- Zegeer, C.V., and Council, F.M. (1992). Safety Effectiveness of Highway Design Features, Volume III: Cross Sections. McLean, VA: Federal Highway Administration.

Safety Effectiveness of
Highway Design Features

VOLUME III

CROSS SECTIONS

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was part of TR89
now UNC/HSRC-92/1/12

FHWA-RD-91-048

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NCP# 3A5A-0292

prepared under contract for the
Federal Highway Administration
Contract #DTFH61-89-C-00034
Contract Manager: Joe Bared

PREFACE

This is the third volume in a series of six publications providing research results on the safety effectiveness of highway design features. This series provides designers and traffic engineers with useful information on the relationship between accidents and highway geometrics.

The Scientex Corporation, the Highway Safety Research Center at the University of North Carolina, Charlotte, and Michael Baker Jr., Inc., have compiled this Compendium under contract with the Federal Highway Administration. The six volumes include:

Volume I:	Access Control
Volume II:	Alignment
Volume III:	Cross Sections
Volume IV:	Interchanges
Volume V:	Intersections
Volume VI:	Special Features

Authors with extensive experience in each subject area have reviewed past research, and significant findings are summarized here, along with an additional bibliography for reference.

CROSS SECTIONS

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FOREWORD

In the early 60's, the highway community became increasingly interested in the safety effects of geometric design. The first attempt to quantify the state of knowledge on this topic was undertaken by the Highway Users Federation for Safety and Mobility (HUFSAM) in 1963 and 1971.

Considerable research on geometrics and safety was then initiated, and in the late 1970's, the Federal Highway Administration (FHWA) provided a consolidated resource for the safety impacts of various geometric and traffic control alternatives. This document, the Synthesis of Safety Research Related to Traffic Control and Roadway Elements Volumes I and Volume II (FHWA Report No. FHWA-TS-82-232), which updated the earlier HUFSAM reports, served a critical and useful purpose by providing valuable geometric/accident relationships.

This present compendium is the result of the FHWA implementing one of the 23 recommendations contained in TRB Special Report 214, "Designing Safer Roads - Practices for Resurfacing, Restoration and Rehabilitation." This report specifically responds to the recommendation, calling for the FHWA to "...develop, distribute, and periodically update a compendium that reports the most probable safety effects of improvements to key highway design features..."

As an initial task, all available United States literature potentially relating a geometric feature with traffic accidents was identified. Resources included the Transportation Research Information Service, libraries at the University of North Carolina and United States Department of Transportation, and the personal documents of the project team. In addition, accident/geometric data bases were identified as possible sources of data which could be used to develop needed relationships.

This identification effort revealed a lack of many new (post-1973) documents for several geometric topic areas. Accordingly, some major pre-1973 reports, along with the post-1973 reports were included for critical review.

Critical reviews of these reports involved determination of the appropriateness of the study design, the adequacy of the sample size, the application of proper statistical tests and correct interpretation of results. Only information meeting all of these criteria is reported in each volume of this report. These documents are listed in the reference section at the end, and an additional bibliography section is included, covering related research of interest, but not used in this report.

CROSS SECTIONS

INTRODUCTION

Past studies have revealed that of more than 50 roadway-related features which can significantly affect crash experience, cross-sectional elements are among the most important.[1,2] Such elements include lane width, shoulder width, shoulder type, roadside features (e.g., sideslope, clear zone, placement and types of roadside obstacles), bridge width, and median width, among others.

In addition to these elements, multilane design alternatives may also be considered where basic two-lane roads are not adequate. Such alternatives include the addition of through lanes, passing lanes, various median designs (e.g., raised medians), left-turn lanes (two-way, alternating), and others. Such design alternatives can affect traffic operations, as well as safety, along a highway section.

Following is a discussion of relationships between cross-sectional elements and accident experience, along with the accident reductions expected due to related roadway safety improvements. All of the information on crash relationships for lanes, shoulders, and bridges (and corresponding effectiveness information for countermeasures) are for two-lane, rural roads only. Most of the discussion on roadside effects relates to rural two-lane roads, although multilane roads and urban areas are included in some of the discussion (e.g., relating to utility pole accidents and countermeasures). The discussion of median design includes only multilane interstate and parkway roads in rural areas.

SUMMARY OF RESEARCH

Of the many cross-sectional roadway elements discussed at left, an illustration is given in figure 1 for those typically found on two-lane roads. Illustrations of cross-sectional features and design alternatives for multilane roads are presented later. Following is a discussion of such roadway features and their known safety effects.

Lanes and Shoulders

Travel lanes are that portion of the highway intended for use by general traffic. The lane width of a two-lane road is measured from the centerline of the highway to the edgeline, or to the joint separating the lane from the shoulder. Shoulders are that portion of the highway immediately adjacent to, and outside of, the lanes. Shoulders are typically designed and intended to accommodate occasional use by vehicles, but not continual travel. Part or all of the shoulder may be paved. The combination of lane and shoulder widths plus median, if any, comprises the roadway width. Total roadway width is among the most important cross-section considerations in the safety performance of a two-lane highway. Generally, wider lanes and/or shoulders will result in fewer accidents.

Numerous studies have been conducted in recent years to determine the effects of lane width, shoulder width, and shoulder type on accident experience. However, few of them were able to control for roadside condition (e.g., clear zone, sideslope), roadway alignment, and other factors which,

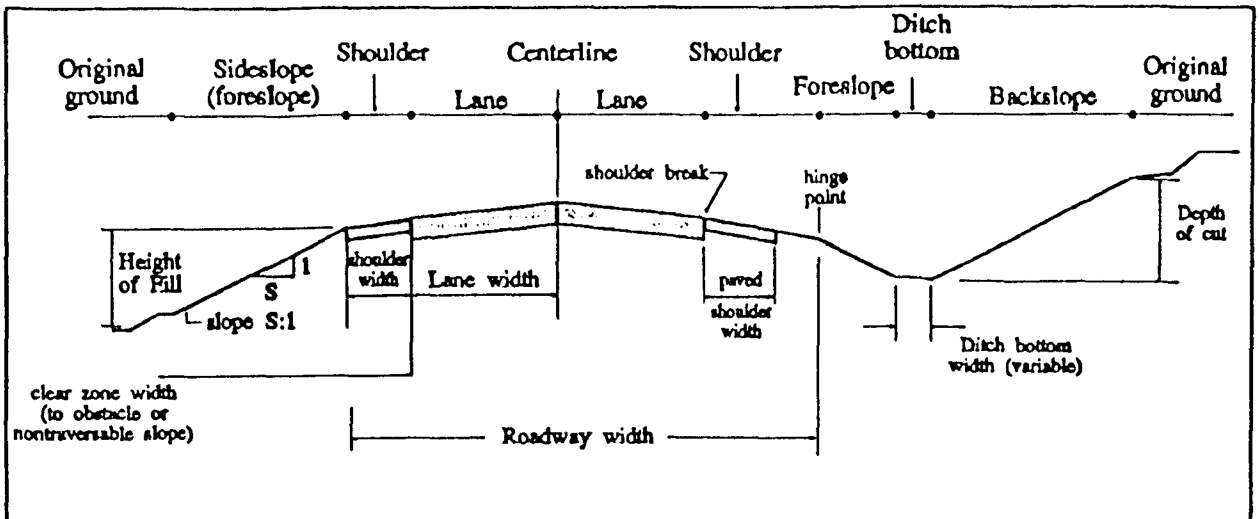


Figure 1. Elements of rural two-lane highway cross sections

together with lane and shoulder width, influence accident experience. Also, since lane and shoulder width logically affect some accident types (e.g., run-off-road, head-on) but not necessarily other accident types (e.g., angle, rear-end), there is a need to express accident effects as a function of those related accident types.

A 1987 Federal Highway Administration (FHWA) study by Zegeer et al., quantified the effects of lane width, shoulder width, and shoulder type on highway crash experience based on an analysis of data for nearly 5,000 miles of two-lane highway from seven states.[3] The study controlled for many roadway and traffic features, including roadside hazard, terrain, and average daily traffic (ADT). Accident types found to be related to lane and shoulder width, shoulder type, and roadside condition include run-off-road (fixed object, rollover, and other run-off-road accidents), head-on, and opposite- and same-direction sideswipe accidents, which were together termed as "related accidents." An accident prediction model was developed and used to determine the expected effects of lane and shoulder widening improvements on related accidents.

As shown in table 1, lane widening of 1 ft (e.g., from 10 ft to 11 ft lanes) will be expected to reduce related accidents by 12 percent, and 4 ft of widening (e.g, from 8 to 12 ft lanes) should result in a 40 percent reduction in related accident types.

Table 1. Percentage of accident reduction of related accident types for lane widening only.[3]

Amount of Lane Widening (ft)	Percent Reduction in Accident Types
1	12%
2	23%
3	32%
4	40%

Note: These values are only for two-lane rural roads

Reductions in related accidents due to widening paved or unpaved shoulders are given in table 2. For example, widening 2 ft gravel shoulders to 8 ft will reduce related accidents by 35 percent (i.e., for a 6 ft increase in unpaved shoulders). Adding 8 ft paved shoulders to a road with no shoulders will reduce approximately 49 percent of the related accidents.[3] It should be noted that the predicted accident reductions given in tables 1 and 2 are valid only when the roadside characteristics (sideslope and clear zone) are reestablished as before the lane or shoulder widening.

Table 2. Percentage of accident reduction of related accident types for shoulder widening only.[3]

Shoulder Widening per Side (ft)	Percent Reduction in Related Accident Types Paved	Unpaved
2	16%	13%
4	29%	25%
6	40%	35%
8	49%	43%

Note: These values are only for two-lane rural roads

When two or more roadway improvements are proposed simultaneously, the accident effects are not additive. For example, implementing two different improvements having accident reductions of 20 and 30 percent will not result in a combined 50 percent accident reduction.

Table 3 provides accident reduction factors for projects involving various combinations of lane widening, shoulder widening, and shoulder surfacing. For example, assume a roadway section currently has 10 ft lane widths and 4 ft unpaved shoulders, and the proposed improvement will result in 12 ft lanes with 6 ft paved shoulders. To determine the combined accident reduction of this improvement project, find the value in table 3 corresponding to 2 ft of lane widening (left column), and 4 ft unpaved shoulder in the existing condition. Go across horizontally to the column indicating a 6 ft paved shoulder and read the 38 percent reduction in related accidents. If additional improvements are also considered at the same location (e.g., roadside improvements), accident reduction factors must be combined (not added) as described in a related user guide.[4]

The accident reduction factors in tables 1 through 3 are correctly applied by multiplying them by the number of related accidents on a section. However, if a user knows only the number of total accidents on the section, table 4 gives factors to convert between total and related types. Since ADT and terrain are factors which influence the proportion of various accident types on a section, the table provides adjustments for these factors.

Assume, for example, that 25 total accidents per year have occurred on a mountain road with an ADT of 2,000 vehicles per day (vpd). From table 4, an average of approximately 72 percent of these 25 accidents, or 18 accidents per year, would be "related" accidents. Widening lanes from 10 to 12 ft on this section would save 4 accidents per year (18 related accidents x reduction from table 1).

The results from this study, as given in tables 1 through 4, are recommended for use in estimating accident reduction effects of lane and shoulder improvements. These factors are appropriate for two-lane roads with ADT's of 100 to 10,000 vpd, lane widths of 8 to 12 ft, and 0 to 12 ft shoulders which are paved or unpaved (or partly paved and unpaved).[3]

A 1989 study by Griffin and Mak quantified accident effects of roadway widening on rural, farm-to-market roads in Texas.[5] Single-vehicle accident rates decreased for wider road widths for various ADT groupings. The accident reductions matched closely those found in the Zegeer study.[3] The authors also found that roadway widening is not generally cost-effective for farm-to-market roads with ADT's below 1,000 vpd.

Numerous other studies in recent years have also analyzed large State data bases to determine accident effects of lane and shoulder width. These include studies by Foody and Long in Ohio; Zegeer, Mayer and Deen in Kentucky; Shannon and Stanley in Idaho; and an NCHRP study by Jorgensen using data from Washington and Maryland,

Table 4. Factors to convert total accidents to related accidents on two-lane rural roads.[3]

	Terrain Adjustment Factors		
ADT (vpd)	Flat	Rolling	Mountainous
500	.58	.66	.77
1,000	.51	.63	.75
2,000	.45	.57	.72
4,000	.38	.48	.61
7,000	.33	.40	.50
10,000	.30	.33	.40

Note: Related accidents include run-off-road, head-on, opposite-direction and same-direction sideswipe.

among others.[1,6,7,8] While these studies used a wide range of sample sizes and analysis techniques, all basically found that accident rates decrease due to wider lanes and/or shoulders, even though there was considerable variation in the exact amount of crash reduction.

While the studies reported above involved developing relationships between roadway width and accident experience from State data files and estimating crash reduction due to the accident relationship, studies by Rinde (California) and Turner et al., (Texas) involved evaluating actual pavement widening projects.[9,10]

As shown in table 5, percent reductions are given in total, single-vehicle, and head-on accidents due to widening pavements or adding full-width paved shoulders. Although sample sizes are small in certain cells, these results support the findings in the other studies in terms of the beneficial effects of lane and shoulder widening, the types of crashes reduced, and the relative magnitude of the effects of widening. A 1974 study by Heimbach, Hunter, and Chao in North Carolina also found that paving 3 to 4 ft unpaved shoulders will result in significant reductions in accident frequency and severity.[11]

Table 5. Summary of accident reductions for pavement widening projects.[9,10]

		Expected Percent Reduction in Accidents		
Type of Project	ADT Range (vpd)	Total Accidents	Single-Vehicle Accidents	Head-On Accidents
Widening 20 to 24 ft, pavement to 28 ft	0-3,000	16.0 (C)	22.0 (C)	45.0 (C)
Widening 18 to 24 ft, pavement to 32 ft	<5,000	35.0 (C)(s)	49.0 (C)(s)	48.0 (C)(s)
Widening 18 to 24 ft, pavement to 40 ft	>5,000	29.0 (C)(s)	22.0 (C)(s)	51.0 (C)(s)
Adding full-width	1,000-3,000	27.0 (T)(s)	55.0 (T)(s)	Unknown
paved shoulders	3,000-5,000	12.5 (T)	21.4 (T)(s)	Unknown
to two-lane roads	5,000-7,000	17.6 (T)(s)	0.0 (T)	Unknown

Notes:

(C) = values from the Rinde study in California
(T) = values from the Rogness et al. study in Texas
(s) = significant at the 95 percent level of confidence for (C) sites and 90 percent confidence level for the (T) sites.

The single vehicle and head on accident percentages for California were adjusted by 4 to 6 percent to account for external effects, and are now on the same basis as total accidents. These values are only for two-lane rural roads.

Roadside Condition

The condition of the roadside is another of the cross-sectional elements which most affects crash frequency and severity. This is due to the high percentage of crashes, particularly on rural two-lane roads, which involve a run-off-road vehicle. Providing a more "forgiving" roadside relatively free of steep slopes and rigid objects will allow many of these off-road vehicles to recover without having a serious crash.

The relative hazard of the roadside may be described in terms of several characteristics, including:

- Roadside recovery distance (or roadside clear zone),
- Sideslope (foreslope), and
- Presence of specific roadside obstacles (e.g., trees, culverts, utility poles, guardrails).

Both severity of crashes and crash frequency are affected by such roadside features. Following is a discussion of these roadside characteristics.

Roadside Recovery Distance/Clear Zone

The roadside recovery distance is a relatively flat, unobstructed area adjacent to the travel lane (i.e., edgeline) where there is a reasonable chance for an off-road vehicle to safely recover.[3] Therefore, it is the distance from the outside edge of the travel lane to the nearest rigid obstacle (e.g., bridge rail, tree, culvert, utility pole), steep slope, non-traversable ditch, or other threat (e.g., cliff, lake) to errant motor vehicles. This is similar to the clear zone definition, except that the recovery distance includes a recoverable slope, whereas according to the definition in the new AASHTO "Roadside Design Guide," a clear zone also includes a non-traversable slope.[12]

A 1982 study by Graham and Harwood determined the effect of clear zone policy on single vehicle accident rate.[13] As shown in figure 2, single vehicle accidents per mile per year are highest for roads with a non-clear zone, next highest for a 4:1 clear zone policy (i.e., same clear area with a 4:1 sideslope), and lowest for a 6:1 clear zone policy for various ADT's. The authors point out that clear zone policies of the sample sections did not necessarily agree with what actually existed in the field. Even with the lack of field verification of roadside conditions, however, this study indicates the high potential for safety benefit resulting from increased roadside clear zones.

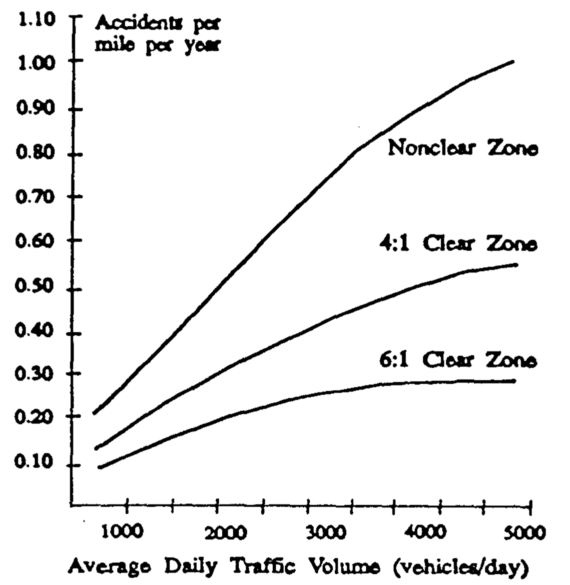


Figure 2. Relationship between single-vehicle, run-off-road accidents per mile per year and ADT for two-lane highways.[3]

Along a roadway section, the roadside recovery distance may vary considerably. The recovery distance for a roadway section can be determined by taking an average of measurements (e.g., 3 to 5 measurements per mile on each side of the road). Roadside recovery distances of 0 to 30 ft are generally recorded. For roadways with limited recovery distances (particularly less than 10 or 15 ft from the roadway edgeline) where roadside improvements are proposed, accident reduction factors may be found in table 6. These factors are again based on the previously cited Zegeer, et al., study.[3] For example, increasing the roadside recovery distance by 12 ft (e.g., from 4 to 16 ft) will reduce "related" accidents (as defined earlier) by an estimated 29 percent. Examples of roadside improvements which can increase the recovery distance include cutting trees near the roadway, relocating utility poles further from the road and use of sideslopes of about 4:1 or flatter. For an improvement involving only sideslope flattening, see the discussion on sideslope given later.

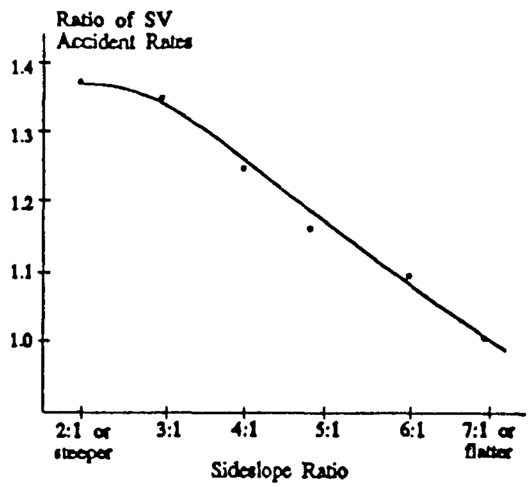
Table 6. Accident reduction factors due to increasing roadside clear recovery distance.[3]

Amount of Increased Roadside Recovery Distance (ft)	Percent Reduction in Related Accident Types
5	13%
8	21%
10	25%
12	29%
15	35%
20	44%

Sideslope

The steepness of the roadside slope or sideslope, also termed foreslope, is a cross-sectional feature which affects the likelihood of an off-road vehicle rolling over or recovering back into the travel lane. Existing guidelines for acceptable sideslopes have historically been based on computer simulations and observations of controlled vehicle test runs on various slopes, as well as on "informed" judgments. Until recently, little was known on true accident relationships with sideslopes.

As part of their 1987 study, Zegeer et al. developed relationships between single-vehicle crashes and field-measured side-slopes from 1:1 to 7:1 or steeper for 1,776 miles of roadway in three states: Michigan, Alabama, and Washington.[3] As shown in figure 3, single-vehicle accidents (as a ratio of accidents on a 7:1 slope) are highest for slopes of 2:1 or steeper, and drop only slightly for 3:1 slopes. Single-vehicle accidents then drop linearly (and significantly) for flatter slopes. This plot represents the effect of sideslope after controlling for ADT and roadway features.[3]



Note: These values are only for two-lane rural roads, and include adjustments for ADT, lane width, shoulder width, and recovery distance.

Figure 3. Plot of single-vehicle (SV) accident rate for a given sideslope versus single-vehicle accident rate for a sideslope of 7:1 or flatter.[3]

The relationship shown in figure 3 was used to develop accident reductions matching various sideslope flattening projects. The percent reductions are given in table 7 for single vehicle and total accidents. For example, flattening an existing 2:1 sideslope to 6:1 should result in a reduction of approximately 21 percent and 12 percent of single-vehicle and total accidents respectively.[3] These reductions assume that the roadside slope to be flattened is relatively clear of rigid obstacles.

The use of flatter slopes not only reduces the accident rate, but it may also reduce rollover accidents, which are typically quite

Table 7. Effects of sideslope flattening on single-vehicle and total accidents.[3]

	Sideslope in After Condition							
	4:1		5:1		6:1		7:1 or Flatter	
Sideslope in Before Condition	Single Vehicle Accs	Total Accs	Single Vehicle Accs	Total Accs	Single Vehicle Accs	Total Accs	Single Vehicle Accs	Total Accs
2:1	10	6	15	9	21	12	27	15
3:1	8	5	14	8	19	11	26	15
4:1	0	-	6	3	12	7	19	11
5:1	-	-	0	-	6	3	14	8
6:1	-	-	-	-	0	-	8	5

Note: these values are only for two-lane rural roads

severe. In fact, injury data from three States reveals that 55 percent of run-off-road rollover accidents result in occupant injury and 1 to 3 percent end in death. Of all other accident types, only pedestrian accidents and head-on crashes result in higher injury percentages.[3] The recent FHWA study found that sideslopes of 5:1 or flatter were needed to significantly reduce the incidence of rollover accidents (i.e., not 4:1, as is often assumed).[3]

Specific Roadside Obstacles

While previous discussions have addressed general roadside improvements to clear zones and sideslopes, recent studies have also quantified the effects of more specific roadside obstacle improvements, including utility poles, trees, mailboxes, culverts, guardrail, and fences.

Utility Poles

Improvements which should reduce the frequency of utility pole crashes include relocating the poles further from the roadway, increasing pole spacing, removing the poles and undergrounding the utility lines, and multiple pole use (i..e, removing poles on one side of the road and using poles on the other side to carry multiple electric and/or utility lines). However, on rural roads with relatively low traffic volumes, undergrounding of lines is seldom practical. For reducing crash severity, breakaway utility poles are currently being tested for possible future use on a more widespread basis.

Reductions in utility pole crashes due to such utility pole treatments were defined in a 1983 study.[14] The study analyzed traffic, accident, roadway, and utility pole data for 2,500 miles of two-lane and multilane roads in urban and rural areas in four States. The resulting accident relationships with pole offset and poles per mile are given in figure 4.

The nomograph shown in figure 5 was developed for utility pole accidents (per mile per year) as a function of ADT, pole density (number of poles per mile), and pole offset (average distance of the utility poles from the edgeline). This nomograph shows, for example, that a road with an ADT of 10,000 vpd and 60 poles per mile, offset 5 ft from the edgeline, can be expected to have approximately 1.2 utility pole accidents per mile per year. If a countermeasure were implemented to offset the poles to 15 ft, the nomograph shows that the expected accidents in the after period would be about 0.6, or about a 48 percent reduction in utility pole accidents.[14]

In the FHWA study report, numerous tables of accident reduction factors were developed based on the accident model for different countermeasures under a variety of traffic and utility pole conditions.[14] All accident reductions in the study apply to roadway sections 0.5 miles or longer with ADT's between 1,000 and 60,000 vpd, pole offsets between 2 and 30 ft, and pole densities of 20 to 70 poles per mile.

Table 8 provides example percent reductions in utility pole crashes due to several relocation alternatives. Relocating a line of utility poles by a 15 ft increase would reduce utility pole crashes by 61 percent. All accident reductions in this example table correspond to roadway sections with ADT's of 1,000 vpd and 40 poles per mile. The full study also provides information on which improvements are cost-effective under various roadway conditions.[14,15]

Other Obstacle Types

In a 1990 FHWA study by Zegeer et al., a model was developed for accidents involving trees, mailboxes, guardrails, and fences, and accident reductions were determined for clearing or relocating such obstacles further from the roadway.[14,15] The model only applies to obstacle distances between 0 and 30 ft from the outside edge of

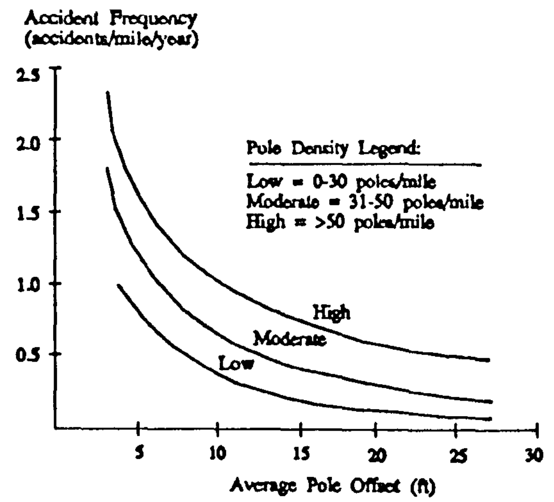


Figure 4. Relationship between frequency of utility pole accidents and pole offset for three levels of pole density.[14]

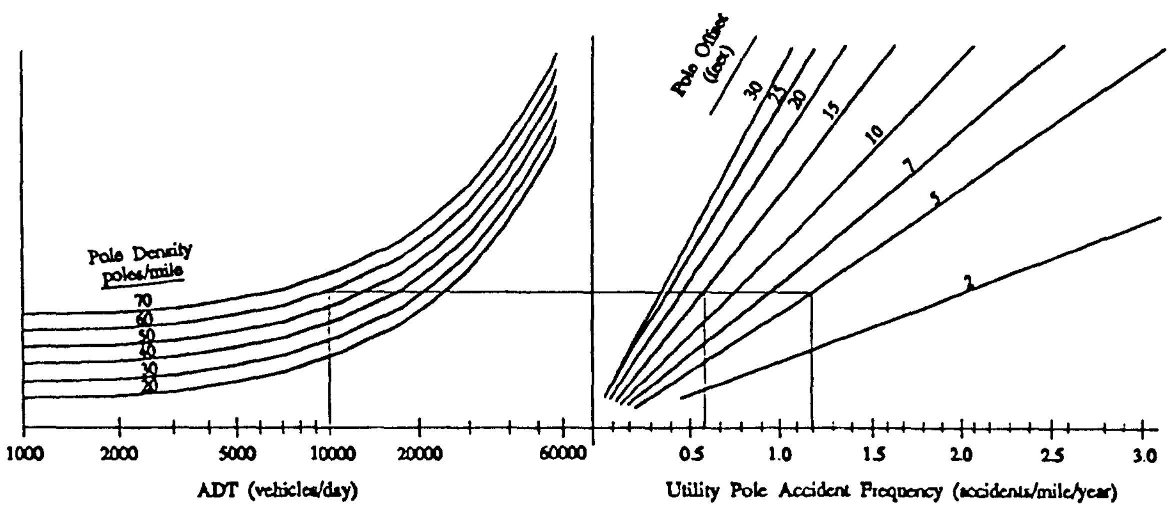


Figure 5. Nomograph for predicting utility pole accident frequency.[14]

Table 8. Reduction in utility pole crashes due to pole relocation for roadway sections with an ADT of 1,000 vpd and 40 poles per mile.[14]

Increase in Pole Offset (ft)	Pole Offset Before	Pole Offset After	Percent Reduction in Utility Pole Crashes
	3	6	36%
3	5	8	26%
	9	12	18%
	3	8	47%
5	5	10	37%
	7	12	30%
	15	20	18%
	2	12	69%
10	5	15	52%
	10	20	38%
	15	25	31%
	2	17	75%
15	5	20	61%
	10	25	48%

Note: these values apply to urban or rural areas on two-lane or multi-lane roads.

Table 9. Percent reductions in specific types of obstacle accidents due to clearing/relocating obstacles further from the roadway.[16]

Increased Obstacle Distance from Roadway (feet)	Trees	Mailboxes, Culverts, & Signs	Guard-rails	Fences/ Gates
3	22.1	14.3	36.4	19.6
5	34.1	22.6	53.0	30.4
8	48.7	33.7	70.1	44.0
10	56.6	40.1	77.9	51.6
13	66.2	N.F	N.F	N.F.
15	71.4	N.F.	N.F.	N.F.

Notes:

N.F. = generally not feasible to relocate obstacles to specified distances

These values are only for two-lane rural roads

the travel lane (i.e. edgeline).[16] Model results are described below.

Tree accidents can be reduced based on accident reductions shown in table 9. For example, clearing trees by 10 ft (e.g, from 8 ft to 18 ft) will reduce tree accidents by an expected 57 percent. These values assume that by clearing back trees from the roadway, run-off-road vehicles would have additional roadside area to recover provided the trees were not on a steep sideslope. Since trees are the fixed-object most often struck on many rural roads, clearing trees back from the road (particularly on roads with severe alignment) can be an effective roadside safety treatment.[16]

Culvert headwalls can result in serious injury or death when struck at moderate or high speeds on rural roadways. While relocating such culverts further from the roadway may be feasible under certain conditions, the ideal solution would be to reconstruct the drainage facilities so that they are flush with the roadside terrain and present no obstacle to motor vehicles. Such designs essentially would eliminate culvert accidents, although run-off-road vehicles could still strike other obstacles (e.g., trees) beyond the culverts or roll over on a steep sideslope (see discussion of sideslope in an earlier section). Accident reductions are shown in table 9 which correspond to placement of culvert headwalls further from the roadway. For example, a 40 percent reduction in culvert hits is expected for culverts located 15 ft from the road compared to 5 ft (i.e., a 10-ft difference in distance).[16] Other useful information on drainage structures is contained in the *Roadside Design Guide*. [16]

Sign placement is largely a function of their readability to drivers, so in some respects signs should not be placed too far from the road. Even though sign posts represent a roadside obstacle, sign placement must be within the driver's cone of vision to be useful. Where practical, the use of breakaway sign posts is highly desirable to minimize the severity of impacts between motor vehicles and the posts. Where not practical, the sign should be relocated further from the pavement edge. The percent reductions in sign crashes are given in table 9 for various distances of the signs from the roadway.

While relocating *mailboxes* further from the road would be expected to reduce the frequency of mailbox accidents, such relocation is not practical in many situations. A more promising alternative, which would affect crash severity but not crash occurrence, would be to make use of mailboxes with less rigid posts or breakaway design in place of the heavy steel, wooden posts, or multiple posts.[16]

Guardrail is installed along roadways to shield a vehicle from striking a more rigid obstacle or from rolling down a steep embankment. When installed, guardrail is generally positioned at the greatest practical distance from the roadway to reduce the incidence of guardrail impacts. Thus, it is not often feasible to relocate guardrail further from the roadway along a section, unless some flattening of the roadside occurs. However, when it is feasible to flatten roadsides to a relatively mild slope (e.g., 5:1 or flatter) with appropriate removal of obstacles, then guardrail should be removed since the guardrail itself presents an obstacle which vehicles can strike. The accident reductions in table 9 for guardrail placement illustrate the crash benefits from relocating guardrail.[16]

Fences and gates are sometimes placed by private property owners just beyond the highway right-of-way, and can present a hazard to run-off-road vehicles. As shown in table 9, the effect of relocating fences is a 20 percent accident reduction for 3 ft of relocation, 44 percent for 8 ft of relocation, and 52 percent for 10 ft of relocation. Unfortunately, having fences relocated further from the roadway could require that an agency purchase more right-of-way along a route, which could be quite expensive. [16]

Crash Severity of Obstacles

In addition to crash frequency, the severity of crashes involving specific roadside obstacles is also important. A 1978 FHWA study by Perchonok et al., analyzed accident characteristics of single vehicle crashes, including crash severity related to types of objects struck.[18] For non-rollover fixed-object crashes, the obstacles associated with the highest percent of injury occurrences are, in order: bridge or overpass entrances, trees, field approaches (i.e., ditches created by driveways), culverts, embankments, and wooden utility poles. Actual percent injuries and fatalities of these crashes are shown in table 10. Obstacle types with the lowest crash severity include small sign posts, fences, and guardrail.[18]

A separate analysis was also conducted for severity of crashes involving ditches. The authors found that ditches which were 3 ft or deeper were associated with a higher percent of injury accidents (61 percent)

Table 10. Severest injury by object struck in non-rollover accidents.[18]

Object	Accident Sample Size	Percent Injured	Percent Killed
B/O Entrance	88	75.0	15.9
Tree	667	67.9	7.2
Field Approach	75	66.7	1.3
Culvert	231	62.3	6.1
Embankment	406	57.6	4.4
Wood Util Pole	598	51.2	2.3
B/O Siderail	82	51.2	2.4
Rock(s)	73	49.3	1.4
Ditch	368	48.9	1.1
Ground	153	48.4	3.3
Trees/Brush	255	38.4	2.0
Guardrail	284	31.7	1.8
Fence	325	24.3	0.3
Small Sign Post	76	22.4	1.3
Total	3,681	50.8	3.6

Note: B/O = bridge or overpass

when compared to crashes involving ditches 1 to 2 ft deep (54 percent injury). Percent fatal accidents were about the same for each depth category (i.e., about 5 percent for both the 1 to 2 ft and 3 ft plus groups).

The information reported on crash severity should be considered along with frequency information when considering specific roadside safety improvements. For example, if one wishes to compute the dollar savings from tree removal, this can be done by first determining the number of tree crashes which would be reduced through the tree clearing project. Then, the average cost can be computed per tree accident reduced based on the expected percentages of injury and fatal crashes reduced (from table 10) along with the average cost per injury or fatal accident. Such accident cost values have been given by the FHWA and others.[19]

Bridges

Highway bridges are sometimes associated with accident problems, particularly rural highway bridges with narrow width, poor sight distance (e.g., just past a sharp horizontal curve), unprotected bridge end, and/or with poor signing and delineation. Numerous studies have analyzed the effects of various traffic control devices (e.g., signs and markings) on crashes and on vehicle operations such as vehicle placement on the bridge. However, research is scarce on the effects of bridge geometrics on crash experience.

The features which are of most importance in terms of affecting bridge accident rate are the bridge width, and/or the width of the bridge in relation to the approach width. The best known accident relationship with bridge width was developed in a 1984 study by Turner.[20] Based on accidents at 2,087 bridges on two-lane roads in Texas, an accident model was developed as a function of "relative bridge width" (RW), which is defined as the bridge width (C) minus the width of the traveled way (B) (see figure 6).

According to Turner's accident model, and as shown in figure 7, the number of accidents per million vehicles decreases as the relative bridge width increases.[20,21] This relationship indicates that it is desirable to have bridge widths at least 6 ft wider than the travelled way. In other words, shoulders of 3 ft or more should be provided on each side of the bridge.

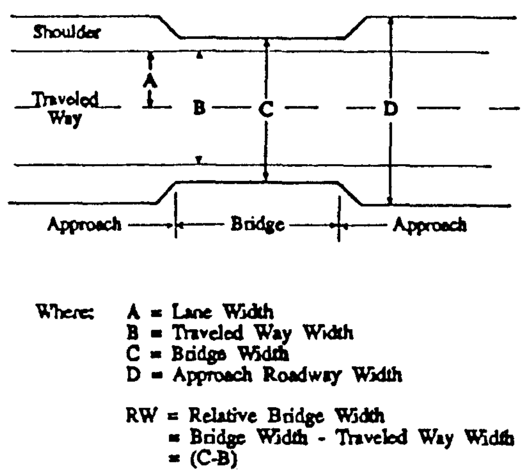


Figure 6. Key Elements at a Bridge Site.[20,21]

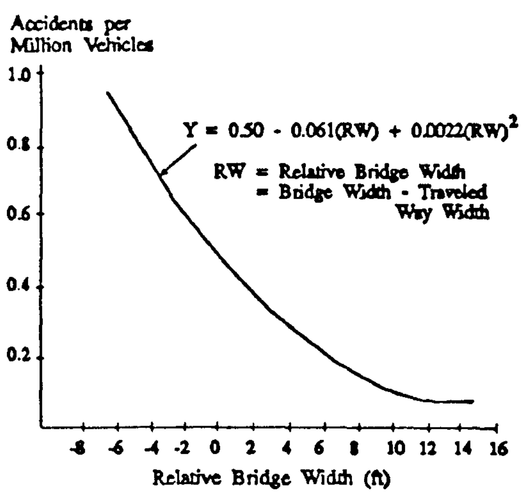


Figure 7. Accident Rate by Relative Bridge Width.[20,21]

Based on Turner's model, the percent reduction in total accidents due to reconstructing narrow bridges to make them wider can be determined. Accident reduction factors given in table 11 provide percent reductions in total crash rate expected due to widening shoulders on bridges. For example, assume that a bridge width is 24 ft wide with 10 ft lanes and 2 ft shoulders on each side. According to table 11, widening the bridge to 32 ft (i.e., two 10 ft lanes with two 6 ft shoulders) would reduce the total bridge accident rate by 62 percent.

Note that values in table 11 assume that the lane width stays constant in the before and after condition. When the bridge lane width is increased, a conservative estimate of accident reduction would be to use table 11 and only include the amount of increased shoulder width. For example, when widening a 20 ft bridge (two 10 ft lanes and no shoulder) to a 30 ft bridge (two 12 ft lanes and two 3 ft shoulders), assume an increase in shoulder width from 0 to 3 ft, for at least a 42 percent "minimum" accident reduction.

Median Design

Elements of median design which may influence accident frequency or severity include median width, median slope, median type (raised or depressed) and presence or absence of a median barrier. Wide medians are considered desirable in that they reduce the likelihood of head-on crashes between vehicles in opposing directions. Median slope and design can affect rollover accidents and also other single vehicle crashes (fixed object) and head-on crashes with opposing traffic. The installation of median barriers typically increases overall accident frequency due to the increased number of hits to the barrier but reduces crash severity, resulting from a reduction or elimination of head-on impacts with opposing traffic. A controlling factor in median width is often the limited amount of highway right-of-way available.

A comparison was made of the safety of a raised (mound) median design vs. depressed (swale) medians in the 1974 Ohio study by Foody and Culp.[22] Using a sample of rural interstates, all having 84-ft wide medians and other similar geometrics, accident experience was compared between the two median designs. The typical median cross sections for the sample mound and swale medians used in the study are shown in figure 8.[22] No differences were found in the number of injury accidents, rollover accident occurrence, or overall accident severity between the raised and depressed

Table 11. Summary of accident reduction factors associated with widening shoulders on bridges.[a]

Bridge Shoulder Width Before Widening (ft)		Bridge Shoulder Width (ft) After Widening Each Side (total of Both Sides in Parenthesis)						
Each Side	Total of Both Sides	2(4)	3(6)	4(10)	5(8)	6(12)	7(14)	8(16)
0	0	23	42	57	69	78	83	85
1	2	--	25	45	60	72	78	80
2	4	--	--	27	47	62	71	74
3	6	--	--	--	28	48	60	64
4	8	--	--	--	--	28	44	50

[a] Assumes that the width of lanes on the bridge remain constant. Values in the table were derived based on the accident model developed by Turner on rural, two-lane roads.[20]

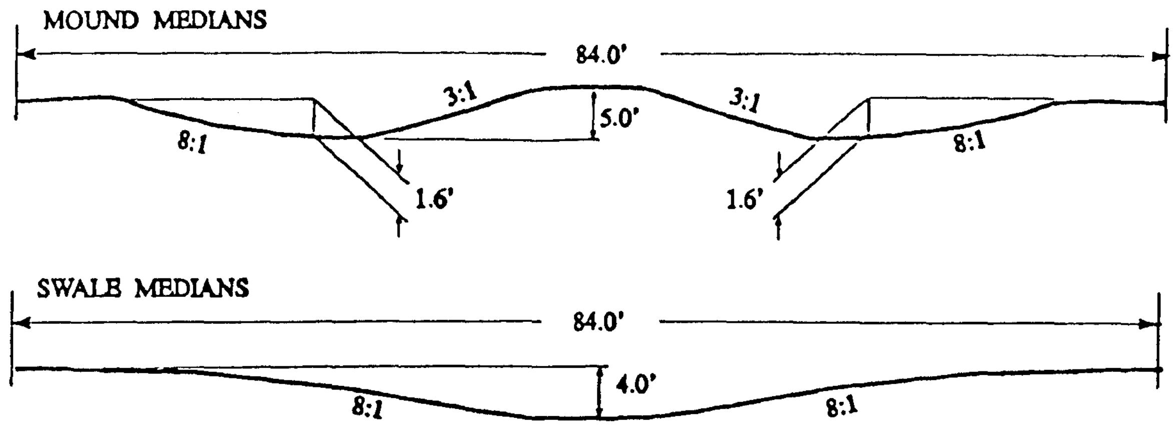


Figure 8. Typical Median Cross Sections.[22]

median designs. However, a significantly lower number of single-vehicle median-involved crashes were found on sections with depressed medians compared to raised medians. The authors concluded that this may indicate that mildly depressed medians provide more opportunity for encroaching vehicles to return safely to the roadway.

A 1973 study by Garner and Deen in Kentucky compared the crash experience of various median widths, median types (raised vs. depressed), and slopes on Interstate and turnpike roads in Kentucky.[23] As shown in figure 9, highways with at least 30 ft wide medians had lower accident rates than for those with narrower median widths. For wider medians, a significant reduction was also found in the percent of accidents involving a vehicle crossing the median. Median slopes of 4:1 or steeper had abnormally high accident rates for various median widths, while a higher crash severity and higher proportion of vehicle overturn accidents were found for medians which were deeply depressed. For median widths of 20 to 30 ft, the use of a raised median barrier was associated with a higher number of accidents involving hitting the median and losing control.[23]

The authors recommended minimum median widths of 30 to 40 ft, slopes of 6:1 or flatter (particularly where median widths are less than 60 ft.), and 12-ft paved shoulders on roadway sections where guardrail is installed in the median. Raised medians were found to be undesirable based both on accident experience and on less-than-ideal surface drainage.

Taken together, the two median studies indicate that where a wide median width can be provided (e.g., 84 ft), a mildly depressed median (depressed by 4 ft with 8:1 down-slopes) and mound median (3:1 upslope) provide about the same crash experience. However, in cases with narrower medians (e.g., 20 to 40 ft), slopes of 6:1 or flatter are particularly important. Deeply depressed medians with slopes of 4:1 or steeper are clearly associated with a greater occurrence of overturn crashes. While accident relationships are unclear for median widths of less than 20 ft, wider medians in general are better, and median widths in the range of 60 to 80 ft or more with flat slopes appear to be desirable, where feasible.

Multilane Design Alternatives

A majority of two-lane highways carry relatively low traffic volumes and experience few operational problems. However, considerable safety and operational problems exist on some higher volume two-lane highways, particularly in suburban and

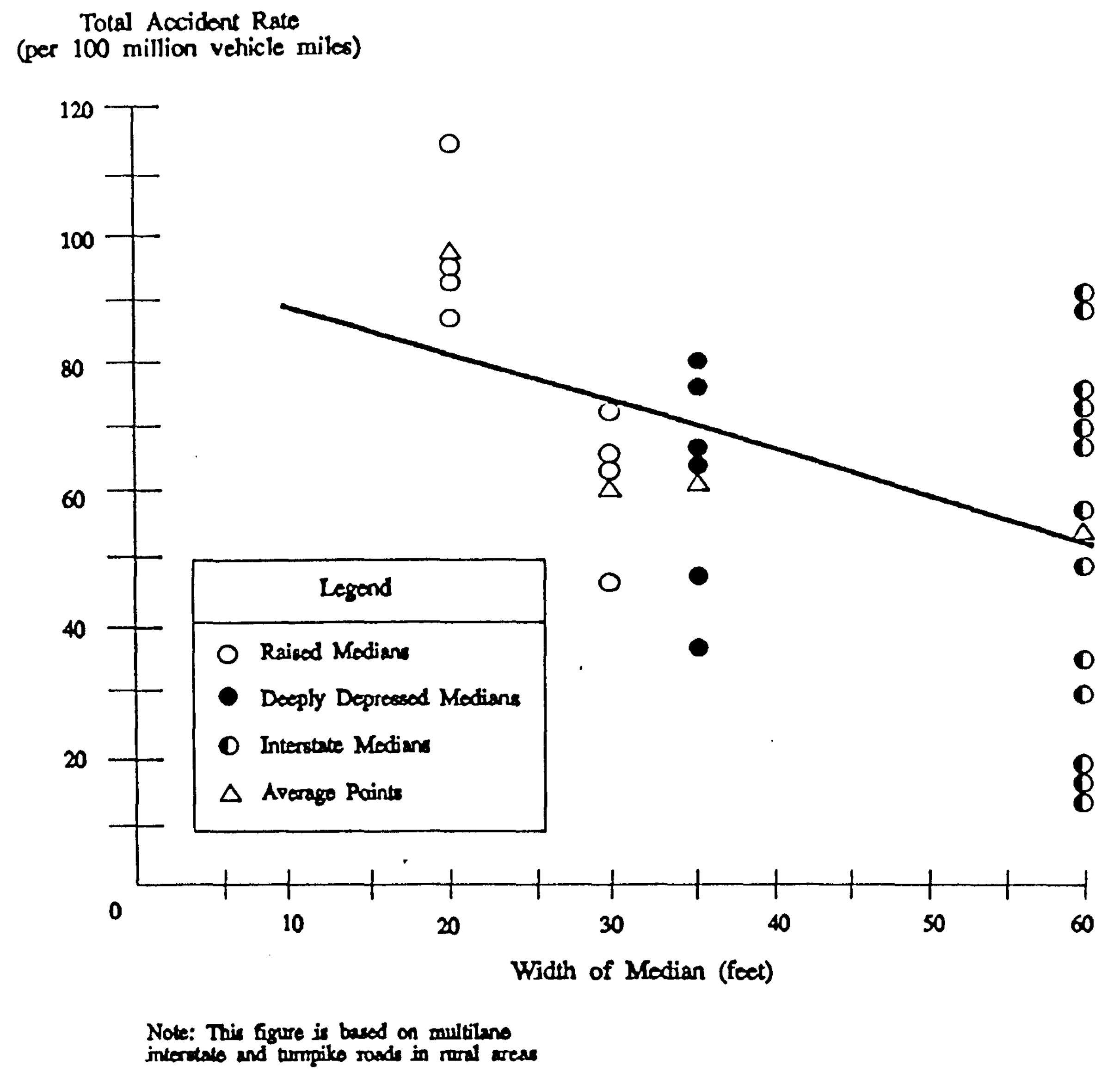


Figure 9. Total accident rate versus median width.[23]

commercial areas. Such problems are often due to inadequate geometry (steep grades, poor sight distance), the lack of passing opportunities (due to heavy oncoming traffic and/or poor sight distance), or turns at intersections and driveways. While a major reconstruction project may be used to reduce the problem (e.g., widening to a four-lane facility or major alignment changes), other lower-cost alternatives have been used successfully to reduce accident operational problems.[24]

As illustrated in figure 10, a 1985 study by Harwood and St. John evaluated the following five different operational and safety treatments as alternatives to basic two-lane highways:[25]

1. Passing lanes,
2. Short four-lane sections,
3. Shoulder use sections (i.e., shoulders are used as driving lanes),
4. Turnout lanes (a widened, unobstructed area on a two-lane highway allowing slow vehicles to pull off through lane to allow other vehicles to pass), and
5. Two-way left-turn lanes (TWLTL's).

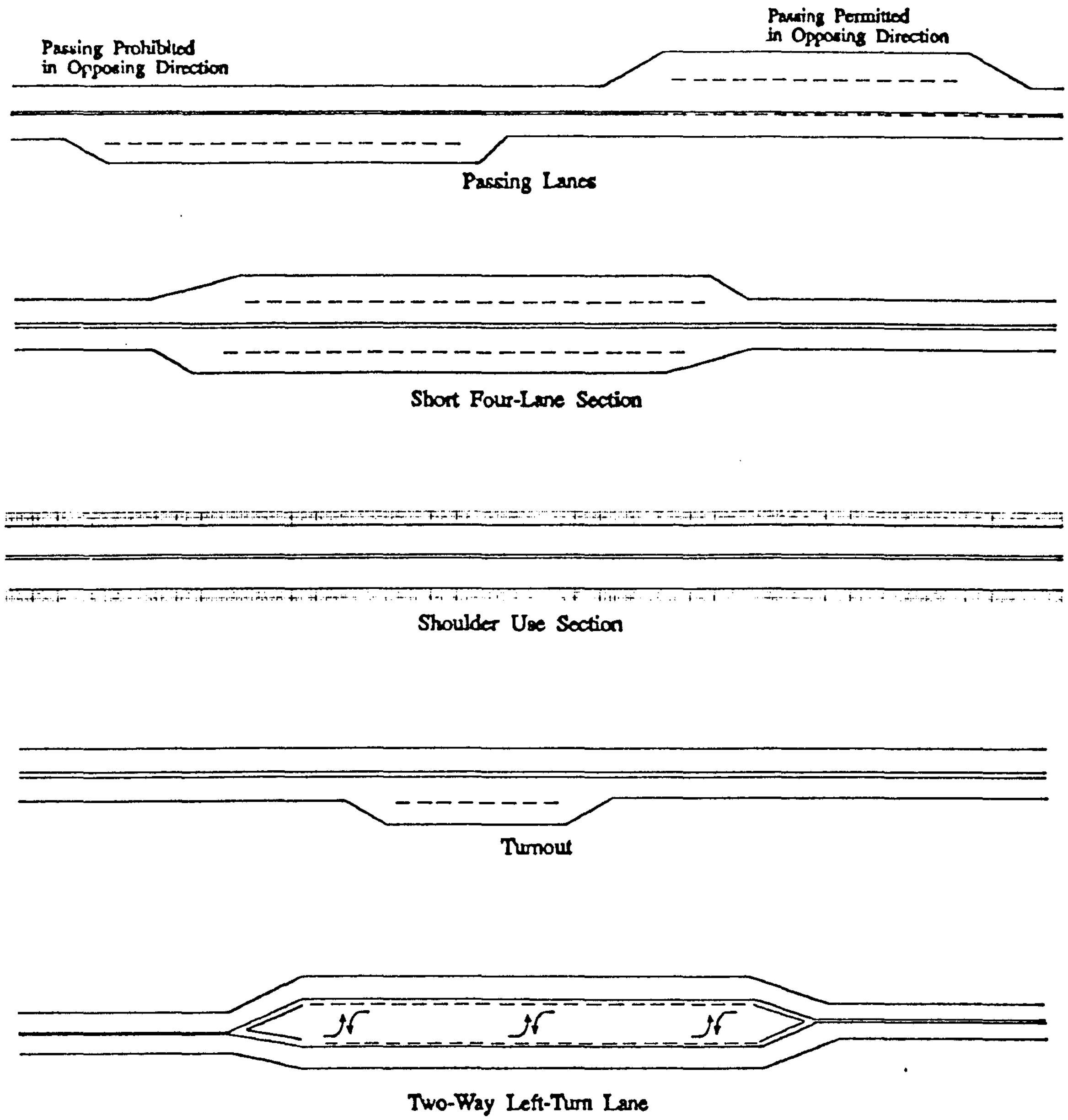


Figure 10. Typical operational treatments used on two-lane rural highways.[25]

In addition to an operational analysis, the accident effects of these design alternatives were evaluated for 138 treated sites, compared to adjacent "untreated" two-lane highway sections. The results were used along with some related past studies to determine expected accident reductions due to making such design improvements on two-lane roads.[25,26] Note that these reductions are based on sites which carried predominantly higher traffic volumes than average two-lane sections. Thus, the reductions shown in table 12 may not apply to low-volume two-lane roads.

Table 12. Accident reductions related to five multi-lane alternatives, as compared to a basic two-lane road design.

Multilane Design Alternative	Type of Area	Percent Reduction in Accidents: Total Accs	Percent Reduction in Accidents: F + I Accs
Passing lanes	Rural	25	30
Short four-lane section	Rural	35	40
Turnout lanes	Rural	30	40
Two-way, left-turn lane	Suburban	35	35
Two-way, left-turn lane	Rural	70-85	70-85
Shoulder use section	Rural	no known significant effect	

Notes:

F + I = fatal plus injury accidents

These values are only for two-lane roads, in rural or suburban areas.

As shown in table 12, two-way left-turn lanes (TWLTL's) were found to reduce accidents by approximately 35 percent in urban fringe areas and at from 70 to 85 percent in rural areas. Accident reductions of 25 to 40 percent were reported for passing lanes, short four-lane sections, and turnout lanes. No known accident effects were found for shoulder use sections, although sample sizes were quite small.[25,26]

The reader should use caution regarding the accident effects of these design alternatives, since accident experience may vary widely depending on the specific traffic and site characteristics. In addition, not all of these alternatives are even appropriate for all possible roadway sections. Also, while such alternatives may reduce some safety and operational problems, other problems may be created in some cases. For example, at rural locations where passing zones exist, using TWLTL's can create operational problems with respect to same-direction passing maneuvers. More detailed guidelines are given in an Informational Guide by Harwood and Hoban for optimal use of these design alternatives.[26]

A 1986 NCHRP study by Harwood investigated the safety, operational, and cost characteristics of multilane designs for suburban areas.[24] These designs generally involve adding one or more lanes to a two-lane road design and generally are more extensive than the two-lane undivided road alternatives (termed the 2U design "base"conditions) alternatives mentioned for the other study above. These multilane designs include:[24]

- Three-lane divided, with two-way, left-turn lane in the median (3T design),
- Four-lane undivided (4U design),
- Four-lane divided with one-way left-turn lanes in the median (4D design), and
- Five-lane divided with two-way left-turn lane in the median (5T design).

In addition to these five alternatives, a less detailed analysis was also conducted for three other design alternatives, namely:

- Five-lane divided roads with continuous alternating left-turn lane in the median,
- Six-lane divided highways with a raised median, and

- Seven-lane highways with TWLTL's in the median.

These eight alternatives are illustrated in figure 11.

An analysis was conducted of accident, operational traffic, and roadway data for sample sections from California and Michigan. Average accident rates were computed for each of the five basic design alternatives (see table 13) for commercial and residential areas. The 3T design had a safety advantage over standard two-lane (2U) highways and requires only a minor amount of increase in road width. Four-lane undivided (4U) highways had generally higher accident rates than other multilane design alternatives, due in part to the lack of special provisions for left-turn vehicles. Installation of a five-lane highway with a TWLTL (5T design) was associated with reduced accident rates compared to other four-lane design options.[24]

To compare accident rates in table 13 for two or more design options, first select the adjusted average rate for a given design option (e.g., 3T, 4U, 4D) for commercial or residential area. Then, adjust this average rate (add or subtract) based on the number of driveways per mile, intersections per mile, and truck percentage. For example, compare the rate of a 4U vs a 5T design on a section in a commercial area with 65 driveways per mile (adjustment = +0.35), 7 intersections per mile (adjustment = +0.28), and 8 percent trucks (adjustment = -0.15). The adjusted rate for the 4U design in a commercial area is (7.62) + (.35) + (.28) - (.15) = 8.40. The adjusted accident rate for the 5T design in the same commercial area would be (5.80) + (.35) + (.28) - (.15) = 6.28. Thus, the 5T design would have an accident rate which is 2.12 (= 8.40 - 6.28) lower, or a 25 percent reduction, compared to the 4U design.

The reader should note that while such accident rates represent the most reliable information available, the results should still be used with caution. For example, little difference resulted in average rates between the 4U and 4D design, due perhaps to some

Table 13. Average accident rates for suburban arterial highways (including nonintersection and unsignalized intersection accidents.[24]

BASIC ACCIDENT RATES
(accidents per million-vehicle-miles)

Type of Development	Design Alternative 2U	3T	4U	4D	5T
Commercial	4.50	3.99	7.62	7.61	5.80
Residential	4.76	3.55	4.00	4.10	3.24

ADJUSTMENT FACTORS

Driveways/mile	<30: -0.41	30-60: -0.03	>60: +0.35
Intersections/mile	<5: -0.99	5-10: +0.28	>10: +1.55
Truck percentage	<5: +0.40	5-10: -0.15	>10: -0.71

Notes:

2U = two-lane undivided roads
3T = three-lane divided, including TWLTL
4U = four-lane undivided
4D = four-lane divided with one-way LTL
5T = five-lane divided including TWLTL

unexplained variables which could have affected the results. There is strong evidence that accident and operational problems are generally reduced on 4-lane roads which are divided compared with undivided design. Also, the accident rate adjustment for trucks is puzzling, since rate adjustments are higher for lower percent trucks. Finally, numerous operational, safety, and cost factors should be considered before selecting a multilane design alternative. In fact, a 10-step procedure is provided in the full study for selecting the optimal design alternative for a given suburban highway section.[24]

Other Cross-Sectional Features

In addition to lane and shoulder, roadside features, bridge width, and other features discussed above, there are a multitude of

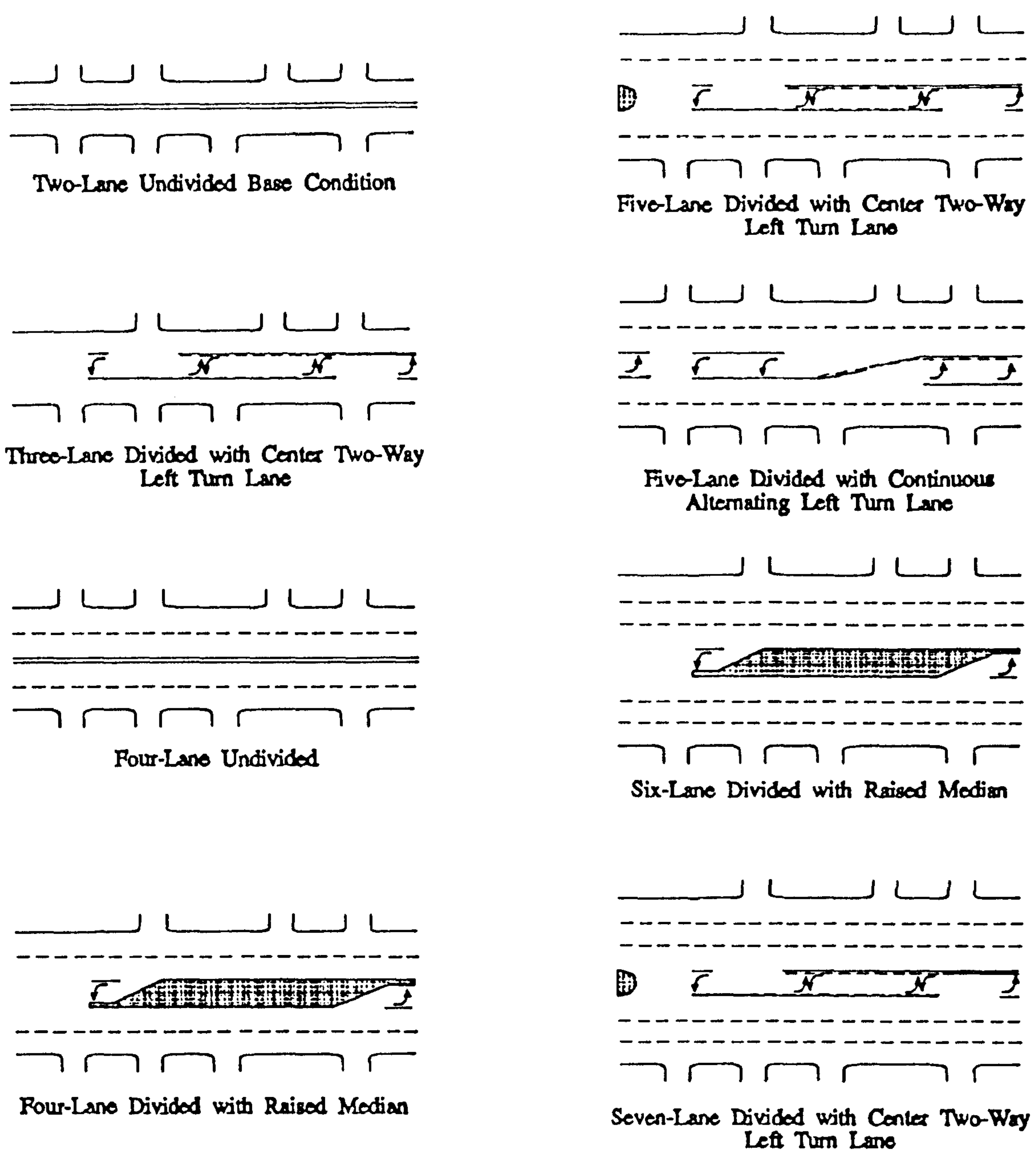


Figure 11. Design Alternatives for Improving Suburban Arterial Highways.[24]

other cross-sectional variables which can affect crash frequency and/or severity. For example, the cross slope along a highway section normally is characterized on tangent sections by the crown of the road (for drainage purposes) and on horizontal curves by the superelevation (and superelevation transition). The safety effects of superelevation are discussed in more detail in the alignment volume (Volume II). The effect of cross slope on tangent sections is difficult to quantify due to the fact that (1) cross slopes may vary within a given section, and (2) the cross slope may be altered somewhat each time a section is repaved (whether intentional or not).

Studies have also found that characteristics of roadside ditches play a role in crash severity and/or frequency. Ditch shape (e.g., V-ditch, trapezoidal) can influence the vehicle direction and the likelihood of a rollover and/or type of impact. Specific crash effects, however, have not been fully quantified.

Relationships also exist between cross-sectional elements and roadway alignment. For example, the effects of lane and shoulder width reported above involve rural roads with all types of alignment. However, if one analyzes accident effects of roadway width on horizontal curves, different relationships are found.

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