5	0.598	5.90	0.0001**
	After	11	1.683		

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) means significant at the 0.05 level and two asterisks (**) means very significant at the 0.01 level.

balance (4 lanes feeding 5 lanes in the interchange). After the lane was installed, five lanes provided more volume than the five interchange lanes could accommodate. The two lanes to Route 101 (Ventura) were seriously overloaded and account for a large portion of the increase in accidents.

Table 27. I-405 Middle Lane Rear-End Accidents at the Downstream Subsegment

Period	Year	Accidents (ACC/MVM)	Mean (ACC/MVM)
Before	74	0	
		(0)	
	75	1	
		(0.048)	(0.028)
After	77	6	7
		(0.268)	
	78	4	
		(0.154)	
	79	4	
		(0.161)	(0.197)

US-101, Marin. Segment 9 results of the T-test indicate a non-significant decrease in accident rates. This segment had 0.65 acc/mvm before restriping and 0.42 acc/mvm after (Figure 50). Restriping was accomplished to increase mainlanes from three to four. The full inside shoulder was reduced to no inside shoulder (2-ft. wide) and the outside shoulder was also reduced but remained as a full outside shoulder (8-ft. wide). This short segment improvement was a localized solution to a truck traffic problem because of trucks entering the freeway from a truck weighing station while going uphill. This project is not typical of left shoulder changes.

Accident observations for this short segment were very scant. Frequency bar charts were normal. Results would be insignificant standing alone;

however, they are provided for completeness of reporting on all sections that were analyzed.

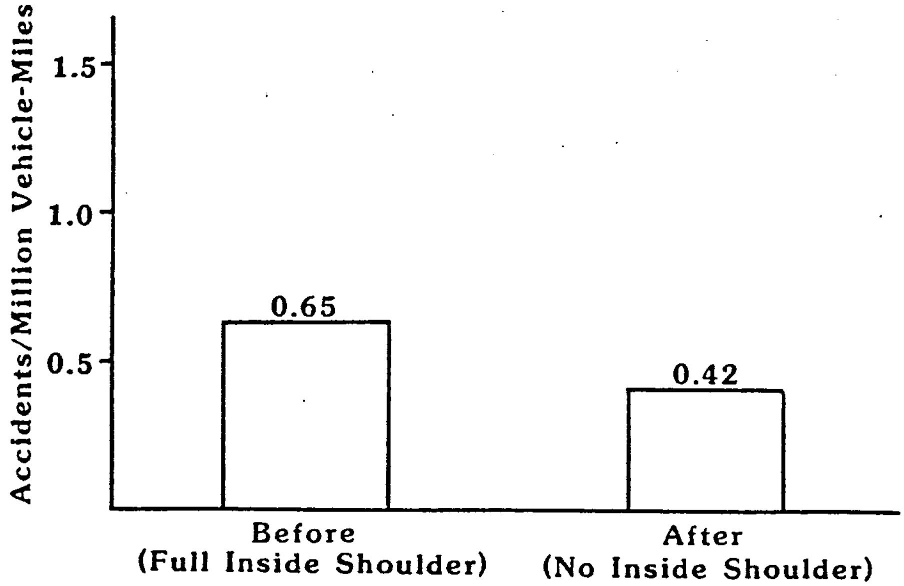
I-580, Alameda. The T-test for segment 10 indicates a decrease in accident rates significant at the 0.05 level. Prior to restriping accident rates were 1.96 acc/mvm and after restriping dropped to 1.44 acc/mvm. Figure 51 illustrates those rates. Before restriping there was a full inside shoulder, four mainlanes, a 10-ft. auxiliary lane with no outside shoulder but a grass area to the right of the outside lane. After restriping, no inside shoulder was provided (1-ft. wide), four through lanes remained, the auxiliary lane was moved inside and a 10-ft. permissive lane (4:00-6:00 pm) was located where the auxiliary lane used to be.

The sample number is good but the observations per sample is fair. The frequency bar chart indicates a reduction around milepoint 43.0 which may be related to weaving at the approach to the off-ramp. After restriping, the extra lane available for weaving during peak hours seems to help reduce this problem.

I-680, Contra Costa. The T-test for this short segment indicates a non-significant reduction in accident rates. Before restriping, accident rates were 1.07 acc/mvm and were reduced to 1.02 acc/mvm after. Figure 52 shows the above rates. Before restriping, a full inside shoulder existed with three through lanes and a full outside shoulder. After improvements, no inside shoulder (2-ft. wide) was provided to allow for three through lanes plus an auxiliary lane between on-to-off ramps. A full outside shoulder was retained.

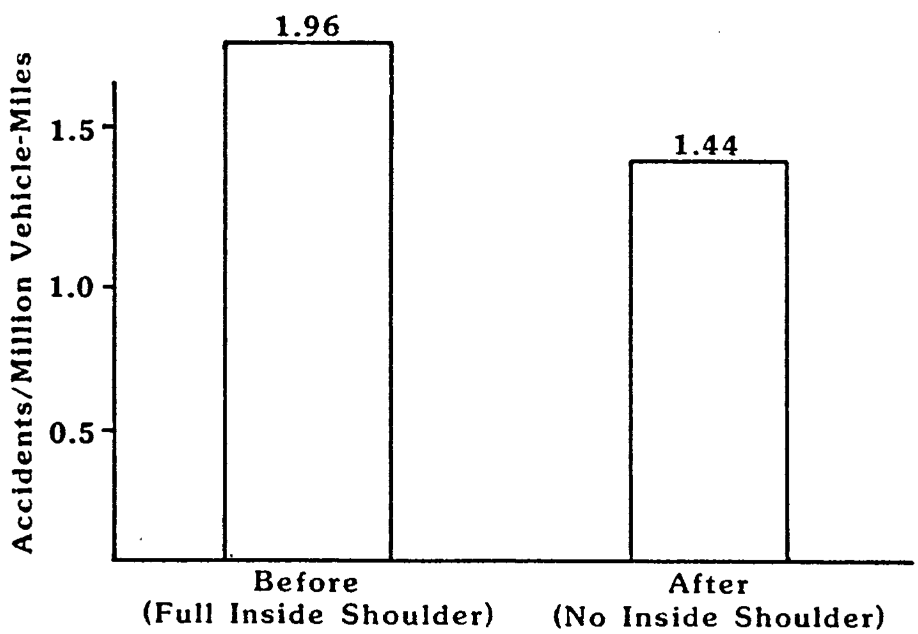
The number of samples is very limited and the number of observations per sample is very limited. The frequency bar charts are not clear due to the limited number of observations although they seem to indicate that accidents near milepoint 18.0 were reduced.

CA-94, San Diego The Segment 12 T-test indicates a non-significant reduction in accident rates. Prior to restriping these were 0.62 acc/mvm and were reduced to 0.56 acc/mvm after. Figure 53 shows these rates. Initially



a) US-101, Milepoints 14.8 - 15.11, SB

Figure 50. US 101 Overall Accident Rates Before and After Changes in Left Shoulder



b) I-580, Milepoints 42.74 - 43.35, EB

Figure 51. I-580 Overall Accident Rates Before and After Changes in Left Shoulder

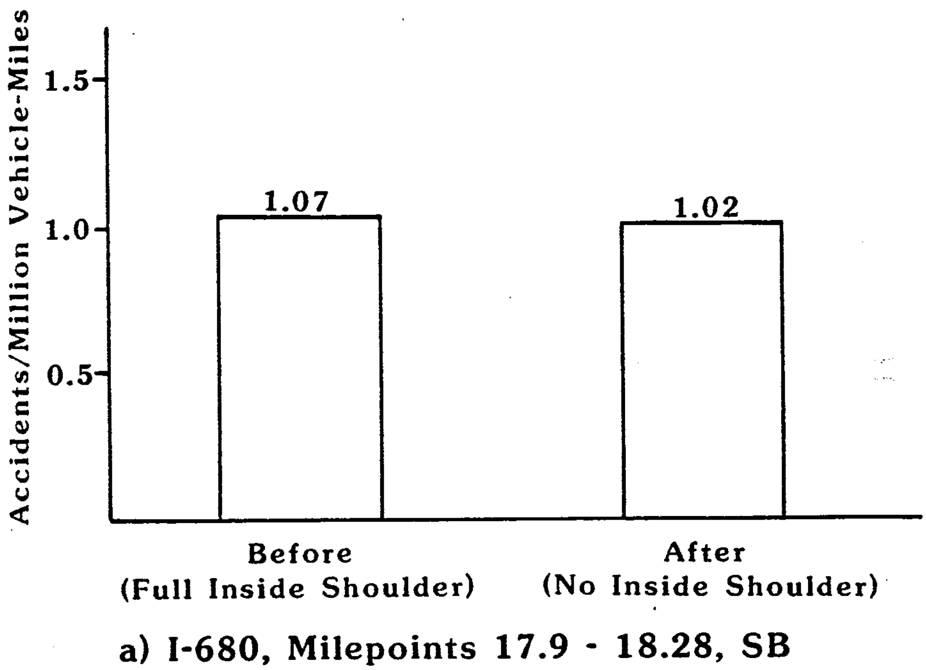


Figure 52. I-680 Overall Accident Rates Before and After Changes in Left Shoulder

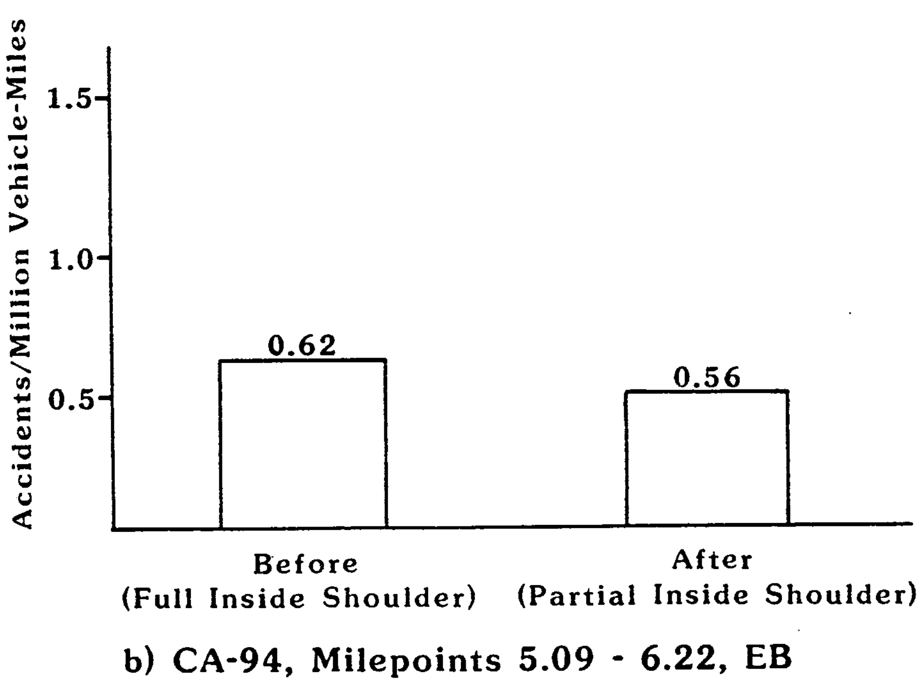


Figure 53. CA-94 Overall Accident Rates Before and After Changes in Left Shoulder

there was a full inside shoulder, four mainlanes and a full right shoulder. Restriping changed this to a partial inside shoulder (3-ft. wide), five narrower lanes and a full outside shoulder. A short segment has an auxiliary lane between on-to-off ramps.

The number of samples is adequate but the observations per sample is poor. In spite of the limited observations, the frequency bar charts suggest a downstream shift in accidents. That is, the additional capacity relieved an upstream problem but recreated it at a reduced level further downstream.

Accident Severity Experience on Inside Shoulder Removals

In addition to the concern about traffic safety in general, a concern exists that the absence of a shoulder may increase accident severity even if overall accidents are decreased. This analysis will explore accident severity. It must be cautioned that the analysis is more difficult as the accidents are subdivided into more categories of fewer and fewer accidents. That is to say, no conclusions are appropriate if there was one accident before and 2 accidents after because of the very small number of accidents. The severity analysis, therefore, requires more aggregation of data than the overall analysis in order to draw any conclusions.

Table 28 summarizes the severity rates by study site for the 12 inside shoulder cases. The fatal accident rate was 0.0032 acc/mvm before and 0.0043 acc/mvm after. These rates are based on a total 13 accidents and no conclusion is warranted because of the low number of accidents. The injury rate was 0.35 acc/mvm before and 0.37 acc/mvm after. If we combine the injury and fatal accident rates on a before and after basis, a two-means T-test indicates that the differences are not statistically significant at the 0.05 level. A similar test for the non-injury (object of PDO) accidents does indicate a statistically significant decrease in non-injury accidents due to the removal of left shoulders. There is no indication that accident severity is significantly affected by inside shoulder removals. The severity data is consistent with the hypothesis that shoulder reduction projects improved operations by reducing congestion which would be expected to reduce non-injury accidents.

Table 28. Accident Severity Rates on California Freeways Where Inside Shoulders Were Removed

Seg. No.	Freeway, County Length, Direction	Before Rate			After Rate		
		Fatal	Injury	Object	Fatal	Injury	Object
1.	I-5, Los Angeles (1.34 mi., SB)	0.000	0.46	0.60	0.020	0.53	0.73
2.	I-5, Los Angeles (0.69 mi., NB)	0.000	0.33	0.84	0.020	0.48	0.30
3.	I-10, Los Angeles (1.41 mi., EB, WB)	0.000	0.22	0.54	0.000	0.16	0.26
4.	I-10, Los Angeles (2.28 mi., EB, WB)	0.005	0.51	1.35	0.003	0.43	0.80
5.	CA-22, Orange (3.25 mi., WB)	0.003	0.26	0.56	0.006	0.25	0.36
6.	CA-60, Los Angeles (0.68 mi., EB)	0.000	0.26	0.64	0.000	0.47	0.22
7.	US-101, Los Angeles (0.67 mi., NB)	0.000	0.28	0.50	0.000	0.30	0.38
8.	I-405, Los Angeles	0.000	0.29	0.93	0.000	0.30	0.53
	(7.72 mi., NB)	0.018	0.16	0.39	0.000	0.25	0.42
9.	US-101, Marin (0.31 mi., SB)	0.000	0.07	0.58	0.000	0.25	0.16
10.	I-580, Alameda (0.61 mi., EB)	0.000	0.97	0.99	0.000	0.82	0.61
11.	I-680, Contra Costa (0.38 mi., SB)	0.000	0.41	0.65	0.000	0.14	0.87
12.	CA-94, San Diego	0.000	0.27	0.35	0.023	0.28	0.25
	Weighted Average	0.0032	0.349	0.780	0.0041	0.323	0.484

Upstream and Downstream Analysis

Besides analysis of the segments where inside shoulders have been reduced to provide a travel lane, sites upstream and downstream from those undergoing a treatment were investigated. The term site is used here to refer to the segment upstream or downstream from the one that was restriped. Table 29 presents the accident experience of upstream and downstream sites. Only sites upstream and downstream from segments with a good accident data base were considered, to allow for meaningful correlation.

I-5, Los Angeles. The site upstream from Segment 1 had a non-significant decrease in accident rates going from 0.87 acc/mvm before restriping to 0.82 acc/mvm after. The site downstream from Segment 2 showed a non-significant decrease in accident rates, going from 0.72 acc/mvm before to 0.52 acc/mvm after. This suggests that restriping and adding capacity had no effect on accident rates at adjacent sites.

I-10, Los Angeles. Four sites have been analyzed. Figure 54 shows each site location. Due to other freeway work, the downstream sites associated with each segment are not adjacent to each other. Of the two associated with Segment 3, the site upstream experienced a significant decrease going from 1.04 acc/mvm before restriping to 0.57 acc/mvm after. Accidents in the site downstream from Segment 3 increased slightly and non-significantly, going from 0.56 acc/mvm before to 0.63 acc/mvm after.

The site upstream from Segment 4 had a significant decrease in accident rates going from 1.01 acc/mvm before restriping to 0.64 acc/mvm after. The site downstream from Segment 4 decreased but not significantly, going from 1.28 acc/mvm before restriping to 1.22 acc/mvm after.

Table 29. Accident Experience Upstream and Downstream From Freeway Segments Where Inside Shoulders Have Been Removed[1]

Freeway, County (Distance/Direction)	Period	Rate (Acc/MVM)	Comments
Upstream from <u>Segment No. (Table 22)</u>			
1. I-5, Los Angeles	Before	0.87	Decreased,
(0.95 mi./SB)	After	0.82	not significant.
2. I-10, Los Angeles	Before	1.04	Decreased,
(1.42 mi./EB)	After	0.57	significant.
3. I-10, Los Angeles	Before	1.01	Decreased,
(1.21/WB)	After	0.64	significant.
4. I-580, Alameda	Before	1.52	Decreased,
(1.19/EB)	After	1.45	not significant.
5. CA-22, Orange	Not considered; site located at interchange with I-5.		
6. I-405, Los Angeles	Not considered; site located at interchange with I-10.		
Downstream from <u>Segment No. (Table 22)</u>			
7. I-5, Los Angeles	Before	0.72	Decreased,
(0.96 mi./NB)	After	0.52	not significant.
8. I-10, Los Angeles	Before	0.56	Increased,
(0.89 mi./WB	After	0.63	not significant.
9. I-10, Los Angeles	Before	1.28	Decreased,
(1.12/EB)	After	1.22	not significant.
10. CA-22, Orange	Before	0.73	Decreased,
(1.23 mi./WB)	After	0.48	significant.
11. I-405, Los Angeles	Not considered; section located at interchange with US 101.		
12. I-580, Alameda	Not considered; downstream segment had right shoulder work.		

[1]Only those subsegments related to a main segment with a good accident sample base are included.

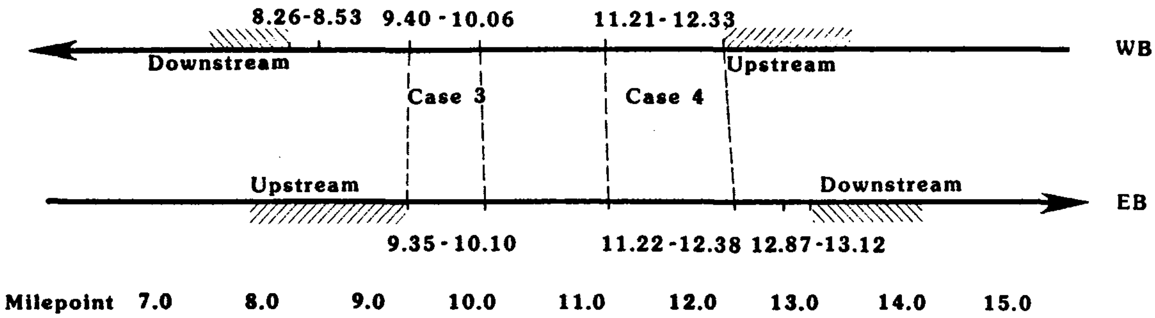


Figure 54. I-10 Upstream and Downstream Sites, Los Angeles

Frequency bar charts for all four sites suggest stability even though specific milepoints may have increased or decreased. The I-10 sites (Segment 3 and Segment 4 in Table 22) did not have changes in capacity. Whether the reinstatement of the right shoulder is a contributing factor to the reduction in accidents (especially upstream) is unknown.

CA-22, Orange. The site upstream from Segment 5 was not considered because the site is located at the interchange with I-5 and other intervening factors affect traffic and its composition. The site downstream from Segment 5 had a significant reduction in accident rates, going from 0.73 acc/mvm before restriping to 0.48 acc/mvm after. Reasons for the decrease are not apparent. The frequency bar charts reflect such decrease but no unusual condition is evident.

I-405, Los Angeles. Both ends of this long segment are very close to major interchanges. Therefore, the upstream and the downstream sites were not considered for this analysis.

I-580, Alameda. The upstream site from Segment 10 experienced a nonsignificant reduction in accident rates. These went from 1.52 acc/mvm before restriping to provide an extra lane to 1.45 acc/mvm after. No unusual condition could be detected from the frequency bar charts. The downstream site from Segment 10 included a subsegment where concurrent with the restriping project a right shoulder was removed and was not considered for analysis.

Based on analysis of the four upstream and the three downstream sites it can be inferred that restriping of the segments studied had no negative effect on safety beyond the limits of the project.

Effects of Congestion

Table 30 summarizes the data in terms of the degree of congestion before and after the changes. The degree of congestion is shown in terms of ADT per lane. Only those sections with before ADTs per lane greater than 20,000 showed accident reductions. Two segments (numbers 5 and 10) experienced significant accident reductions, they likely resulted from some operational improvement. Segment 8, excluding the downstream segment which was identified as having a lane balance problem (see pp. 90-91), also showed an accident reduction. Segment 9, which did not have a reduction in accidents, is an atypical project. The I-680, Segment 10, data base was poor. The accident reductions appear to occur on the sections where ADT per lane is greater than 20,000 before the change and less than 18,000 per lane after. I-680, Contra Costa, has similar volumes and a non-significant accident reduction.

Summary of Inside Shoulder Experience

The experience with inside shoulder removals was either no significant change or a significant reduction in overall accidents at all sites in California with one exception. The significant increase at I-405, was determined to be related to a lane balance problem at the downstream terminus. In addition, accidents upstream were reduced in some instances, and no downstream problems were detected except for the I-405 segment as just described. Congestion reduction appears to account for those sections experiencing accident reductions. The data suggests that accident reductions occur when the ADT/Lane before is greater than 20,000 and the ADT/Lane is less than

Table 30. Relationship Between Congestion and Accidents on Sections with Inside Shoulder Removals

Segment# (Table 22)	Freeway, County	Congestion[1]		Significant Accident Reduction
		Before	After	
1	I-5 Los Angeles	14,400	13,300	No
2	I-5 Los Angeles	14,400	13,300	No
5	CA-22 Orange	20,600	16,900	Yes
6	CA-60 Los Angeles	15,200	11,200	No
7	US 101 Los Angeles	29,712	26,530	No
8	I-405 Los Angeles	20,900	20,100	Yes[2]
9	US 101 Marin	16,300	13,300	No[3]
10	I-580 Alameda	20,200	16,700	Yes
11	I-680 Contro Costa	20,300	16,600	No[4]
12	CA-94 San Diego	11,300	10,700	No

[1]Congestion indicated as ADT per lane.

[2]This is a very atypical project.

[3]Poor database.

18,000 after. The analyses also suggest that accident severity is not affected; the only significant change in accidents is a reduction in non-injury accidents.

Outside Shoulder Treatments

Segment Characteristics

Table 31 presents basic characteristics of segments where outside shoulders were removed to provide a travel lane. Five are located in Los Angeles County, one in Santa Clara County, and one in Alameda County. The San Francisco-Oakland Bay Bridge, located in San Francisco and Alameda counties, is presented as a special mitigation that never had inside or outside shoulders, but has special mitigation measures. The primary segments (all except the Bay Bridge) are under one mile in length and involve one-way traffic only. For study purposes, shoulders two ft. or narrower are considered as "no shoulder", those three-to seven-ft. wide are considered "partial shoulder" and those eight or more ft. are considered "full shoulder". The segments are further divided into part time and full time categories.

The segments had full outside shoulders (except San Francisco-Oakland Bay Bridge) prior to restriping and other associated work. After changes, four of the segments operated with no outside shoulder all the time and three of the segments only during peak periods. Segments whose outside shoulder is used as a permissive (peak period) lane operate as a regular shoulder during off-peak hours. No inside shoulders are provided along the four I-5 segments studied (two partial and two full time).

Table 31 describes the respective cross sections before and after improvements. Also shown is their ADT; all segments had over 100,000 vehicles per day and US 101 and the Bay Bridge were above 200,000 vehicles per day. The column on vehicles per lane, estimated from peak hour traffic data (16), shows that all segments carried over 1,900 vehicles per hour per lane before changes. Although this is an estimate, it indicates the congestion levels experienced on those segments from day to day.

Table 31. Characteristics of California Freeways Where Outside Shoulders Were Adjusted

Freeway, County Distance/Direction	Beg. Mile Post	Period	Cross Section			ADT	Peak Hour Volume	Vehicles per lane
			Left Shoulder	Main Lanes[1]	Right Shoulder			
			*** PART TIME REMOVAL ***					
1. I-5, Los Angeles		Before	0'	3-12'	8'	137,400	10,560	2,110
(0.73 mi/NB)	11.83	After	0'	3-11', 11'P.L.	0'	132,500	10,400	1,560
2. I-5, Los Angeles	13.93	Before	0'	4-12'	8'	195,200	7,700[3]	1,930
(0.95 mi./NB)	15.17	After	0'	1-12, 3-11', 11'PL	0'	197,500	8,500[3]	1,700
3. I-280, Santa Clara		Before	2' paved + graded	3-12'	10'	102,300	10,230	2,050
(0.74 mi./NB)	8.54	After	2' paved + graded	3-12', 10'P.L.	0'	131,000	13,100	1,970
			*** FULL TIME REMOVAL ***					
4. I-5, Los Angeles		Before	0'	3-12'	8'	145,600	11,080	2,200
(0.45/NB)	12.57	After	0'	4-11'	0'	139,000	10,850	1,630
5. I-5, Los Angeles		Before	0'	4-12'	8'	194,400	7,700[3]	1,930
(0.75/NB)	14.4	After	0'	1-12, 4-11'	0'	197,000	8,500[3]	1,700
6. US 101, Los Angeles		Before	10'	4-12'	8'	215,000	16,730	2,510
(0.89 mi./SB)	17.47	After	10'	5-11'	1'	245,700	14,060	2,110
7. I-580, Alameda		Before	8'	4-12'		147,500	14,060	2,110
(0.50 mi/EB)	41.42	After	8'	5-11'	3'	153,500	14,620	1,750
			*** SPECIAL CASE ***					
8. I-80, San Francisco Oakland, Bay Bridge	5.59	Before	0'	59' total	0'	184,000	16,580	1,990
(4.53 mi./two-way)		After	0'	59' total	0'	206,200	18,560	2,230

[1]P.L. means peak period lane.

[2]Peak hour traffic multiplied by 0.6 and divided by the number of lanes.

[3]Data from CALTRANS evaluation of the initial operation, dated October 20, 1985.

Procedures used are similar to those previously used to analyze the inside shoulder treatments.

Segment Comparisons

Segments where the outside shoulder was taken away, totally or in part, to provide additional capacity are briefly analyzed. Table 32 presents the accident experience.

I-5, Los Angeles. The four I-10 segments studied here are independent from the ones previously presented. Segments 1 and 2 are part time and segments 4 and 5 are full time removals. Figure 55 shows their respective location. All projects were implemented at the same time. The entire section from post mile 11.83 to 15.96 had the right shoulder converted to either a full time or part time traffic lane. The decision to make some sections part time removals was an engineering judgement as to potential operational problems during off-peak operation. Some sections near the California Route 7 interchange were excluded from the analysis due to the proximity to the interchange and the presence of left hand entrance and exit ramps. The problem addressed by the project was congestion approaching major interchange (US 101/LA 5/LA 10) which backed up to LA 7 (see Figure 55).

The first I-10 segment experienced a non-significant decrease in accident rates as the right shoulder was turned to a peak period lane (6.00 am to 9:00 am). Rates were 0.70 acc/mvm before restriping and 0.68 acc/mvm after. The cross section had no inside shoulder and three through lanes before changes. Major work was required in this project to restripe the mainlanes (narrowing to 11 ft.) and reconstructing the outside shoulder to provide the peak period lane. Accident samples are poor and not very stable. Frequency bar charts of accidents by mile point are stable and show the principal reduction occurring at milepoint 12.2.

Table 32. Accident Experience on Freeway Segments Where Outside Shoulders Have Been Removed

Freeway, County (Distance/Direction)	Period	Rate (Acc/MVM)	T-Value	Probability[1] of Greater T
	*** PART TIME SHOULDER REMOVAL ***			
1. I-5, Los Angeles	Before 1/74-3/75	0.700	-0.112	0.20
(0.73 mi/NB)	After 1/76-12/77	0.677		
2. I-5, Los Angeles	Before 1/74-3/75	1.368	2.03	
(0.49 mi./NB)	After 1/76-12/77	1.995		
3. I-280, Santa Clara	Before 1/74-6/75	0.240	1.12	0.03
(0.74 mi./NB)	After 1/77-12/79	0.319		
	*** FULL TIME SHOULDER REMOVAL ***			
4. I-5, Los Angeles	Before 1/74-3/75	1.403	1.59	0.14
(0.45/NB)	After 1/76-12/77	1.970		
5. I-5, Los Angeles	Before 1/74-3/75	2.048	-1.04	0.32
(0.76/NB)	After 1/76-12/77	1.647		
6. US 101, Los Angeles	Before 1/76-12/78	1.044	1.38	0.18
(0.89 mi./SB)	After 1/80-12/82	1.318		
7. I-580, Alameda	Before 1/79-9/81	1.68		
R42.1	After 4/82-12/84	0.83	-2.74	0.01 **
	*** SPECIAL CASE ***			
8. I-80, San Francisco	Before 1/74-12/79	1.784	-1.30	0.20
(4.53 mi./two-way)	After 1/80-12/84	1.662		

[1]One asterisk (*) means statistically significant at the 0.05 level and two asterisks (**) means statistically significant at the 0.01 level.

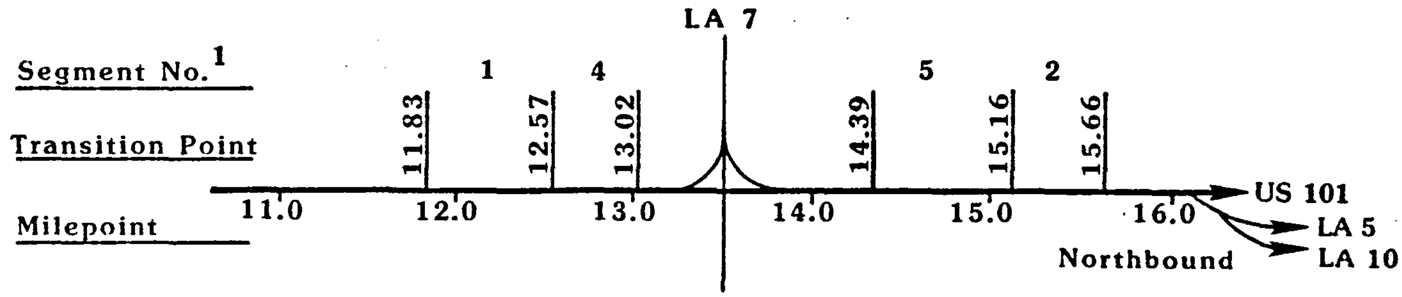


Figure 55. I-5 Segment Locations, Los Angeles

The second segment (see Figure 55) was also a part time removal and experienced a non-significant increase in accident rates. The rate went from 1.37 acc/mvm before reconstruction to 1.99 acc/mvm after. Changes turned the outside shoulder into a peak period lane (6:00 am to 9:00 am), making it a continuous fifth lane with the extra lane provided along the fifth segment. As with other segments, no inside shoulder was provided before or after improvements. The frequency bar charts by milepoints were stable and the increase was obvious. The problem at this location is difficult to diagnose, due to the difficulty in extracting the necessary accident detail from the accident records. For example, the project report indicated some initial problems with traffic exiting to LA 10 being in the third lane from the left and trying to enter lanes 4 and 5 mid-queue. Since lanes 1, 2 and 3 were moving faster, the result could be either a rear-end or weaving accident. Furthermore, the length of the weaving section was changed as was the number of lanes available for each of the three principal interchanging movements. The result is a complex change that is difficult to analyze.

The number four segment on I-5 freeway is a full time removal upstream of the LA 7 interchange that shows a non-significant increase in accident rates going from 1.40 acc/mvm before reconstruction to 1.97 acc/mvm after. This segment immediately follows the first but here the outside shoulder was turned into another through lane, rather than a peak period lane. No inside shoulder was available before or after restriping. Accident samples were also poor. The frequency bar charts show the principal increase in accident rate happening at milepoint 12.9.

The I-5 freeway segment designated as segment 5 had a non-significant reduction in accident rate going from 2.05 acc/mvm before reconstruction to 1.65 acc/mvm after. This segment, together with the second, was the principal bottleneck that prompted the reconstruction project. The outside shoulder was turned into a fifth lane. No inside shoulder was available before or after improvements. The accident samples are fair due to the limited number of samples during the before period. The accident frequency bar charts by milepoints were stable.

Any conclusions regarding the four I-5 segments (numbers 1, 2, 4 and 5) must be considered speculative. Nevertheless, some informed judgement appears appropriate based on a synthesis of all available data. Overall, the accident rate on I-5 from post mile 11.83 to 15.96 increased significantly (0.05 level) from 1.30 accidents/mum before to 1.66 accidents/mum after. Sideswipe accidents increased from 0.29 before to 0.48 accidents per million vehicle miles. The change was statistically significant, and suggests a weaving problem. Rear-end accidents were virtually unchanged at 0.76 before and 0.81 after. Similarly, a.m. peak period accidents were unchanged at 0.21 acc/mvm before and after.

The data is also consistent with the notion that outside shoulders (or parking areas) are necessary for safe operations. However, there are clearly other factors including weaving and speed differentials between lanes that are possibly causing accident problems. The strongest conclusion that can be drawn is that caution is appropriate when removing right shoulders without providing parking opportunities. Furthermore, added capacity upstream of major interchanges may be inappropriate if the added capacity will overload the interchange.

US-101, Los Angeles. This southbound (physically eastbound at this location) segment had a non-significant increase in the accident rate, going from 1.04 acc/mvm before reconstruction of the right shoulder to 1.32 acc/mvm after. Initially the section had a full inside shoulder, four mainlanes and an 8-ft. outside shoulder. After reconstruction of the outside shoulder, five 11-ft. lanes were provided with no outside shoulder (1-ft. to an asphalt concrete dike). The downstream segment also had the outer shoulder removed to add a sixth lane, but due to the different cross section and very short length it is not considered here. Accident samples are good and reliable. The frequency bar charts of accidents show a shift toward the segment's end, which can be expected as segment capacity increases without a similar increase in downstream capacity. Contributing to a higher rate may be the increasing two-way ADT which went from an average of 215,000 vehicles per day prior to changes to 246,000 vehicles per day after changes. The 31,000 vehicles per day increase is assumed to occur as a result of growth in both directions. Since this may not be the case due to changes occurring in only one direction, the after accident rate may be overstated.

I-280, Santa Clara. This segment experienced a non-significant increase in the accident rate. Prior to restriping the peak period (6:00 am to 8:30 am) lane, the segment had 0.24 acc/mvm and this increased to 0.32 acc/mvm after. It should be noticed that these are very low rates. The cross section had a graded median and a 2-ft. paved inside shoulder, three mainlanes and a 10-ft. outside shoulder prior to restriping. The restriping work only affected the outside shoulder to permit peak period traffic. The samples are very poor in number as well as in accidents per sample. The frequency bar charts are stable but not much can be inferred due to the limited data base. This case is included for completeness, but should be considered cautiously in drawing conclusions.

I-80, San Francisco-Oakland Bay Bridge. This two-way case had no inside or outside shoulders before and after. This case is presented to broaden the view on shoulders. In this instance, conditions were very controlled due to limited access ramps and the presence of surveillance and road patrols. Before and after periods were arbitrarily selected as 1974-80 and 1981-84, respectively, since shoulders were not available in either period.

This case had 1.78 acc/mvm during the before period and 1.66 acc/mvm after. A non-significant decrease in accident rates occurred. Frequency bar charts reflect no unusual abnormality nor shift in pattern.

Accident Severity Experience On Outside Shoulder Removals

Table 33 summarizes the accident severity data by study site. The first three locations are part time removals, the next four are full time removals and the last location is the special case San Francisco-Oakland Bay Bridge. The Bay Bridge dramatically illustrates the difficulty in analyzing small data sets. Although no changes were made between the before and after conditions, the fatal accident rate quadrupled based on 2 fatal accidents "before" and 8 fatal accidents "after". The "before" and "after" rates for injury accidents are clearly stable based on nearly 1000 accidents in each period.

Table 33. Accident Severity Rates on California Freeways Where Outside Shoulders Were Removed

Segment Number (Table 31)	Freeway and County	Before Rate			After Rate		
		Fatal	Injury	Object	Fatal	Injury	Object
1	I-5 Los Angeles	0	0.13	0.57	0	0.17	0.51
2	I-5 Los Angeles	0	0.36	1.00	0	0.51	1.50
3	I-280 Santa Clara	0	0	0.23	0	0.11	0.21
4	I-5 Los Angeles	0	0.27	1.14	0	0.70	1.27
5	I-5 Los Angeles	0	0.27	1.78	0.018	0.37	1.26
6	US 101 Los Angeles	0.010	0.33	0.66	0.017	0.65	0.63
7	I-580 Alameda	0.029	1.10	0.71	0.024	0.31	0.35
8	I-80 San Francisco-Oakland Bay Bridge	0.001	0.60	1.16	0.004	0.55	1.10

Despite a small number of accidents involved in all except the San Francisco-Oakland Bay Bridge case, there appears to be a trend toward higher accident rates without right shoulders. This trend is not supported by statistical analysis; however, the inability to detect differences is limited by the small data base. The only case with an accident rate reduction is I-580, Alameda.

Summary of Outside Shoulder Experience

The experience with outside shoulder removals is not clear. However, the data does show some tendency towards increased severity rates. It is also inferred from other data that the critical consideration is the presence or absence of a place for disabled vehicles to park. The early analysis of the I-10 Segments 3 and 4 where a left shoulder was converted to a right shoulder is also consistent with the hypothesis that right shoulders are more important than left shoulders.

CHARACTERISTICS OF STOPPED VEHICLES ON URBAN FREEWAYS

The existence of a shoulder provides an opportunity for vehicles to stop outside of a traffic lane. These stops may be voluntary or involuntary. The lack of a shoulder may or may not result in a mainlane vehicle stop. This operational analysis is intended to assess the tradeoffs involved by identifying available data and developing additional data to allow quantification of the tradeoffs.

Existing Data

Some of the early research on shoulder use (19, 20, 21) was done by Bellis (1957), Billion (1959) and Blensley and Byers (1959). It is difficult to draw conclusions from this early work or apply it to today's conditions. The most significant impact of this work was the publication of a "Shoulder and Rest Area Use Study Procedure Guide" (22) by the Highway Research Board (now the Transportation Research Board) in 1962. Despite the data limitations, the following summary of miles per stop (See Table 34) was prepared by Hauer and Lovell (23).

Table 34. Previously Reported Vehicle Stop Rates (Miles per Stop)

Vehicle Types	Taragin N.A. N.A.	Bellis New Jersey* 6am-10pm	Billion New York 8am-8pm	Blensley Oregon** N.A.	Cheeseman and Voss South Dakota*** 6am-6pm	Reilly et. al. New Jersey Day & Night
EMERGENCY STOPS						
Passenger car	7500	13450	23000	4200	11600	
Truck		5200	5200	2200	4100	
						714****
LEISURE STOPS						
Passenger car	300	980	2200	1800	2600	
Truck		150	2000	1000	1000	

* Skyway, no shoulders available for stopping.

** Freeway signed: No Parking on Highway Shoulders.

*** Categories are: involuntary and voluntary stops.

****All vehicles and stops.

Hauer and Lovell also draw conclusions concerning general relationships (23). For every emergency stop by a passenger car, there are 7 to 8 leisure stops. For every emergency stop by a truck, there are about 5 leisure stops. Trucks stop for emergencies almost 3 times more frequently than cars. It is cautioned that this data is primarily for daytime stops.

Data from the New Jersey Turnpike Authority (24) in 1981 and 1982 indicated 38,226 to 39,891 vehicle miles per aid. Aids included mechanical assistance, out of gas, flats, overheating, and miscellaneous. This may be consistent with the notion of 7 to 8 leisure stops for every involuntary stop.

Data from California Department of Transportation (25) for Los Angeles freeways based on stationary observation of a 2.62 mile section of the Hollywood Freeway (State Route 101) indicates a stop vehicle rate of 1 per 9,800 vehicle-miles based on 337 observations. The disablement rate (stops greater than 8 minutes) was 1 per 25,000 vehicles miles. The median stop time was 4.75 minutes, and the mean was approximately 17 minutes.

The mainlane stop vehicle rate on the Hollywood Freeway was one per 110,000 miles based on 30 traffic lane stops in 3.31 million vehicle miles. This included 14 brief stops of which 10 were momentary stalls. The stop rate excluding momentary stalls would be 1 per 165,000 vehicle miles. It should be noted that momentary stalls would likely be missed in the moving vehicle method used in some other studies.

The Hollywood Freeway study section had few opportunities for left shoulder stops, with only 2 in lane stops being observed (0.6 percent of total). The data could reasonably be considered representative of the no left shoulder situation.

The other sixteen of the Hollywood Freeway traffic lane stops were disablements. Twelve of the disablements drove or were pushed to the right shoulder. Only four of the disablements remained in the lane until removed from the scene. The stopped vehicle rate is one in 825,000 vehicle miles for those remaining in the traffic lane for the duration of the disablement.

The California study (25) also excluded 66 stops by police and 6 by maintenance vehicles. If these vehicles are added to the data base, the overall stopped vehicle rate drops to 1 in 8100 vehicle-miles. As will be seen later, this is still rather infrequent relative to Texas data. A possible explanation is the number of discretionary stops. However, there is no method available to test this thesis.

In conclusion, the California data at least partly suggest why the variation exists in mainlane stop rates. The California data is collected using stationary observers which indicates a significant number of momentary stalls. Also, a number of mainlane stops are either driven or pushed to the shoulder. Stops that remain in the mainlane occur about once in 825,000 vehicle-miles. If momentary stops are included, the mainlane stop rate is 1 in 110,000 vehicle-miles. Excluding momentary stalls yields a stopped vehicle rate of 1 in 165,000 vehicle-miles.

Given the wide variation in data, and the inconsistencies in collecting and reporting vehicle stop data, two data collection efforts were undertaken. The first study was undertaken because it could quickly produce some data at virtually no cost. A second study as a part of this project used the experiences of the first data collection effort to refine a data collection methodology appropriate to the study objectives. Both efforts are reported in the following sections.

Study 1

The first data collection effort in Texas was added to another study's data collection in Houston during the period of November 1983 to March 1984. The study that was underway involved travel time runs on sections of the Gulf (I-45 South), North (I-45 North), and Katy (I-10 West) freeways in Houston, Texas. During the travel time runs, the observer was also responsible for recording shoulder usage and vehicles stopped (i.e. parked) in the mainlanes.

The section of Gulf Freeway was 18.2 miles long from Choate Raod to Hogan Street. The North Freeway section covered a distance of 9.3 miles from FM 149 to Hogan Street. The last section on the Katy Freeway included the

12.7 mile section between State Highway 6 and Washington Street. The data was collected using one vehicle rotating through each section at 30 minute headways. Each site was studied from 6:00 a.m. to 10:30 a.m. and also between the hours of 4:00 p.m. and 6:30 p.m.

The results of the study are summarized in Table 35. The data is consistent with that reported elsewhere given the wide fluctuation generally reported. Some trends do appear to exist in these data. Of particular importance is the rate of mainlane stops. Mainlane stops appear to be disproportionately represented in the section without any shoulders. Mainlane stops were observed at a rate of 1 in 167,196 vehicle-miles overall as compared to 1 in 16,129 vehicle-miles for the one section without any shoulders. The no shoulder rate is also consistent with the Bellis data (see Table 34). It should also be noted that the no inside shoulder sections are underrepresented in the occurrence of mainlane stops. This would suggest that the absence of left shoulders does not contribute to significantly increased mainlane stops.

Study 2

The data collected expressly for this project initially included two sites in Dallas (Airport Freeway and Old DFW Turnpike) and three sites in Houston (North Freeway, Gulf Freeway and Katy Freeway). The stopped vehicle data was collected using one vehicle operating at 10 minute headways except on State Highway 183 where data was collected every 20 minutes.

Two adjacent sections of Airport Freeway (State Highway 183) in Dallas, Texas were studied from August 20-24, 1984. Site A runs from County Line Road on the west to Belt Line Road on the east, a total of 2.2 miles. The second section, Site B, continues east from Belt Line Road a distance of 3.5 miles to Carl Road. Site A is a full shoulder section and described more fully in a previous section on accident analysis. Site A had an 1984 ADT of 103,000 on six lanes. Site B is a no shoulder section and is more fully described in a previous section on accident analysis. Site B had an 1984 ADT of 120,000 on six lanes.

Table 35: Vehicle Stop Rates by Location in Houston, Texas

Number of Directional Lanes	Vehicle Miles of Travel	Type of Left Shoulder	Left Shoulder Stops	Left Shoulder Stop Rate	Mainlane Stops	Mainlane Stop Rate	Type of Right Shoulder	Right Shoulder Stops	Right Shoulder Stop Rate	Total Stops	Total Stop Rate
3	29,469	50% Full 50% None	1	29,469	0	0	50% unpaved 50% None	0	0	1	29,411
3	42,400	Full	3	14,084	0	0	Full unpaved	0	0	3	14,084
3	1,155,719	Full	37	31,250	6	200,000	Full	233	4,950	276	4,187
3	61,982	None	0	0	0	0	50% Full unpaved 50% None	1	62,500	1	62,500
3	50,488	None	0	0	0	0	50% Full 50% None	3	16,949	3	16,949
3	10,698	None	0	0	0	0	Full	6	1,782	6	1,782
3	21,960	None	0	0	0	0	75% None 25% Full unpaved	6	3,623	6	3,623
3	59,935	None	0	0	0	0	50% Full	16	3,745	16	3,745
3	279,526	None	0	0	0	0	Full unpaved	22	12,658	22	12,658
3	80,073	None	0	0	5	16,129	None	0	0	5	16,129
4	464,764	Full	14	33,333	2	250,000	Full	108	4,310	124	3,748
5	84,001	Full	4	21,276	1	84,001	Full	31	2,710	36	2,333
Total Avg.	2,340,750		59	39,674	16	167,196		426	5,495	499	4,694

A summary of the types of stops observed is shown in Table 36. In addition to recording shoulder usage, the vehicle license plate number was recorded so that the owner could be sent a questionnaire. Details of the questionnaire are discussed in a later section.

Table 36: Airport Freeway Shoulder Stop Time Summary

Location	# of Stops	Mean Time (Minutes)	Median Time (Minutes)
Right Shoulder	99	98.9	20
Left Shoulder	4	35.0	28
Mainlanes	1	40.0	40
TOTAL	104	95.9	20

The second set of sites was on the Katy Freeway (Interstate Highway 10 West) in Houston, Texas. Three adjacent sections were studied from November 5-9, 1984. Site A goes from State Highway 6 on the west to Dairy Ashford, a distance of 2.3 miles. Site B continues east from Dairy Ashford a distance of 2.2 miles to Brittmoore. Site C continues east from Brittmoore to Blalock. Site C is 2.3 miles in the eastbound direction and 2.9 miles in the westbound direction. Site A has full shoulders. Sites B and C have no left shoulders, full right shoulders, and six traffic lanes.

The 1984 ADTs for the sites are 114,000, 150,000, and 175,000 for sites A, B, and C, respectively. Stopped vehicle data was collected using two vehicles passing through the sites at ten minute headways. A summary of the data collected is presented in Table 37.

Table 37: Katy Freeway Shoulder Stop Time Summary

Location	# of Stops	Mean Time (Minutes)	Median Time (Minutes)
Right Shoulder	168	61.9	13.5
Left Shoulder	5	37.6	13.0
Mainlanes	0	0	0
TOTAL	173	61.2	13.0

The third set of sites was on the old DFW Turnpike (Interstate Highway 30) in Dallas, Texas. The data was collected during the week of December 17-21, 1984. Site A begins at the western end of the study section which is Loop 12 and runs for a distance of 2.2 miles to Marker 2. The last section is designated Site C and runs from Marker 2 a distance of 0.8 miles to Beckley Road. Sites A, B, and C have full shoulders, partial left/full right shoulders, and no left/full right shoulders, respectively. All sites have six traffic lanes.

The ADT for Sites A, B, and C is 78,000, 86,000, and 94,000 vehicles per day, respectively. Stopped vehicle data was collected using two vehicles passing through the study sections at 10 minute headways. A summary of the data is shown in Table 38.

Table 38: Old DFW Turnpike Shoulder Stop Time Summary

Location	# of Stops	Mean Time (minutes)	Median Time (minutes)
Right Shoulder	179	44.4	10
Left Shoulder	2	10.0	10
Mainlanes	0	0	0
TOTAL	181	44.0	10

The fourth set of sites was on the North Freeway (Interstate Highway 45) in Houston, Texas. Three adjacent sections were studied the week of January 7-11, 1985. The northern limit is North Belt and Site A runs 3.0 miles southward to FM 149. Site B continues south from FM 149 1.5 miles to Norht Shepherd. Continuing south, Site C runs 2.3 miles to Tidwell. Sites A and B have full shoulders on both sides. Site C has no left shoulders and full right shoulders.

The ADT for Sites A, B, and C is 165,000, 172,000, and 171,000 vehicles per day, respectively. Stopped vehicle data was collected using two vehicles at ten minute headways. A summary of the shoulder stops is given in Table 39.

Table 39: North Freeway Shoulder Stop Time Summary

Location	# of Stops (minutes)	Mean Time (minutes)	Median Time
Right Shoulder	139	63.9	14
Left Shoulder	4	276.2	27
Mainlanes	0	0	0
TOTAL	143	69.8	14

The last site in this study group of five was the Gulf Freeway (Interstate Highway 45 South) in Houston, Texas. Data was collected at a single site during the week of March 25-29, 1985. The limits of the study were Airport Blvd. on the north and Alameda-Genoa Road on the south. The length of the study section was 2.1 miles. The site has full shoulders on both sides. The data are summarized in Table 40.

Table 40: Gulf Freeway Shoulder Stop Time Summary

Location	# of Stops (minutes)	Mean Time (minutes)	Median Time
Right Shoulder	96	39.9	11
Left Shoulder	8	31.2	30.5
Mainlanes	0	0	0
TOTAL	104	39.2	11

The data from the five sites is summarized by stop location (left shoulder, mainlanes, or right shoulder) in Table 41. Usage of the left shoulder is infrequent even on sections with full paved inside shoulders. The one observed mainlane stop was on a section with no inside shoulder. It cannot be determined if the lack of an inside shoulder contributed to the mainlane stop. The observed stop represents a rate of 1 per 483,000 vehicle

Table 41: Summary of Stop Frequency by Location (Study 2)

Number of Directional Lanes	Vehicle Miles of Travel	Left Shoulder Type	Left Shoulder Stops	Left Shoulder Stop Rate	Mainlane Stops	Mainlane Stop Rate	Right Shoulder Type	Right Shoulder Stops	Right Shoulder Stop Rate	Total Stops	Total Stop Rate
3	83,842	Full	2	41,666	0	0	Full	75	1,118	77	1,089
3	809,877	Full	21	38,461	0	0	Full	333	2,433	354	2,288
3	483,760	None	0	0	1	483,752	Full	200	2,421	201	2,407
3	88,290	Partial	0	0	0	0	Full	73	1,209	73	1,209
TOTAL	1,465,770		23	63,729	1	1,465,770		681		705	2,079

*This inside shoulder has a cross section that is 4.5' paved and 14.5' unpaved.

miles based on attributing the stop to the lack of inside shoulders. If the stop is unrelated to inside shoulkders, the rate is 1 per 1,465,770 vehicle-miles observed. These data appear to be somewhat high relative to Table 35 and the California data. Table 35 appears more representative of mainlane stops.

The Study 2 data were collected on a more frequent basis (10-20 minutes versus 30 minute for Study 1). This would likely produce a shorter mean miles/stop due to the observation of more short duration stops. However, Study 2 produced less frequent stop rates for left shoulders and mainlanes. The data for left lanes and mainlanes would have to be considered less reliable due to the limited number of observations. Overall, general patterns do emerge.

Table 42 portrays the data by cross section type. Comparing the sections with and without inside shoulders (the third and fourth group in Table 41) suggests that the overall shoulder stop rate is only slightly affected by the lack of an inside shoulder.

Table 42: Summary of Stop Frequency by Cross Section Type

# of Lanes	Left Shoulder	Right Shoulder	Freq.	Cum. Freq.	Vehicle-miles of Travel	Miles/ Stop
3	Partial	Full	73	73	88,290	1,209
3	Full *	Full	77	150	83,842	1,089
3	None	Full	201	351	483,760	2,407
3	Full	Full	354	705	809,877	2,288

*This inside shoulder has a cross section that is 4.5' paved and 14.5' unpaved in width.

Given the low usage rate of left shoulders, it is logical that the overall stop rate would be little affected by the presence or absence of a left shoulder. As will be shown later, left shoulder stops involve less leisure or discretionary purpose stops.

Table 43 summarizes the data by study location. The data appears to be consistent. The mean stop time can easily be distorted by one long term stop and the median value is clearly the preferred indicator of stop time.

Table 43: Stop Time by Study Location

* Right Shoulder *			
Site	Total Stops	Mean	Median
I-10	168	61.9	13.5
I-30	179	44.4	10.0
I-45 (North)	139	63.9	14.0
I-45 (Gulf)	96	39.9	11.0
SH 183	99	98.9	20.0[1]
TOTAL	681	60.0	13.0
* Left Shoulder *			
Site	Total Stops	Mean	Median
I-10	5	37.6	13.0
I-30	2	10.0	10.0
I-45 (North)	4	276.2	27.0
I-45 (Gulf)	8	31.2	30.0
SH 183	4	35.0	28.0[1]
TOTAL	23	74.0	20.0
* All Shoulders *			
Site	Total Stops	Mean	Median
I-10	173	61.2	13.0
I-30	181	44.0	10.0
I-45 (North)	143	69.8	14.0
I-45 (Gulf)	104	39.2	11.0
SH 183	104	95.9	20.0[1]
TOTAL	705	60.4	13.0

[1]All sites used 10 minutes between observation except for SH 183 which used 20 minutes.

Motorist Survey

The above reported data is based on the observation of a survey vehicle driving through the study sites every 10 minutes. In order to maintain consistent headways and also due to the difficulties in changing lanes in heavy traffic to stop on the appropriate shoulder, it was determined that additional information concerning vehicle stops could be obtained by recording vehicle license plates and mailing the registered owner a survey questionnaire. The questionnaire was pretested and refined based on some early experience in Dallas, Texas. The final form of the survey is shown in Figure 56 except that the individual questionnaire for each study location included a map at the top of the survey form indicating the study section location. Surveys were distributed on the Airport Freeway, Old DFW Turnpike, Katy Freeway, and the North Freeway. There was no survey distributed to the Gulf Freeway motorists.

A total of 455 questionnaires were mailed. This is 76 percent of the 601 observed stops on the study sections. Those not mailed questionnaires included trucks registered to companies, vehicles registered in other states, unreadable license plates, and license plates that were read incorrectly. The response rate for the questionnaires was 26 percent, yielding a total of 119 useable responses as summarized in Figure 56. However, only 41 percent of those responding indicated that they had in fact stopped on the study section. This may have been the result of a variety of factors including the casual nature of some stops, other drivers using the vehicle, and errors in recording license plate numbers. Therefore, out of 703 observed stops, only 49 useable responses (7 percent of the total observed) were received. This is not considered an acceptable number of responses to draw conclusions; however, the data is reported for information purposes.

Seventy-seven percent of the respondents indicated that their stop was involuntary. This is not consistent with the previously reported rate of one emergency stop for every 7 or 8 leisure stops. Looking at a map might be considered voluntary. Certainly it could be deferred. This would make virtually all other stops involuntary. However, one could also consider stopping to assist another motorist voluntary, unless it was a friend or

MOTORISTS SURVEY RESPONSE SUMMARY[1]

- Reasons for Stopping on Outside Shoulders -

This survey concerns the portion of **Interstate Highway** [2] between and

1. Do you recall recently stopping on the shoulder or the actual traffic lanes of **Interstate Highway?**

   49(41%) Yes 48(40%) No 22(19%) Do not use the highway 119 Responses

If you answered this question "Yes," please fill out the remainder of the survey. If you answered "No" or "Do not use" please return the survey in the enclosed envelope.

2. What was the reason for stopping along **Interstate Highway?** 49 Responses

   16(33%) Mechanical ______ Changing Drivers/Adjusting Load 4(8%) Assisting Another Motorist 11(22%) Looking at map
   6(12%) Flat 1(2%) Rest/Sleep ______ Stopped for Violation ______ Other (specify) ______
   4(8%) Accident 1(2%) Bad Weather
   6(12%) No Gas

3. Was your stop 11(23%) voluntary (you could have driven to the next exit) or 36(77%) involuntary?

   47 Responses

4. What is your vehicle type? 49 Responses

   9(18%) Compact 6(12%) Pickup 3(6%) Light Truck (2-Axles) ____ Heavy Truck (3 Axles or more)
   27(55%) Full size 2(4%) Van 2(4%) Other (specify) ______

5. If there was no shoulder to stop on, what would you have done? 30 Responses

   15(50%) Stopped in the traffic lane
   12(40%) Driven to the next exit or safe place to stop that was not in the traffic lanes.
   3(10%) Other (explain) ______

6. Please indicate whether or not you left your vehicle, and if so, why? 49 Responses

   27(55%) Did not leave 4(8%) Picked up by other motorist/friend/police
   14(28%) Get help or gas 4(8%) Other (explain) ______

7. Approximately how long was your vehicle stopped?

   -- Days 2 Hours 6 Minutes 43 Responses
   std error: 37 minutes

[1]Returned surveys, totaled 119 out of 455 mailed out.

[2]Highway description, as appropriate. Survey were mailed to users of SH 183 and I-30 in Dallas, and users of I-10 and I-45 in Houston.

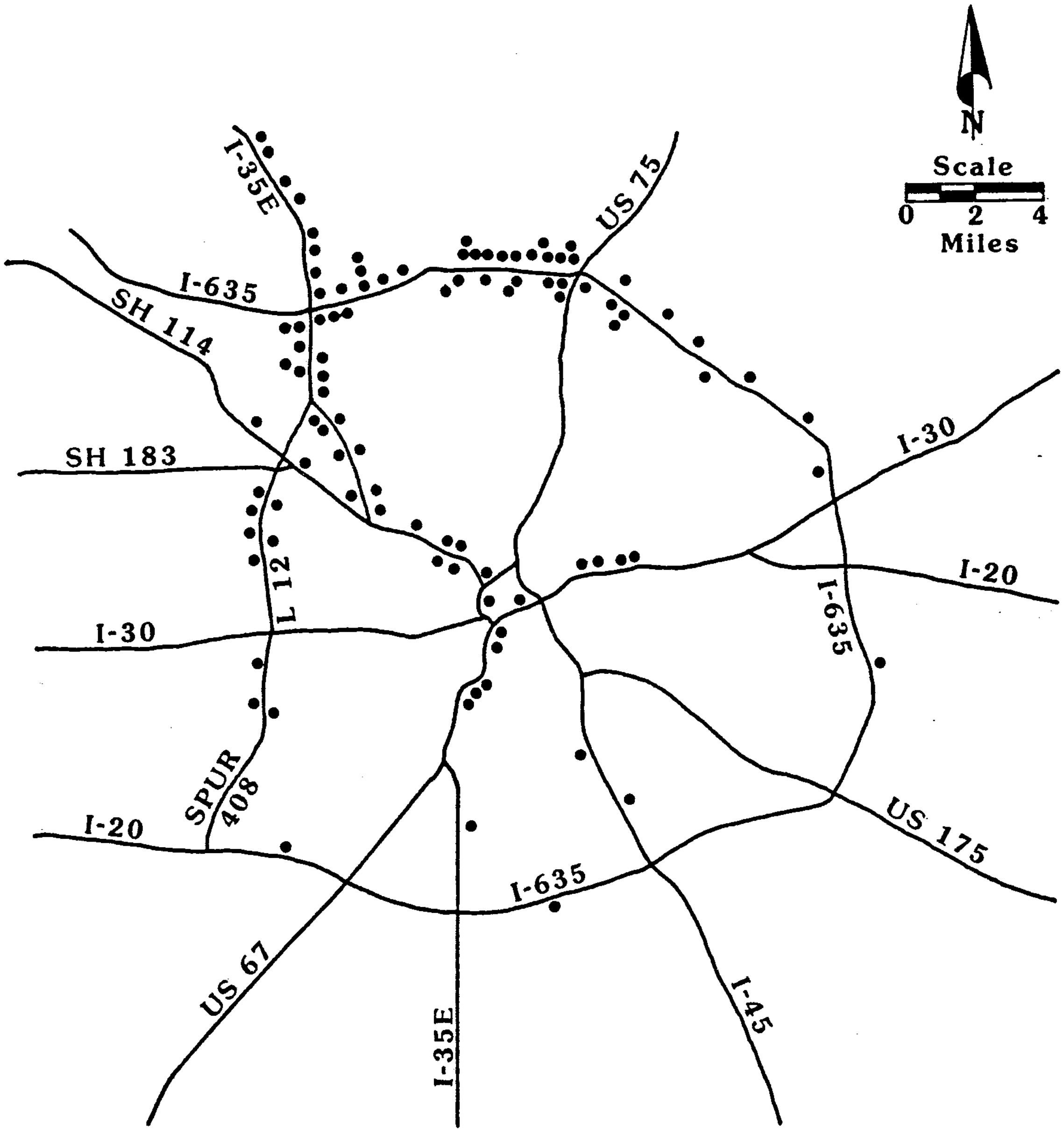
Figure 56. Outside Shoulder Survey Form and Responses

spouse. It appears there is an overrepresentation in responses from those persons who had more serious reasons for stopping. That is, those who made leisure stops may not have been as likely to remember stopping as would someone who had "car trouble". Given the low response rate (7 percent), the inconsistency with other surveys, and the inconsistency with observed stop rates, the results of the survey must be viewed cautiously.

The fifth question is intended to determine the deferrable nature of stops in another way by asking if the vehicle could be driven to the next exit. Only 40 percent of the respondents indicated that they could have driven to the next exit. Furthermore, 50 percent of the respondents indicated that they would have had to stop in the mainlanes. These responses appear to over estimate stop rates. Looking at the data reported earlier in Table 33, the overall stop rate was 1 per 4,694 vehicle-miles. If 50 percent of the stops were not deferrable, then a section with no shoulders should experience a stop rate of about 1 per 9,000 vehicle miles. Using Table 33 the observed rate was on per 16,129 vehicle-miles, or nearly 2 times less frequent than would be predicted from the survey.

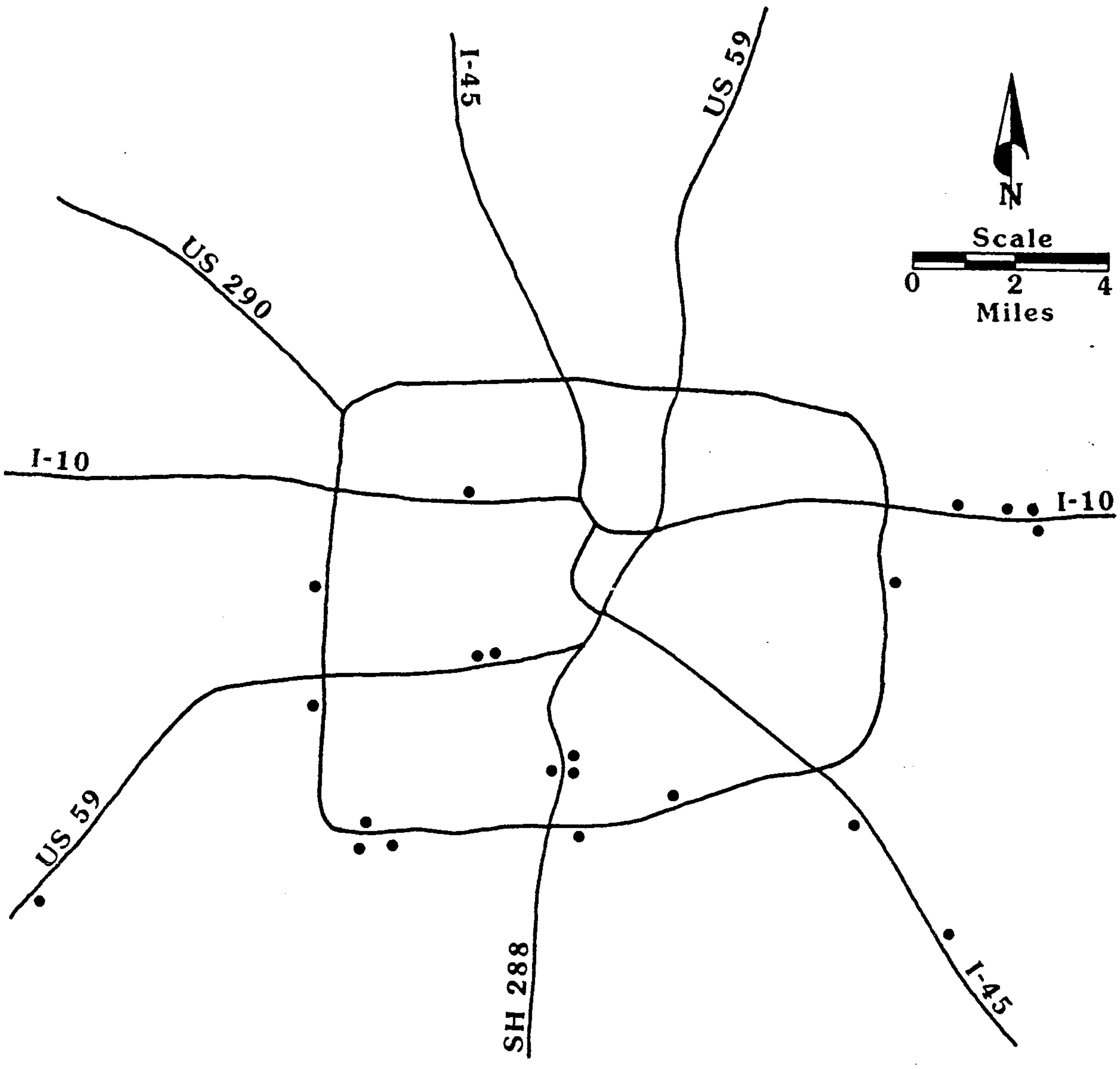
The low effective response rate on the motorist survey led to consideration of abandoning further survey work. However, given the desire to obtain additional information on left shoulder usage, a new approach was developed. A special survey was undertaken to obtain information only from users of the left shoulder. No attempt was made to control the time at which a left shoulder user was observed as had been the case for the general survey. Furthermore, the survey vehicle was only concerned with the left shoulder, so the survey vehicle driver could position himself in the left lane. This allowed for the driver to stop and either hand a questionnaire to the driver or leave a questionnaire on the windshield of the vehicle. This approach obviously eliminated the problem of identifying the correct vehicle and driver. The survey forms are shown in Appendix D.

Figure 57 shows the locations in Dallas, Texas where left shoulder users were surveyed. A total of 100 questionnaires were distributed. On average, one vehicle was observed for every ten miles traveled. Figure 58 shows the locations surveyed in Houston, Texas. An average of 41 miles of travel was



***100 Surveys Distributed.**
Average 10.1 Miles Per Breakdown.

Figure 57. Survey Distribution Locations Dallas, Texas



***24 Surveys Distributed.**
Average 40.9 Miles Per Breakdown.

Figure 58. Survey Distribution Locations Houston, Texas

required for every left shoulder survey distributed. A total of 24 questionnaires was distributed. No explanation is available for the wide variation in the usage between Dallas and Houston, although the overall vehicle stop rate is twice as frequent in Dallas as Houston.

The questions and responses to the questionnaire are shown in Figure 59. The response rate for the inside shoulder survey was 34 percent or 42 responses. The most significant finding would be the higher rate of involuntary stops for those using the left shoulder. This is consistent with the notion that drivers would appear to prefer to use the right shoulder when the option exists.

The responses appear to be inconsistent with observed mainlane stop rates. Referring to Table 35, an average, overall stop rate might approximate 1 in 5000 vehicle-miles. Further, the left shoulder stop rate is about 1 in 30,000 miles. If only 17 percent of those stopping could use the right shoulder, the mainlane stop rate would be estimated at 1 in about 36,000 vehicle-miles. The observed mainlane stop rate with full shoulders both sides is about 1 in 189,000 miles in the Table 35 data set. The California data (25) suggest a rate of 1 in 165,000 vehicle miles for no left/full right shoulders. This would suggest that the 1 in 36,000 vehicle-miles stop rate is unreasonably frequent for a section without a left shoulder. It is difficult to accept the survey data given the discrepancy between the two data sets. At this point in time, it would appear more appropriate to use an estimated value given the subjective nature of the survey, the low number of responses, and the fluctuation in observed data (25).

The inside shoulder survey generated comments from more than half of the respondents (23 comments of the 42 responses). The comments, which are included in Appendix D, included 13 positive remarks (i.e., expression of need) about shoulders. Motorists who use shoulders clearly appreciate them as indicated by the effort taken to write a comment. This is an unusually large number of comments especially considering the remarks were all generally about the need or value of inside shoulders.

MOTORISTS SURVEY RESPONSE SUMMARY[1]

Inside Shoulder Stops

1. What was the reason for stopping on the freeway shoulder? 42 Responses

Involuntary		Voluntary	
(48%)	20 Mechanical Problem		_____ Changing Drivers
(21%)	9 Flat Tire	(5%)	2 Rest/Sleep
(24%)	10 Out of Gas		_____ Assisting Motorist
	_____ Stopped for Violation		_____ Looking at Map
(2%)	1 Other		_____ Other

2. Had there been no left (inside) shoulder, could you have driven to the right (outside) shoulder?

   (17%) 7 Yes (83%) 35 No 42 Responses

3. Had there been no left or right shoulder, could you have driven to the nearest freeway exit?

   (12%) 5 Yes (88%) 36 No 41 Responses

4. Approximately, for how long was your vehicle stopped?

   2 Days 3 Hours 9 Minutes 41 Responses

   Mean: 4.9 Hours

   Median: 3 Hours

5. Comments: 26 Responses

[1]A total of 124 survey forms were delivered to cars stopped on the inside shoulder of freeways in Dallas and Houston.

Figure 59. Inside Shoulder Survey Form and Response

LANE POSITIONING WITH NO LEFT SHOULDER

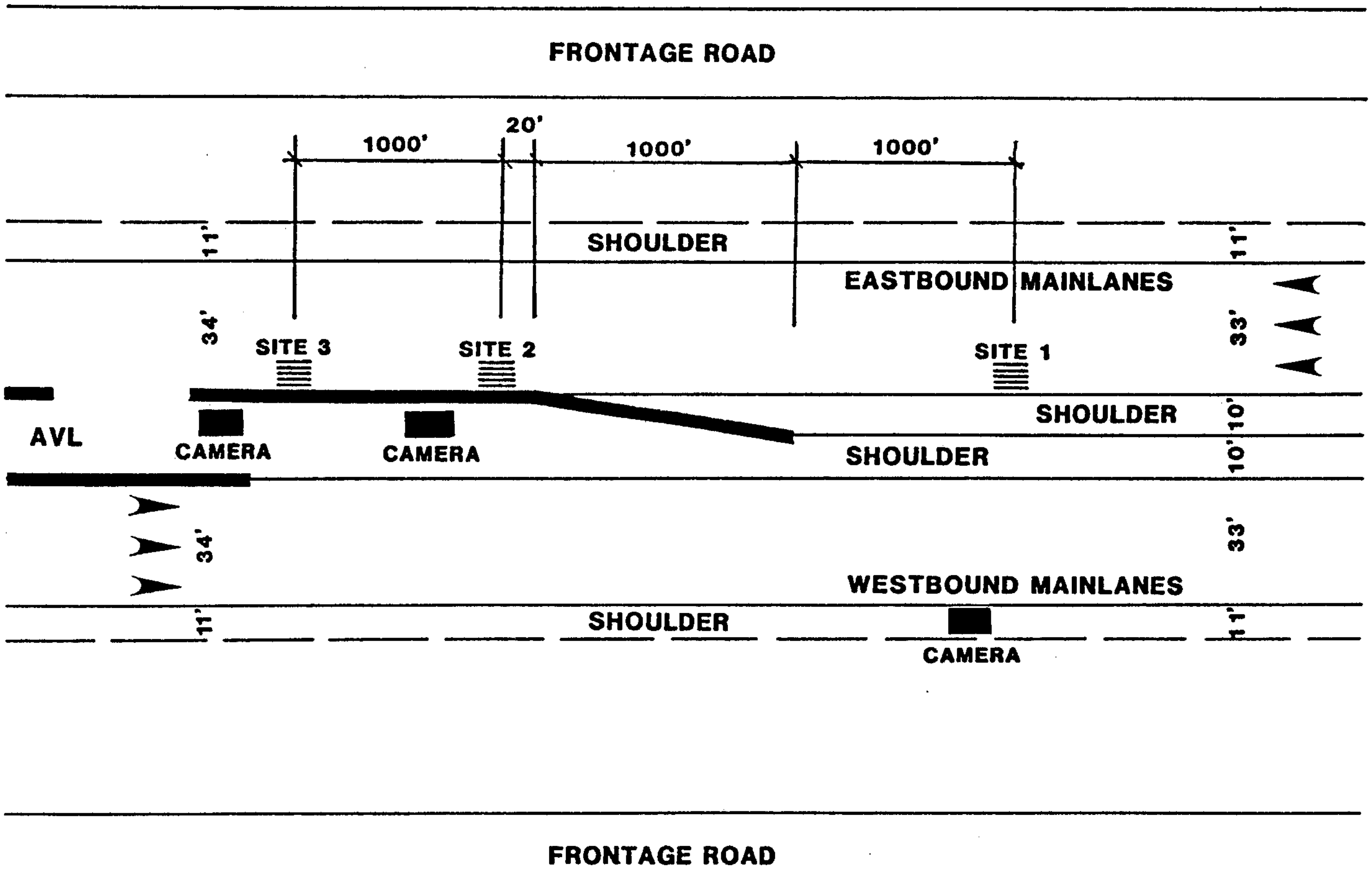
The elimination of the left shoulder potentionally impacts operation in a number of ways including capacity and increased mainlane stops. Furthermore, shoulder removals have typically narrowed lanes to 11 ft. (and occasionally less). Given the need to allocate available cross section space between lanes and perhaps providing some shoulder space for barrier "shy" (the tendency to move away or avoid) distance, a study was made of the impact of a concrete median barrier on lane placement. The study on the Katy Freeway section involved a 6" shoulder section separating a concrete median barrier from an 11-foot, six-inch traffic lane. Essentially, the inside lane is 12 ft. and the lane line is approximately 6" from the toe of the barrier.

Figure 60 shows the three study locations. Lane placement was measured at three locations using an overhead camera. Markings were placed on the pavement at one foot intervals. The results are segregated by peak and off-peak periods, trucks (i.e. vehicles with more than 2 axles) and cars. The data was collected during the period August 19 to 23, 1985. The peak period observations were between 7 a.m. and 9 a.m. Off-peak observations were between 11 a.m. and 1 p.m. The weather was clear.

Tables 44 and 45 present the data collected. The data is portrayed graphically in Figures 61 and 62. The data generally shows a greater impact on trucks than cars and a greater impact during off-peak hours.

Table 44 indicates cars move 1.1 ft. right during off-peak periods and 0.9 ft. right during peak periods. Trucks follow a similar pattern; however, they move only 0.6 ft. during off-peak and 0.5 during peak periods. Clearly, increasing traffic volume causes some "shy" factor from the right.

The conclusion to be drawn from the data is that a barrier with 1 foot of an eleven foot lane causes vehicles to "shy" away up to about 1 foot. This suggests that some additional shoulder width would be desirable to eliminate or reduce the "shy" distance. Further study would be necessary to quantify the relationship. It would seem reasonable to add an additional



I-10 KATY FREEWAY
DATA COLLECTION SITE
(NOT TO SCALE)

Figure 60.

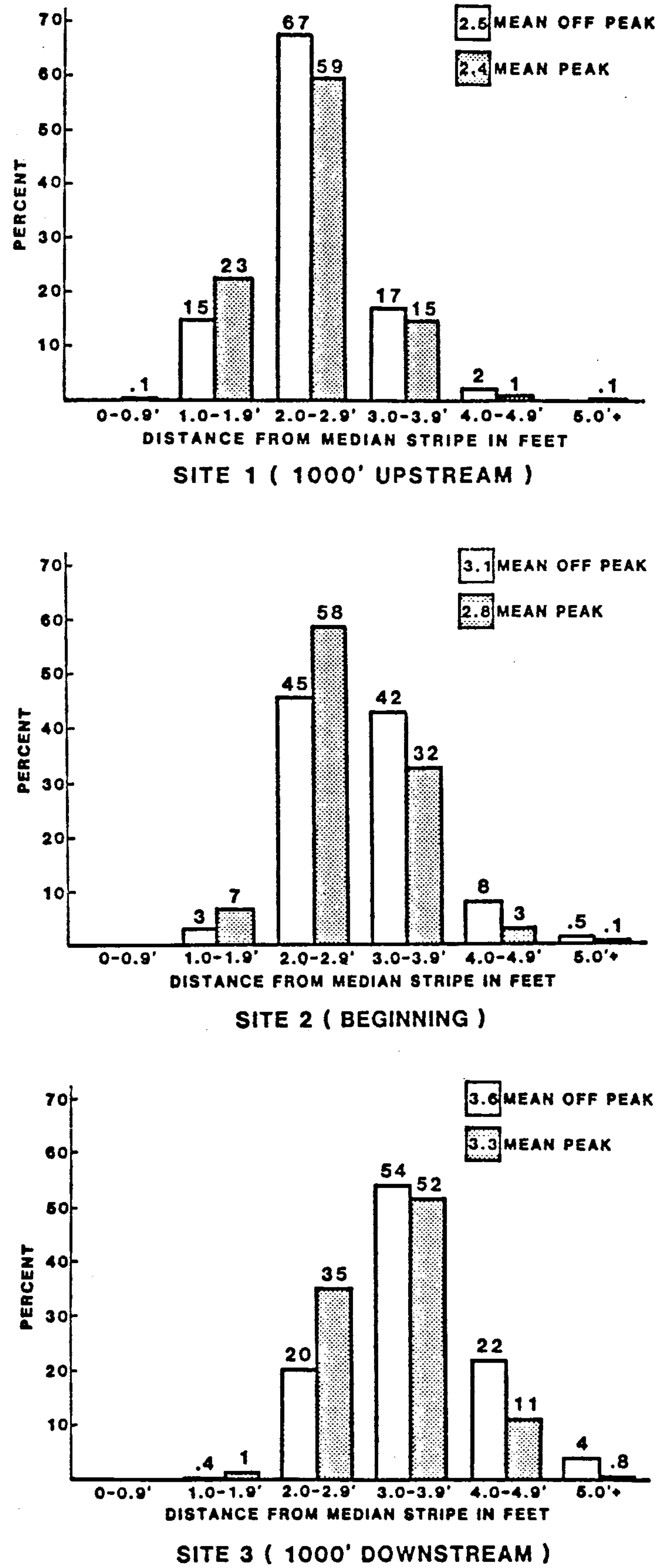


Figure 61. Katy Freeway Lane Placement-Cars

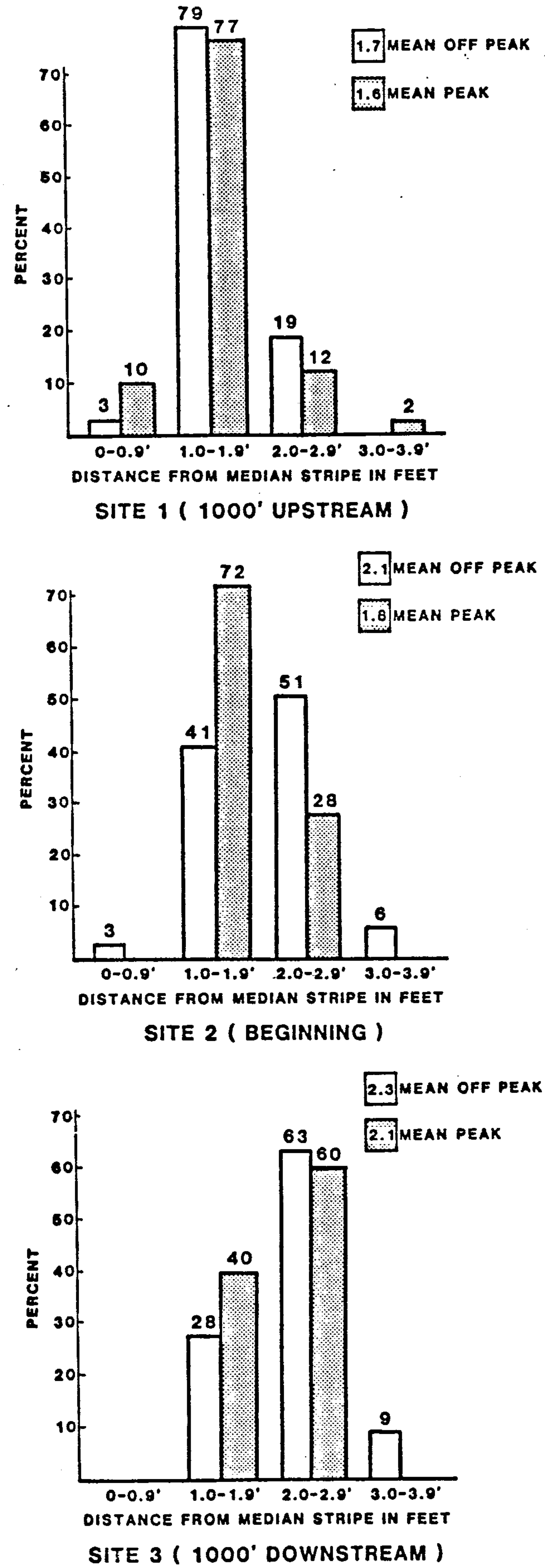


Figure 62. Katy Freeway Lane Placement-Trucks

foot to the shoulder width to account for the one-foot "shy" distance experienced by cars. This suggest a 2 ft. minimum left shoulder width.

Table 44: Katy Freeway Barrier Clearance Study - Cars

Location	Peak Distance in Feet from Left Edge Line to Vehicle					
	0 - 0.9	1.0 - 1.9	2.0 - 2.9	3.0 - 3.9	4.0 - 4.9	5.0+
Site 1	1	267	680	177	16	1
(Mean = 2.4 ft)	(0.09)	(23.4)	(59.5)	(15.5)	(1.4)	(0.09)
Site 2		87	677	379	31	1
(Mean 2.8 ft)		(7.4)	(57.6)	(32.2)	(2.6)	(0.08)
Site 3		15	403	604	133	10
(Mean 3.3 ft)		(1.3)	(34.6)	(51.8)	(11.4)	(0.8)
All Sites	1	369	1760	1160	180	12
(Mean 2.8 ft)	(0.03)	(10.6)	(50.5)	(33.3)	(5.2)	(0.3)
Location	Off Peak Distance in Feet from Left Edge Line to Vehicle					
	0 - 0.9	1.0 - 1.9	2.0 - 2.9	3.0 - 3.9	4.0 - 4.9	5.0+
Site 1		165	750	191	19	
(Mean 2.5 ft)		(14.7)	(66.7)	(17.0)	(1.7)	
Site 2		37	511	479	96	6
(Mean = 3.1 ft)		(3.3)	(45.3)	(42.4)	(8.5)	(0.5)
Site 3		5	218	603	244	44
(Mean 3.6 ft)		(0.4)	(19.6)	(54.1)	(21.9)	(3.9)
All Sites		207	1479	1273	359	50
(Percent Mean = 3.1 ft)		(6.1)	(43.9)	(37.8)	(10.6)	(1.5)

Values shown are number of observations per cell and row percentage in ( ).

Table 45. Katy Freeway Barrier Clearance - Trucks

Location	Peak Distance in Feet from Left Edge Line to Vehicle			
	0 - 0.9	1.0 - 1.9	2.0 - 2.9	3.0 - 3.9
Site 1	6	44	7	1
(Mean =1.6 ft)	(10.5)	(77.2)	(12.3)	(1.7)
Site 2		18	28	
(Mean = 1.8 ft)		(72.0)	(28.0)	
Site 3		14	21	
(Mean = 2.1 ft)		(40.0)	(60.0)	
All Sites	6	76	35	1
(Mean = 1.8 ft)	(5.1)	(64.4)	(29.7)	(0.8)

Location	Off Peak Distance in Feet from Left Edge Line to Vehicle			
	0 - 0.9	1.0 - 1.9	2.0 - 2.9	3.0 - 3.9
Site 1	2	59	14	
(Mean = 1.7 ft)	(2.7)	(78.7)	(18.7)	
Site 2	2	29	36	4
(Mean = 2.1 ft)	(2.8)	(40.8)	(50.7)	(5.6)
Site 3		24	54	8
(Mean = 2.3 ft)		(27.9)	(62.8)	(9.3)
All Sites	4	112	104	12
(Mean = 2.0)	(1.7)	(48.3)	(44.8)	(5.2)

Values shown are number of observations per cell and row percentages in ( ).

DELAY CONSIDERATIONS

One benefit of shoulder removals is reduced delay resulting from added capacity. A variety of means might be used to alter the median cross section in order to increase effective person-movement capacity. An example of the magnitude of benefits can be seen by example, using the Southwest Freeway (US 59) in Houston.

The analysis is based on a 10 mile section of the Southwest Freeway from West Belt to just inside the West Loop (I-610). The data is based on the FREQ7 computer simulation model developed by the University of California at Berkeley. An estimate of benefits (present value of a 20-year benefit stream) associated with selected alternative approaches is summarized in Table 46 (26, 27). These costs define the general magnitude of benefits on a congested freeway.

Table 46. Estimated Present Value of Benefits Associated with Alternative Uses of the Median Area, Southwest Freeway (US 59) Analysis

Alternative Use	Present Value of Benefits[1] (millions of dollars)
One Additional Traffic Lane In Each Direction	$600
One Lane Reversible Transitway	$600
Two Lane Transitway	$680

[1]Benefits included are reduced passenger hours of travel, reduced fuel consumption and reduced transit operating cost. A 10% discount rate, a $7.00 per hour value of time, and a $50 per bus hour rate is used for a 20-year analysis period.

Source: FREQ analysis, Southwest Freeway, West Belt to I-610 (approx. 10 miles).

What has not generally been considered in the past is the magnitude of disbenefits caused by incidents. Capacity increases are noted on "typical" days which ignore incidents. The analysis of delay disbenefits requires data on breakdown which was reported earlier. It should be cautioned that the data are at best estimates, but should at least indicate the magnitude of the disbenefits.

In order to estimate the increase in mainlane breakdowns due to the absence of a left shoulder, it would be necessary to assume a number of factors. Looking at Table 33, there are 484,319 vehicle-miles of travel observed with no left shoulder and no mainlane stops. However, the same data set indicates a mainlane stop rate of 1 in 189,000 vehicle-miles with full shoulders. The mainlane stop rate for the entire data set in Table 33 is 1 in 167,196. The previously reported survey data would suggest a mainlane breakdown every 60,000 vehicle-miles based on 50 percent of the left shoulder users indicating they would stop in the mainlanes. Using another set of assumptions, the rate was estimated earlier at one in 161,000. It is difficult to explain the apparent inconsistencies in the data. Fortunately, the accuracy of the mainlane breakdown rate does not affect the conclusion relative to operational effects.

An analysis of the delay caused by a breakdown suggests a median time of 15 minutes is appropriate for analysis. Recalling the California data, vehicles disabled in traffic are generally moved or pushed to the shoulder. It is reasonable to conclude that stop time is generally less than that observed for vehicles stopping on shoulders, which is 13 minutes. Since the delay incurred per breakdown is a function of the time of day the breakdown occurs, it is necessary to construct a weighted average cost.

The analysis is again based on the Southwest Freeway for consistency. Delay costs are calculated using a modified version of the QUEWZ (27) model. The modification was necessary to allow use of 15-minute (rather than hourly) volumes and capacity. The assumed capacity is 1,700 vehicles per hour in 4 lanes and 1,500 vehicles per hour in 3 lanes during an incident. Estimated delay costs using QUEWZ are $2,500 per 15 minute incident, based on $10 per vehicle-hour of delay (29).

The approach to be taken for analysis is to estimate the frequency of mainlane stops required to negate the $600 million in potential benefits by converting a shoulder to a traveled lane as shown in Table 44. The uniform annual cost equivalent to a $600 million present value is $70 million assuming a 20 year analysis period and a 10 percent interest rate. Given a $2,500 cost per incident, the number of incidents per year required to generate 70 million is 28,190 or about 77 per day.

Assuming an ADT of 208,000 vehicles per day exists 365 days per year over 10 miles yields 759 million vehicle-miles per year. This is equivalent to a mainlane incident every 27,000 miles. This is clearly more frequent than the worst case estimate of 60,000 miles; it is also much less than a best judgement estimate of 1 mainlane incident per 160,000 vehicle-miles.

It should be noted that the delay cost equivalent of 1 incident per 27,000 vehicle-miles indicates that a no shoulder section (i.e. no left or right) would experience an incident delay cost in excess of the benefits associated with added capacity that could be achieved by removing both shoulders. Increasing capacity by taking away both shoulders (i.e., no emergency parking opportunities available) should not be considered a cost effective treatment.

CONCLUSIONS AND RECOMMENDATIONS

The removal of a left shoulder (i.e., removal of all but 2 ft.) on an existing urban freeway can be a cost-effective and safe means of providing additional mixed-flow or barrier separated high occupancy vehicle lane capacity. Under congested conditions (ADT/Lane greater than 20,000 vehicles per day), the removal of a left side shoulder should be considered an appropriate treatment to improve capacity and appears to improve safety as well when the project can reasonably be expected to reduce the level of congestion (ADT/Lane less than 18,000 vehicles per day).

The conversion of shoulders to travel lanes (either mixed flow or barrier separated high occupancy vehicle lane) does not suggest that full left shoulders are undesirable on new constructions. The provision of inside shoulders is regarded highly by the travelling public and highway engineers as a desirable feature. Furthermore, provision of a full inside shoulder provides increased flexibility to handle future traffic needs.

It has also been concluded that left shoulder removals are preferable to right shoulder removals even though right shoulder removals are often easier to implement. Right shoulder removals appear to be safe treatments when parking opportunities exist beyond the shoulder. It would, however, appear desirable to provide paved parking areas when right shoulders are removed.

Adding a lane at the expense of removing both shoulders does not appear to be a practice that should be considered except in the most unusual circumstances. Sections with no shoulders appear to have higher accident rates. There is also a tendency towards higher accident severity rates on no shoulder sections. These findings are consistent with the unusually high probability of a traffic lane blockage for no shoulder sections. It has also been shown that the delay costs are likely to exceed the benefits of added capacity due to removal of all shoulders. The fact that some short sections of no shoulders have been safely implemented is the basis for suggesting that the treatment may be appropriate in limited instances; however, careful analysis is suggested.

The study findings suggest that left shoulder removals do not affect accident severity. In addition, the effects of "spot" shoulder removals appear to be long-term. That is to say, accident rates do <u>not</u> appear to increase with time after a shoulder has been removed.

It is also concluded indirectly that safety is not significantly affected by narrowing lanes to 11 ft.. The capacity effects of 11-ft. lanes is also believed to be insignificant.

The barrier "shy" study indicates vehicles are being forced to move up to one foot closer to the adjacent lane when the barrier is within one foot of the left lane. It appears reasonable to conclude that a minimum desirable width for "no shoulder" is 2 ft.

REFERENCES

1. Chansky, Sumner B., Must Highway Reconstruction Always Comply with Design Standards?, Traffic Engineering, July 1975, pp 58-60.

2. A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, Washington, D.C., 1984.

3. Shoulder Geometrics and Use Guidelines, NCHRP Rpt. 254, Transportation Research Board, Washington, D.C., 1982.

4. McCasland, W.R., Biggs, R.J.; Freeway Modifications to Increase Traffic Flow, Federal Highway Administration, Washington, D.C. January 1980, FHWA-TS-80-203.

5. McCasland, W.R., The Use of Freeway Shoulders to Increase Capacity, Texas Transportation Institute, Texas A&M University, College Station, Texas, September 1978, Res. Rpt. 210-2.

6. Newman, Leonard, Lane Width Reduction and Lane Width, The California Experience, ASCE Highway Division--Specialty Conference, San Diego, California, April 1985.

7. McCasland, W.R., The Use of Freeway Shoulders to Increase Capacity - A Review, Texas Transportation Institute, Texas A&M Univeristy, College Station, Texas, January 1984, Res. Rpt. 210-10.

8. Evaluation of the I-10 (24th Street to Broadway Road) 6-lane vs 8-lane Freeway Operations, Traffic Design Services, Arizona Department of Transportation, August 1983 (internal paper).

9. Kuo, N.M., Peterson, R.L., and Mounce J.M.; Evaluation of High Occupancy Vehicle Priority Treatment Projects: First Year's Analysis, (draft), Texas Transportation Institute, Texas A&M University, College Station, Texas, August 1984.

REFERENCES CONTINUED

10. Kuo, Nana M. and John M. Mounce, The Katy Freeway Authorized Vehicle Lane: Evaluation of the First Year of Operation, (DRAFT), Texas Transportation Institute, Research Report 339-6, College Station, Texas, February 1986.

11. New Jersey Turnpike report, no date.

12. Smith, Richard N., Predictive Parameters for Accident Rates, Division of Highways, California Department of Transportation, September 1973.

13. 1983 Accident Data on California State Highways (Road Miles, Travel, Accidents, Accident Rates), Division of Traffic Engineering, California Department of Transportation, Sacramento, California.

14. Endo, G., Spinello, J.J., Safety Evaluation Santa Monica Freeway Viaduct Widening (Westbound Interstate Route 10), Freeway Operations Branch, California Department of Transportation, September 1974, CA-DOT-0761d-0-74-10.

15. Endo, G., Anderson, E.R., Safety Evaluation of Restriping and Ramp Control on the Pomona Freeway, Freeway Operations Branch, California Department of Transportation, Los Angeles, California, July 1976, Report 76-1.

16. Dunnet, A.M., Preliminary Evaluation of Median Lane on the San Diego Freeway, Freeway Operations Branch, California Department of Transportation, Los Angeles, California, 1977, Report 77-13.

17. Dunnet, A.M., Chow, P., Interim Operational and Safety Evaluation on Northbound Route 405 Freeway, Route 10 & Route 101, Freeway Operations Branch, California Department of Transportation, Los Angeles, California, October 1977, Report 77-24.

REFERENCES CONTINUED

18. 19-Traffic Volumes on California State Highways, Office of Traffic California Department of Transportation, Sacramento California.

19. Bellis, W.R., Shoulder Use, Highway Research Board Bulletin 170, Washington, D.C., 1957.

20. Billion, C.E., Shoulder Occupancy on Rural Highways, Highway Research Board Proceedings, Vol. 38, Washington, D.C., 1959.

21. Blensleyk, R.C. and W.J. Byers; Highway Research Board Proceedings, Vol. 38, Washington, D.C., 1959.

22. Shoulder and Rest Areas Use Study Procedure Guide, Highway Research Board Bulletin 359, Washington, D.C., 1962.

23. Hauer, E. and J. Lovell, Safety Measures Aimed at Reducing Accidents Occasioned by Vehicles Stopped on Freeway Shoulder, Department of Civil Engineering, University of Toronto, Ontario, 1984.

24. Craft, Jerry, New Jersey Turnpike Authority, New Brunswick, N.J. various telephone calls, 1984.

25. Meyers, K. Phillip, Service for the Stranded Motorist Project, Volume II, Report No. 6, State of California, Department of Transportation, District 7, Los Angeles, California, August 1972.

26. Simulation Analyses of Proposed Improvements for the Southwest Freeway (US 59), Houston, Long Term, Capital Intensive Improvements, prepared for Texas State Department of Highways and Public Transportation, Houston Urban Project, by Texas Transportation Institute, August 1982.

REFERENCES CONTINUED

27. Cost Effectiveness Analyses, Southwest/West Loop Freeways, Authorized Vehicle Lanes, prepared for Metropolitan Transit Authority of Harris County, By Texas Transportation Institute, May 1984.

28. Memmott, Jeffrey L. and Conrad L. Dudek, A Model to Calculate Road User Costs at Work Zones, Texas State Department of Highways and Public Transportation, Research Report 292-1, by Texas Transportation Institute, September 1982.

29. Chui, Margaret K. and William F. McFarland, The Value of Travel Time: New Estimates Developed Using a Speed-Choice Model, Texas State Department of Highways and Public Transportation, Research Report 396-2F, by Texas Transportation Institute, May 1986.

APPENDIX A

SUMMARY OF STATE RESPONSES TO QUESTIONNAIRE ON
THE USE OF HIGHWAY SHOULDERS TO INCREASE CAPACITY

APPENDIX A

SUMMARY OF STATE RESPONSES TO QUESTIONNAIRE ON THE USE OF HIGHWAY SHOULDERS TO INCREASE CAPACITY

No.	State	Response[1]			Comments
		Positive	Negative	None	
1	Alabama		x		
2	Alaska		x		
3	Arizona	x			
4	Arkansas		x		
5	California	x			
6	Colorado			x	
7	Connecticut		x		Climbing lane data provided.
8	Delaware		x		
9	District of Columbia			x	
10	Florida			x	I-95 in Miami has been restriped to provide HOV lane.
11	Georgia	x			No details available.
12	Hawaii	x			Interchange lanes and weaving sections; minor projects.
13	Idaho		x		
14	Illinois	x			
15	Indiana		x		Considering future project.
16	Iowa		x		
17	Kansas		x		Considered for I-35 in Kansas City but rejected for safety reasons.
18	Kentucky			x	
19	Louisiana		x		
20	Maine		x		
21	Maryland			x	
22	Massachusetts	x			Previously cited (1); no new details.
23	Michigan		x		
24	Minnesota			x	
25	Mississippi		x		
26	Missouri			x	
27	Montana		x		
28	Nebraska		x		
29	Nevada			x	

APPENDIX A (con't)

SUMMARY OF STATE RESPONSES TO QUESTIONNAIRE ON THE USE OF HIGHWAY SHOULDERS TO INCREASE CAPACITY

No.	State	Response[1]			Comments
		Positive	Negative	None	
30	New Hampshire			x	
31	New Jersey		x		Provided accident rates tables.
32	New Mexico		x		
33	New York		x		
34	North Carolina		x		Scheduled project to upgrade outer shoulder to travel lane in 1984-89.
35	North Dakota	x			
36	Ohio	x			
37	Oklahoma			x	
38	Oregon	x			Banfield Freeway previously documented (1).
39	Pennsylvania			x	
40	Rhode Island			x	
41	South Carolina		x		
42	South Dakota			x	
43	Tennessee			x	
44	Texas	x			Internal information.
45	Utah		x		
46	Vermont		x		
47	Virginia	x			I-95 previously documented (1).
48	Washington	x			Information not on hand.
49	West Virginia		x		
50	Wisconsin			x	
51	Wyoming		x		

[1]Positive means that information was provided on at least one project; Negative means response stated that no project had been undertaken during the period considered; None means no response was received, thereby projects unknown.

APPENDIX B

PROJECTS USING FREEWAY SHOULDERS
TO INCREASE CAPACITY

Arizona

Location	I-10 between 24th Street and Broadway Road, Phoenix
Dates	Operations Began: March 1980 Operations Stopped: March 1981
Treatment	Restriped six traffic lanes (both ways) to provide eight lanes using right shoulders. After one year of operation lanes were restriped, back to original six lanes.
Design-Half Cross Section	Before: 2', three 12' lanes, 10' During: 2', four 11' lanes, 2'
Project Length	Eastbound: 3.7 miles Westbound: 3.3 miles
Hours of Operation	24 hours
Costs	
Implementation	$73,500
Maintenance	Not available
Results Capacity Traf. Ops Safety	Before: 105,000 vpd; LOS "E-F" During: 115,000 vpd; LOS "C-D" Back to Original: 117,000 vpd; LOS "E-F" Apparent decrease in traffic accidents due to added capacity, with eight lane operation but results are unclear due to other intervening factors.
Comments	Before and during 8-lane operation analyses were conducted but several factors changed during the one year duration of this project. Operating speeds increased and motorist delay decreased during the 8-lane operation.
Reference	<u>Evaluation of the I-10 (24th Street to Broadway Road) 6-lane vs 8-lane Freeway Operations</u>, Internal Report, Arizona Department of Transportation, Traffic Design Services, Phoenix, Arizona, August 1983.

California

Location	LA-7 Northbound between Atlantic Blvd. and Route 5, Los Angeles
Dates	Operations began: February 1981
Treatment	Restriped four lanes to five lanes using 4' of median and 3' of right shoulder. Concrete barrier wall installed.
Design-Half Cross Section	Before: 8', four 12' lanes, 10' After: 4', five 11' lanes, 7'
Project Length	Not available
Hours of Operation	Unknown
Costs Implementation Maintenance	Not available
Results Capacity Traf. Ops Safety	Not available
Comments	
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

California

Location	LA-60 Eastbound at Hacienda Blvd, Los Angeles
Dates	Operations Began: June 1982
Treatment	Restriped four lanes to five lanes by using 7' of the median shoulder before offramp.
Design-Half Cross Section	Not available
Project Length	0.4 miles
Hours of Operation	Unknown
Costs Implementation Maintenance	Not available
Results Capacity Traf. Ops Safety	Not available
Comments	
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

California

Location	LA-110 Southbound at Route 10, Los Angeles
Dates	Operations began: August 1983
Treatment	Restriped three lanes into four lanes.
Design-Half Cross Section	Varying cross section
Project Length	0.5 miles
Hours of Operation	24 Hours
Costs Implementation Maintenance	Not available
Results Capacity Traf. Ops Safety	Collector road is carrying 600 vph more during pm peak. Travel time during pm peak reduced 2 minutes between 3rd Street and Washington Blvd. More weaving required at ramps but no accident data available.
Comments	This is a collector road viaduct project.
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

California

Location	LA-118 Eastbound at Topanga Canyon Blvd., Los Angeles
Dates	Construction Began: Operations Began: Fall 1983
Treatment	Restriped right shoulder as a second lane to offramp.
Design-Half Cross Section	Unknown
Project Length	0.4 mile
Hours of Operation	Part time
Costs Implementation Maintenance	Not available
Results	Not available
Comments	
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

California

Location	ORA-5 Northbound between 17th Street and Main Street, Orange County
Dates	Operations began: December 1983
Treatment	Restriped three lanes to provide four lanes by using 5' ± of median and outside shoulders.
Design-Half Cross Section	Not Available
Project Lenght	Not available
Hours of Operation	Unknown
Costs Implementation Maintenance	Not available
Results Capacity Traf. Ops Safety	Not available
Comments	
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

California

Location	ORA-22 Eastbound between City Drive and Northbound 5 Connector, Orange County
Dates	Operations Began: August 1980
Treatment	Restriped three lane to provide four lanes by using 7' ± of median and outside shoulders.
Design-Half Cross Section	Not available
Project Length	Not available
Hours of Operation	Unknown
Costs Implementation Maintenance	Not available
Results Capacity Traf. Ops Safety	Not available
Comments	
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

California

Location	ORA-22 Westbound between Route 5 and Brookhurst, Orange County
Dates	Operations Began: January 1982
Treatment	Restriped three lanes to four lanes by using 7' $\pm$ of the median and outside shoulders.
Design-Half Cross Section	Not available
Project Length	Not available
Hours of Operation	Unknown
Costs Implementation Maintenance	Not available
Results Capacity Traf. Ops Safety	Not available
Comments	
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

California

Location	ORA-405 Northbound between Harbor Blvd. and Brookhurst, Orange County
Dates	Operations Began: May 1983
Treatment	Restriped four lanes to five lanes using median except at structures where left and right shoulders were reduced.
Design-Half Cross Section	Before: 8' four 12' lanes, 10' After: 3' five 11' lanes, 10'
Project Length	Not available
Hours of Operation	Unknown
Costs Implementation Maintenance	Not available
Results Capacity Traf. Ops Safety	Not available
Comments	
Reference	Internal Memorandum from Isaac Michiel to R. Smith, Division of Traffic Engineering, District 7, California Department of Transportation, February 7, 1984.

Hawaii

Location	I-1 (Hawaii 1) between Pali Highway and Kapiolani Viaduct
Dates	Operations began: 1980
Treatment	Four independent weaving sections built on outside shoulders, with lane width reduced by restriping.
Design-Half Cross Section	Not available
Project Length	Not available
Hours of Operation	24 Hours
Costs Implementation Maintenance	Unknown
Results Capacity Traf. Ops Safety	Not available
Comments	
Reference	Letter from Mr. Eiichi Tanaka, Traffic Engineer, Hawaii Department of Transportation, dated January 11, 1984.

Hawaii

Location	Moanalua Road at Middle Street Interchange
Dates	Operations Began: 1979
Treatment	Restriping from two lanes to three lanes by use of inside and outside shoulders to provide HOV lane.
Design-Half Cross Section	Before: two 12' lanes After: three lanes (two at 10', one at 11')
Project Length	0.23 mile
Hours of Operation	24 Hours
Costs Implementation Maintenance	Not Available
Results Capacity Traf. Ops Safety	Not Available Project implemented as part of safety improvements.
Comments	Freeway reconstruction still underway.
Reference	Letter from Mr. Eiichi Tanaka, Traffic Engineer, dated January 11, 1984.

Illinois

Location	Cook County, I-94 (Kennedy Expressway) between Washington Blvd. and Ohio Street
Dates	Construction began: Operations began: August 1980
Treatment	Widening from four lanes to five lanes by use of inside and outside shoulders. Resurfacing and installation of some barrier walls included.
Design-Half Cross Section	Before: Four 12' lanes, within 59'-4" surface After: 11", five 11' lanes, 11"
Project Length	0.75 mile
Hours of Operation	24 hours
Costs	
Implementation	$1.45 million (estimated)
Maintenance	unknown
Results	Before and after study still in progress
Comments	Overall project costs including drainage, lighting and signing estimated at $2.71 million.
Reference	Request for Non-Major Action Concurrence and Design Approval. Illinois Department of Transportation, July 1978.

New Mexico

Location	I-25 North of "Big I" interchange with I-40
Dates	Construction began: August 1980 Operations began: May 1981
Treatment	Paved inside shoulder; reduced inside shoulder to 3'
Design-Half	Before: 4' (plus 14' grass median) two 12' lanes, 9' (to curb)
Cross Section	After: 3', three 12' lanes, 9' (to curb)
Project Length	0.84 miles
Hours of Operation	24 Hours
Costs	Unknown
Results	Unknown
Comments	No reduction in lane width.
Reference	Design Plans Letter from Mr. G. Parker Bell, Traffic Design Engineer, New Mexico Highway Department, dated December 28, 1983.

Texas

Location	I-10 (Katy Freeway) between North Post Oak and West Belt, Houston
Dates	Construction began: April 1983 Operations began: (full length) August 1984
Treatment	Resurface and restripe three lanes as required to allow transitway in median. Inside shoulders eliminated.
Design-Half Cross Section	Before: L.S. varied (3'-10'), three 12' lanes, 10' After: 6" separation, three (12', 11', 11') lanes, 10'
Project Length	6.4 miles (Phase 1 only)
Hours of Operation	24 Hours
Costs	
Implementation	$14.0 million (estimated for highway only)
Maintenance	Unknown
Results	
Capacity	No significant difference
Traf. Ops.	Study underway
Safety	
Comments	This project is part of a barrier protected median transitway, under construction.
Reference	TTI reports and working papers.

Location	I-45 (North Freeway) between Downtown Houston and North Shepherd (Phase 1); North Shepherd to North Belt (Phase 2), Houston
Dates	Construction began: May 1983 Operations began: 1984 ongoing by segment
Treatment	Resurface, widen and restripe three lanes as required to allow for transitway in median. Inside shoulders eliminated.
Design-Half	Before: 8', three 12' lanes (inside lane is HOV), 10'
Cross Section	After (typical): No L.S., three 12' lanes, 10'
Project Length	13.5 miles
Hours of Operation	24 Hours
Costs	
Implementation	$33.0 million (highway estimate)
Maintenance	Unknown
Results	
Capacity	No loss in capacity
Traf. Ops.	Improved as existing HOV is transferred to transitway
Safety	Study underway
Comments	This project is part of a barrier protected median transitway, under construction.
Reference	TTI reports and working papers.

Location	I-45 (Gulf Freeway) between Lockwood and Hobby (Phase 1); Downtown to Lockwood (Phase 2); Hobby to Choate (Phase 3), Houston
Dates	Construction began: September, 1982 Operations began: 1984 ongoing by segment
Treatment	Resurface, widen pavement and restripe lanes as required to allow for transitway in median. Inside shoulders eliminated.
Design-Half Cross Section	Before: 10', three, four, or five 12' lanes; 12' After: No L.S., three, four, or five 11.5' lanes; R.S. varies.
Project Length	11.7 miles
Hours of Operation	24 Hours
Costs	
Implementation	NA
Maintenance	NA
Results	
Capacity	Same level
Traf. Ops	Same level
Safety	Study underway
Comments	This project is part of a barrier protected median transitway, under construction.
Reference	TTI reports and working papers.

Virginia (Update)

Location	I-395 Northbound King Street to Glebe Road; Southbound Glebe Road to Duke Street
Dates	Operation began: Spring 1984?
Treatment	Inside and outside shoulders used, together with narrower lanes to provide an extra lane
Design-Half Cross Section	Before: 6', three 12' lanes, 10' After: 2', four 11' lanes, 6'
Project Length	Northbound 1.5 miles Southbound 3.5 miles
Hours of Operation	24 Hours
Costs Implementation Maintenance	Northbound $1.2 million (estimated) Southbound $2.8 million $0.4 million per year
Results Capacity Traf. Ops. Safety	 Adequate to handle 1978 demand Unknown Unknown
Comments	These improvements are part of the HOV facility being built together with an electronic Traffic Management System. Total project cost $12. 5 million (estimated)
Reference	Letter from Mr. Richard C. Lockwood, Transportation Planning Engineer, Virginia Department of Highways and Transportation, Richmond, Virginia, dated January 12, 1984.

APPENDIX C

RECENT PUBLICATIONS ON
SAFETY OF FREEWAY SHOULDERS

A search was made for documents analyzing recent experience (1979 through 1984) on the safety of freeway shoulders. Most previous documents were referenced by Dick McCasland in Freeway Modifications to Increase Capacity (1) and are not considered here. However, three reports dated between 1977 and 1978, not listed by Dick McCasland, were found to be relevant to this subject. Publication title and abstracts are listed below.

Abrahamsohn, G.A.; Conversion of Freeway Shoulders to Traffic Lanes for Local Congestion Relief, Ontario Ministry of Transportation & Communication, Canada, October 1982.

The approach applied in this study was divided into two parts consisting of five major tasks. In part 1, all issues and concerns related to the use of freeway shoulders were addressed, and general conclusions derived. In part II, a case study, the conclusions derived in part I were applied to one specific section of the Highway 401. The case study of Part II translates the conclusions of Part I into an evaluation process and serves to illustrate the site-specific nature of this alternative. The use of freeway shoulders is not the only way to eliminate local bottlenecks on freeways. For any given site, the use of the freeway shoulder should be considered as one possible alternative which must compete against various other solutions to the same problem.

Commercial Vehicles in Collisions Involving Vehicles Parked or Stopped on Highway Shoulders - Special Study, Federal Highway Administration, Washington, D.C., 1977, Report HS-021-103.

A pilot study on In-Depth Accident Investigation Reports involving commercial and noncommercial vehicles parked on shoulders of highways covers accidents during nine calendar years, 1967 through 1975. Its purpose is to alert interested parties as to the causes and results of moving vehicles colliding with those parked on shoulders of interstate and other hghways and to stress the importance of motorists stopping on highway shoulders only for purposes relating to motor vehicle breakdowns or other emergency situations. Constant evaluation of causes of specific types of accidents is necessary, through in-depth accident investigations. A series of tables and graphs depict distribution and classification of accidents by type and results. One accident is analyzed with numerous photographs. Of the 58 accidents investigated, involving vehicles parked on highway shoulders, 47 happened on interstate highways; drivers dozing at the wheel and allowing their vehicles to travel onto the paved shoulders was the primary cause factor in 31 of the 58 (53%). Fifty-two occurred between 11:31 p.m.; 90% were rear end type collisions. Recommendations are to study the need for a contrast in texture of highway shoulders from that of the traveled portion of the highway to the point of producing a "rumble effect" to alert dozing drivers that they are leaving the travelled portion of the highway, and induce a safe recovery; a study of the present signing and mapping of rest areas to determine whether adequate information is being given; and a need for additional pedestrian advisory information warning them to stay away from the traveled portion of the road unless actually engaged in the repair of the vehicle.

Downs, H.G., and Wallace, D.W.; Shoulder Geometrics and Use Guidelines, NCHRP Rpt. 254, Transportation Research Board, Washington, D.C., December 1982.

This report contains the results of a study of highway shoulder design practices and operational uses throughout the United States. The study has determined that the shoulders along highways are subjected to a variety of uses by the traveling public, adjacent property and business owners, agencies that build and maintain the highways, law enforcing agencies, and organizations that provide public services. Guidelines are provided for shoulder design elements such as width, surface type, cross slope, special signing, and markings that best satisfy the requirements for each identified shoulder use for various classifications of highways.

The research reveals considerable nonuniformity in the design and modification of highway shoulders to safely, economically, and efficiently satisfy the many uses they serve. Some nonuniformity can be attributed to local laws that permit certain shoulder uses in some states that are illegal in other states. Considerable nonuniformity results from differeing signing and marking practices employed to control shoulder use because the "Manual on Uniform Traffic Control Devices," published by the Federal Highway Administration, permits alternatives for some signing and marking practices.

Appendixes E, F, and G of the agency report covering review of the literature, details of agency visits and interviews, and shoulder occupancy data are not included in this publication but are contained in an Addendum to NCHRP Report 254. Copies of the addendum have been distributed to the program sponsors and are available to other interested persons by contacting the Director, Cooperative Research Programs, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Kragh, B.C.; Stopped Vehicles on Freeway Shoulders, Public Roads, Vol. 47, No. 3, December 1983, pp 77-101.

Because of the concerns expressed by California and Texas regarding the safety problem of vehicles stopped on roadway shoulders, the Federal Highway Administration (FHWA) budgeted research to determine the magnitude of the problem, assess the exposure (opportunity for an accident) of stopped vehicles, identify causal factors, and consider possible countermeasures to decrease the incident and/or severity of shoulder accidents. Before initiating a full-scale study, preliminary in-house activities were conducted to determine if it was feasible to collect exposure data of vehicles stopped along freeways. This article describes the in-house activities that were conducted, which included a literature review, developing a study plan, and limited data collection and analysis.

McCasland, W.R.; The Use of Freeway Shoulders to Increase Capacity - A Review, Texas Transportation Institute, Texas A&M University, College Station, Texas, January 1984, Res. Rept. 210-10.

Every sector of urban transportation faces the problems of rising costs, limited funds, and depleting resources with which to provide for increasing travel demands. Getting the greatest production out of the existing transportation facilties is the goal of every transportation agency. The Texas State Department of Highways and Public Transportation is testing the concept of increasing roadway capacity on urban freeways by restriping the mainlane pavement with narrower lane widths and encroaching on the shoulder to create one additional lane for travel.

Two sections of US 59 Southwest Freeway in Houston were modified for study. Before and after data were collected over a seven-year period to determine the effectiveness of reconfiguring the surface geometrics of freeways to provide an additional lane for travel 24 hours a day. A second section was modified to provide the additional lane during peak periods only on weekdays. This "permissive" design was studied over a four-year period. Both sections have experienced reduced accident rates and improved traffic flow.

Rinde, E.A.; Accident Rates vs Shoulder Width, California Department of Transportation, Sacramento, California, September 1977, Report No. CA-DOT-TR-3147-1-77-01.

The California Department of Transportation used a before-and-after technique to evaluate 37 widening projects representing 143 miles (230 km) of improved road. The projects were completed essentially on existing alignment. Accident rates were reduced for each of the three new widths studied: 28 ft (8.5 m), 32 ft (9.8 m), and 40 ft (12.2 m). These represent shoulder widths of 2 ft (0.6 m), 4 ft (1.2 m), and 8 ft (2.4 m), respectively. Previous widths ranged from 20 to 24 ft (6.1 to 7.3 m) for the 28-ft widening, 18 to 24 ft (5.5 to 7.3 m) for the 32-ft, and 20 to 26 ft (6.1 to 7.9 m) for the 40-ft. Accident reductions were 16 percent for the 28-ft widening with less than 3,000 AADT, 35 percent for 32-ft with less than 5,000 AADT, and 29 percent for 40-ft with more than 5,000 AADT. Reductions were statistically significant for the 32- and 40-ft widths.

The study recommended paving widths of 40 ft (12.2 m) for AADT of more than 5,000; 32 ft (9.8 m) for AADT between 3,000 and 5,000; and either 28 or 32 ft (8.5 or 9.8 m) for AADT less than 3,000, depending on an economic analysis, except that existing 24-ft (7.3 m) roads should be widened to 32. ft.

Although the accident rate reductions were attributed entirely to the shoulder widening, the reduction may, in part, be due to improved signing, striping, intersection geometrics, some small curve corrections, and the new surfacing constructed concurrently with the widening.

Thompson, R.P., and Juge, J.D.; <u>Service for Standed Motorist, Volume 1,</u> California Departmen of Transportation, District 7, Sacramento, California, July 1978, Report No. 07-391-665105.

This report summarizes study objectives of the service for stranded motorist project and presents findings. It quantifies the motorists aid system, analyzes the experimental state owned and operated motorists aid system, and evaluates the service patrol concept as a means of improving conditions for the stranded motorist and as a tool for traffic management.

Results of the evaluation have shown that public response to the service patrol was very favorable, both in terms of its usefulness and capability to meet the needs of the stranded motorist. Also, the benefit cost ratio for the effectiveness of the service patrol operation was 1.51.

This volume, volume II, and volume III comprise the final report for the "Service for Stranded Motorist" project. Volume II contains 8 individual reports of which each report is of a technical nature and presents more detailed analysis of the various studies conducted. The reports are: 1) work and evaluation plan, and 2) preliminary investigation of methods currently in use on Los Angeles Urban Freeways for effecting aid to stranded motorists, 3-preliminary investigation of the Los Angeles Freeway telephones, 4-service patrol pilot study, 5-service patrol pilot study, 6-characteristics of stopped vehicles on urban freeways in Los Angeles, 7-A study of existing freeway call box system on Los Angeles Urban Freeways and 8-comparison of different service patrol operation modes. Volume III contains the service patrol operation manual and the vehicle and equipment report.

Zegeer, Charles U. and Perkins, David D.; <u>The Effect of Shoulder Width and Condition on Safety: A Critique of Current State of the Art</u>, paper prepared for presentation at the 59th Annual Transportation Research Board Meeting, Washington, D.C., January 1980.

Most previous studies were found to be outdated and only 2 of them considered the effect of shoulder width on related accident types (run-off-road and head-on accidents). Several studies used biased samples such as tangent only sections or sections influenced by major intersection data. The study was primarily concerned with rural highways.

APPENDIX D

SHOULDER SURVEY FORMS
AND
RESPONSES

THE TEXAS A&M UNIVERSITY SYSTEM
TEXAS TRANSPORTATION INSTITUTE
COLLEGE STATION TEXAS 77843-3135

TRANSPORT OPERATIONS PROGRAM (409) 845-1535

Dear Motorist:

A survey on the use of highway shoulders along Texas freeways is being conducted for the State Department of Highways and Public Transportation. Your assistance is very important since only a small number of motorists can be contacted. Please help by answering the questionnaire below.

The following questions concern your stop on the freeway shoulder at the time you received this questionnaire. Please answer each question since all are important. Your comments on the use of highway shoulders are welcome. Individual responses will be treated confidentially and you do not need to identify yourself.

Please detach and mail the postage-paid questionnaire at your earliest convenience. Your cooperation is appreciated.

Sincerely,

Thomas Urbanik II
Program Manager

TU:kab

1. What was the reason for stopping on the freeway shoulder?

Involuntary	Voluntary
_____Mechanical Problem	_____Changing Drivers
_____Flat Tire	_____Rest/Sleep
_____Out of Gas	_____Assisting Motorist
_____Stopped for Violation	_____Looking at Map
_____Other	_____Other

2. Had there been no left (inside) shoulder, could you have driven to the right (outside) shoulder?

_____Yes _____No

3. Had there been no left or right shoulder, could you have driven to the nearest freeway exit?

_____Yes _____No

4. Approximately, for how long was your vehicle stopped?

_____Days _____Hours _____Minutes

5. Comments:______________________________

Motorists Survey Comments
Reasons for Stopping on the Inside Shoulders

1. We need left shoulders more than you think.

2. I am so thankful that shoulder was there, if not the huge trucks behind me would of done who knows what. I was in a Ford Escort. You can imagine how I felt.

3. I think the left shoulders in this case was a possible life saver. I tried to get to the right shoulder and exit, but it was impossible, the traffic was too heavy, it would have caused a major traffic jam. Thanks for the concern.

4. Called wrecker immediately. I do not like to leave my vehicle on shoulder.

5. My husband and I both are very happy about the freeway shoulder, but it would really help if there were call boxes also, because its extremely dangerous trying to cross the freeway to call for help.

6. No one stopped or offered help in all that time. No officer of the law was seen.

7. I stopped on the left shoulder because it was wider. I had to get off quick or block rush hour traffic.

8. Conditions of flat was too severe for any other action besides immediate stop.

9. More comfort stations along our highways would help a lot.

10. I was glad there was a shoulder.

11. My car was stopped due to low visibility and high winds and heavy rains. I wrecked.

12. I'm just glad there was a left shoulder.

13. Get the loose gravel off the side.

14. Why not create some street help such as emergency phone about every 60 miles. A few walk overs would be nice.

15. When entering Loop 12 at Shady Grove in Irving before Grawyler, there was large pieces of cement all across the highways. There was no way to avoid those pieces and got two back flat tires.

16. Sure glad there was a left hand shoulder or I would have died. Semi-truck trailers should tie equipment down better so vehicles will not be endangered.

17. The wide left shoulder was extremely helpful since I was on an 8-lane highway.

18. I feel highway shoulders are very important for mechanical reasons. I also feel people should realize what they are for and not use them unnecessarily.

19. It is extremely dangerous to get back to the freeway from the left shoulder after the car has started.

20. I like I-10 because it has an inside shoulder. The Southwest freeway is a mess and always backed up. It has no inside shoulder and I-45 North is becoming the same way. It has no inside shoulder. In work traffic you need an inside and outside shoulder for cars with trouble to be able to pull out of traffic.

21. Shoulders each side absolutely necessary for safety, continuous traffic flow, proper intended use of freeway.

22. There would have been one hell of a traffic jam had the shoulder not been there, this occured at 4:45 pm on the Gulf Freeway.

23. Highway shoulders are necessary and very helpful for emergency stops.