Safety Relationships Associated with Cross-Sectional Roadway Elements

CHARLES V. ZEGEER AND FORREST M. COUNCIL

This study was conducted to summarize the known relationships between accident experience and cross-sectional roadway elements, along with accident reductions expected because of related roadway safety improvements. Such elements include lane width, shoulder width, shoulder type, roadside features, bridge width, median design, and others. A detailed review of literature and available safety research revealed that accident types related to cross-sectional elements on two-lane roads include run-off-road (including fixed-object and rollovers), head-on, opposite direction sideswipe, and same direction sideswipe. Lane widening can reduce these related crashes by up to 40 percent, whereas shoulder widening can reduce related accidents by up to 49 percent [for the addition of 8-ft (2.4-m) paved shoulders]. Improving roadsides can also contribute to the reduction of as much as 44 percent [for a 20-ft (6.1-m) increase in clear zone], whereas sideslope flattening can reduce single-vehicle crashes up to 27 percent (for flattening a 2:1 sideslope to 7:1 or flatter). Bridge widening can reduce total bridge crashes by as much as 80 percent, depending on the width before and after widening. On multilane roads, wider and flatter medians are associated with a reduced rate of total crashes. Lower-cost multilane design alternatives found to reduce crashes compared to two-lane roadways include two-way left-turn lanes, passing lanes, and turnout lanes. Suburban and rural multilane designs found to significantly reduce crashes compared to two-lane roads include those roads having two-way left-turn lanes with three or more total lanes.

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), bridge width, and median width, among others. These elements can be modified to reduce accident rates. For example, lanes and shoulders can be widened, and sideslopes can be flattened.

In addition to modifying 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.

The purpose of this article is to discuss known relationships between cross-sectional elements and accident experience, along with the accident reductions expected because of 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 conditions relates to rural two-lane roads. The discussion of median design includes only multilane Interstate and parkway roads in rural areas.

University of North Carolina, Highway Safety Research Center, 134 1/2 E. Franklin Street, Chapel Hill, N.C. 27599.

SUMMARY OF RESEARCH

Figure 1 illustrates the many cross-sectional roadway elements 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 or shoulders, or both, 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, 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 accident types affected by lane and shoulder width.

A 1987 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 8 050 km (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 together were 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.

The study found that lane widening of 1 ft (0.3 m) [e.g., from 10-ft (3.0-m) to 11-ft (3.4-m) lanes] will be expected to reduce related accidents by 12 percent. Widening lanes by 2 ft (0.6 m), 3 ft (0.9

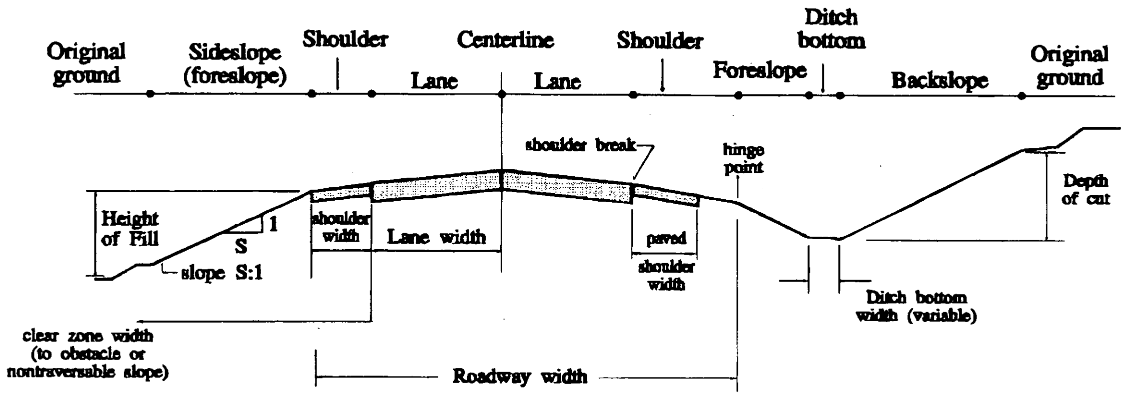

FIGURE 1 Elements of rural two-lane highway cross sections.

m), and 4 ft (1.2 m) will reduce related accident types by 23 percent, 32 percent, and 40 percent, respectively. It is important to mention that the predictive model only applies to two-lane, rural roadways with lane widths of 8 to 12 ft (2.4 to 3.7 m), shoulder widths of zero to 12 ft (3.7 m) (paved or unpaved), and traffic volumes of 100 to 10,000. One should not assume that these accident reductions apply to conditions outside these ranges (*3*).

According to the model, the same percentage of accidents will be reduced for a given amount of lane or shoulder widening, regardless of the lane width or shoulder width in the base (before) condition. For example, adding a 4-ft (1.2-m) paved shoulder to a road with a 10-ft (3.0-m) lane and no shoulder would result in the same accident reduction percentage as adding 4 ft (1.2 m) of shoulder to a 12-ft (3.7-m) lane with an existing 6-ft (1.8-m) paved shoulder. However, the actual number of related accidents eliminated per mile, per year would be greater for adding the 4-ft (1.2-m) paved shoulder to the 10-ft (3.0-m) lane, since the model would also predict a greater number of accidents for the section with the narrower 10-ft (3.0-m) lane. Greater overall benefits would result, then, from adding the 4-ft (1.2-m) shoulder to the 10-ft (3.0-m) lane, compared to adding a 4-ft (1.2-m) shoulder to a 12-ft (3.7-m) lane (*3*).

Reductions in related accidents because of widening paved or unpaved shoulders were also found in that same study. Widening paved shoulders by 2 ft (0.6 m), 4 ft (1.2 m), 6 ft (1.8 m), and 8 ft (2.4 m) will reduce related accidents by 16 percent, 29 percent, 40 percent, and 49 percent, respectively. Similar amounts of widening of unpaved shoulders will reduce related accidents by 13 percent, 25 percent, 35 percent, and 43 percent. Thus, for example, adding 8-ft (2.4-m) 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 above are valid only when the roadside characteristics (sideslope and clear zone) are reestablished as before the lane or shoulder widening.

In general, 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 1 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 (3.0-m) lane widths and 4-ft (1.2-m) unpaved shoulders, and the proposed improvement will result in 12-ft (3.7-m) lanes with 6-ft (1.8-m) paved shoulders. To determine the combined accident reduction of this improvement project, find the value in Table 1 corresponding to 2 ft (0.6 m) of lane widening (left column), and 4 ft (1.2 m) of unpaved shoulder in the existing condition. Go across horizontally to the column indicating a 6-ft (1.8-m) 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 results from this study, as given in Table 1, are recommended for use in estimating accident reduction effects of lane and shoulder improvements. These factors are appropriate for two-lane roads with ADTs of 100 to 10,000 vehicles per day (vpd), lane widths of 8 to 12 ft (2.4 to 3.7 m), and 0- to 12-ft (0- to 3.7-m) shoulders that 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 et al. study (*3*). The authors also found that roadway widening is not generally cost-effective for farm-to-market roads with ADTs 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 (*6*); Zegeer, Mayes, and Deen in Kentucky (*7*); Shannon and Stanley in Idaho (*8*); and an NCHRP study by Jorgensen using data from Washington and Maryland, among others (*1*). Although these studies used a wide range of sample sizes and analysis techniques, all basically found that accident rates decrease because of wider lanes or shoulders, or both, even though there was considerable variation in the exact amount of crash reduction.

Although the studies reported above involved developing relationships between roadway width and accident experience from state data files and estimating crash reduction because of the accident relationship, studies by Rinde (in California) (*9*) and Turner et al. (in Texas) (*10*) involved evaluating actual pavement-widening projects. A 1974 study by Heimbach, Hunter, and Chao in North Carolina also found that paving 3 to 4 ft (0.9 to 1.2 m) of unpaved shoulders will result in significant reductions in accident frequency and severity (*11*).

TABLE 1 Accident Reduction Factors for Related Accident Types for Various Combinations of Lane and Shoulder Widening

Amount of Lane Widening (in feet)	Existing shoulder condition (Before period)		Percent Related Accidents Reduced — Shoulder Condition in After Period							
			2 ft. Shoulder		4 ft. Shoulder		6 ft. Shoulder		8 ft. Shoulder	
	Shoulder width	Surface type	P	U	P	U	P	U	P	U
	0	N/A	43	41	52	49	59	56	65	62
	2	Paved	32	--	43	--	52	--	59	--
	2	Unpaved	34	33	44	41	53	49	60	56
	4	Paved	--	--	32	--	43	--	52	--
3	4	Unpaved	--	--	36	32	46	41	54	49
	6	Paved	--	--	--	--	32	--	43	--
	6	Unpaved	--	--	--	--	37	32	47	41
	8	Paved	--	--	--	--	--	--	32	--
	8	Unpaved	--	--	--	--	--	--	39	32
	0	N/A	35	33	45	42	53	50	61	56
	2	Paved	23	--	35	--	45	--	53	--
	2	Unpaved	25	23	37	33	46	42	55	50
	4	Paved	--	--	23	--	35	--	45	--
2	4	Unpaved	--	--	27	23	38	33	48	42
	6	Paved	--	--	--	--	23	--	35	--
	6	Unpaved	--	--	--	--	29	23	40	33
	8	Paved	--	--	--	--	--	--	23	--
	8	Unpaved	--	--	--	--	--	--	31	23
	0	N/A	26	24	37	34	47	43	55	50
	2	Paved	12	--	26	--	37	--	47	--
	2	Unpaved	14	12	28	24	39	34	48	43
	4	Paved	--	--	12	--	26	--	37	--
1	4	Unpaved	--	--	17	12	20	24	41	34
	6	Paved	--	--	--	--	12	--	26	--
	6	Unpaved	--	--	--	--	19	12	31	24
	8	Paved	--	--	--	--	--	--	12	--
	8	Unpaved	--	--	--	--	--	--	21	12

Notes:

Cells were left blank where they correspond to projects which would decrease shoulder width and/or change paved shoulders to unpaved shoulders

P = paved, U = unpaved

These values are only for two-lane rural roads

1 ft = 0.3048 m

Roadside Condition

Roadside condition is another cross-sectional element that often affects crash frequency and severity. This is because of the high percentage of crashes, particularly on rural two-lane roads, that 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 roadside recovery distance (or roadside clear zone), and sideslope (foreslope). Both the severity of crashes and crash frequency are affected by such roadside features. Following is a discussion of these roadside characteristics.

Roadside Recovery Distance and 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, nontraversable 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 nontraversable slope (*12*).

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., three to five measurements per mile (1.6 km) on each side of the road). Roadside recovery distances of 0 to 30 ft (0 to 9.1 m) are generally recorded.

For roadways with limited recovery distances [particularly less than 10 or 15 ft (3.0 to 4.6 m) from the roadway edgeline] where roadside improvements are proposed, accident reduction factors may be found. These factors are again based on the previously cited Zegeer et al. study (*3*). As with lane and shoulder width, the accident model predicts that accident rates will be reduced by a specific percentage for a given increase in roadside recovery distance. Increasing the roadside recovery distance by 5 ft (1.5 m) (e.g., from 12 to 17 ft) (3.7 to 5.2 m) will reduce "related" accidents (as defined earlier) by an estimated 13 percent. Further, increasing the roadside recovery distance by 10 ft (3.0 m), 15 ft (4.6 m), and 20 ft (6.1 m), will reduce related accidents by 25 percent, 35 percent, and 44 percent, respectively. Examples of roadside improvements that can increase the recovery distance include cutting trees near the roadway, relocating utility poles further from the road, and using sideslopes of about 4:1 or flatter. For an improvement involving only sideslope flattening, see the discussion on sideslope given later.

A 1982 study by Graham and Harwood determined the effect of clear zone policy on the single-vehicle accident rate (*13*). 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 ADTs. This study also indicates a high potential for safety benefits resulting from increased roadside clear zones.

Sideslope

The steepness of the roadside slope or sideslope, also termed foreslope, is a cross-sectional feature that 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 about 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 mi of roadway in three states: Michigan, Alabama, and Washington (*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*).

The accident relationship was used to develop accident reductions matching various sideslope-flattening projects. The percent reductions are given in Table 2 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 rest on the assumption 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 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*). Additional details of accident effects of specific roadside obstacles (e.g., utility poles, culverts, guardrail) are given elsewhere (*14–17*).

TABLE 2 Effects of Sideslope Flattening on Single-Vehicle and Total Accidents

	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.

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 nonrollover 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. Obstacle types with the lowest crash severity include small sign posts, fences, and guardrails (*18*).

A separate analysis was also conducted for severity of crashes involving ditches. The authors found that ditches that were 3 ft (0.9 m) or deeper were associated with a higher percent of injury accidents (61 percent) when compared to crashes involving ditches 1 to 2 ft (0.3 to 0.6 m) 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 (0.3- to 0.6-m) and 3-ft (0.9-m) plus groups).

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, 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 that are of most importance with respect to affecting the bridge accident rate are the bridge width, or the width of the bridge in relation to the approach width, or both. The best known accident relationship with bridge width was developed in a 1984 study by Turner (*19*). 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," which is defined as the bridge width minus the width of the traveled way.

According to Turner's accident model, and as indicated in Figure 2, the number of accidents per million vehicles decreases as the relative bridge width increases (*19,20*). This relationship indicates that it is desirable to have bridge widths at least 6 ft (1.8 m) wider than the travelled way. In other words, shoulders of 3 ft (0.9 m) or more should be provided on each side of the bridge.

Based on Turner's model, the percent reduction in total accidents because of reconstructing narrow bridges to make them wider can be determined. Accident reduction factors given in Table 3 provide percent reductions in the total crash rate expected because of widening shoulders on bridges. For example, assume that a bridge width is 24 ft (7.3 m) wide with 10-ft (3.0-m) lanes and 2-ft (0.6-m) shoulders on each side. According to Table 3, widening the bridge to 32 ft (9.8 m) [i.e., two 10-ft (3.0-m) lanes with two 6-ft (1.8-m) shoulders] would reduce the total bridge accident rate by 62 percent.

Note that values in Table 3 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 3 and only include the amount of increased shoulder width. For example, when widening a 20-ft (6.1-m) bridge [two 10-ft (3.0-m) lanes and no shoulder] to a 30-ft (9.1-m) bridge [two 12-ft (3.7-m) lanes and two 3-ft (0.9-m) shoulders], assume an increase in shoulder width from 0 to 3 ft (0 to 0.9 m), for at least a 42 percent "minimum" accident reduction.

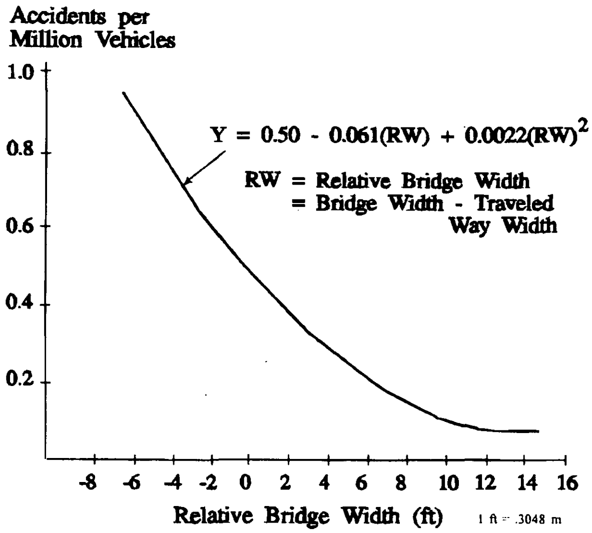

FIGURE 2 Accident rate by relative bridge width.

Median Design

Elements of median design that may influence accident frequency or severity include median width, median slope, median type (raised or depressed), and the 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 because of 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 versus depressed (swale) medians in the 1974 Ohio study by Foody and Culp (*21*). Using a sample of rural interstates, all having 84-ft (25.6-m) wide medians and other similar geometrics, accident experience was compared between the two median designs. No differences were found in the number of injury accidents, rollover accident occurrence, or overall accident severity between the raised and depressed 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 versus depressed), and slopes on Interstate and turnpike roads in Kentucky (*22*). Highways with at least 30-ft (9.1-m) wide medians had lower accident rates than 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

TABLE 3 Summary of Accident Reduction Factors Associated with Widening Shoulders on Bridges

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

1 ft = .3048 m

[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]

slopes of 4:1 or steeper had abnormally high accident rates for various median widths, whereas a higher crash severity and higher proportion of vehicle overturn accidents were found for medians that were deeply depressed. For median widths of 20 to 30 ft (6.1 to 9.1 m), the use of a raised median barrier was associated with a higher number of accidents involving hitting the median and losing control (*22*).

The authors recommended minimum median widths of 30 to 40 ft (9.1 to 12.2 m), slopes of 6:1 or flatter [particularly when median widths are less than 60 ft (18.3 m)], and 12-ft (3.7-m) 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 when a wide median width can be provided [e.g., 84 ft (25.6 m)], a mildly depressed median [depressed by 4 ft (1.2 m) 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 (6.1 to 12.2 m)], 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. Although accident relationships are unclear for median widths of less than 20 ft (6.1 m), wider medians in general are better, and median widths in the range of 60 to 80 ft (18.3 to 24.4 m) 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 commercial areas. Such problems are often caused by inadequate geometry (steep grades, poor sight distance), the lack of passing opportunities (because of heavy oncoming traffic or poor sight distance, or both), or turns at intersections and driveways. Although 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 (*23*).

A 1985 study by Harwood and St. John (*24*) evaluated the following five different operational and safety treatments as alternatives to basic two-lane highways:

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

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 caused by making such design improvements on two-lane roads (*25,26*). Note that these reductions are based on sites that carried predominantly higher traffic volumes than average two-lane sections. Thus, the reductions indicated in Table 4 may not apply to low-volume two-lane roads.

As indicated in Table 4, TWLTLs were found to reduce accidents by approximately 35 percent in urban fringe areas and 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 (*24,25*).

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, although 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 TWLTLs 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 (*25*).

A 1986 NCHRP study by Harwood investigated the safety, operational, and cost characteristics of multilane designs for suburban areas (*23*). These designs generally involve adding one or more

TABLE 4 Accident Reductions Related to Five Multilane Design Alternatives, as Compared to a Basic Two-Lane Road Design

Multilane Design Alternative	Type of Area	Percent Reduction in Accidents	
		Total Accs	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.

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) mentioned for the other study above. These multilane designs include (*23*):

- 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 TWLTLs in the median.

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 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, in part because of 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*).

Other Cross-Sectional Features

In addition to lane and shoulder, roadside features, bridge width, and other features discussed above, there are a multitude of other cross-sectional variables that can affect crash frequency and 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 super-elevation (and super-elevation transition). The effect of cross slope on tangent sections is difficult to quantify because (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, frequency, or both. Ditch shape (e.g., V-ditch, trapezoidal) can influence the vehicle direction and the likelihood of a rollover and the 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.

CONCLUSIONS

In the past 20 years, much has been learned about the safety impacts of cross-sectional roadway features. For example, widening lanes can reduce "related" accidents (i.e., run-off-road, head-on, opposite-direction sideswipe, and same-direction sideswipe) by as much as 40 percent. Shoulder widening can reduce related accidents by up to 49 percent, for the addition of 8-ft (2.4-m) paved shoulders. Increasing the roadside clear zone, flattening roadside slopes, or both, are associated with major reductions in fixed object and rollover crashes. Bridge widening on two-lane rural roads can reduce total bridge crashes by as much as 80 percent, depending on the width before and after widening.

On multilane roads, wider and flatter medians are associated with reduced accident rates. Lower-cost multilane design alternatives that reduce crashes compared to two-lane roads include two-way left-turn lanes, passing lanes, and turnout lanes. Suburban and rural multilane designs found to significantly reduce crashes include those roads having two-way left-turn lanes and also those with three or more lanes.

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