Effect of Lane Width, Shoulder Width, and Shoulder Type on Highway Safety

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Accident experience on rural highways is a complex function of many factors, including not only those associated with physical aspects of the roadway and the roadside but also a multitude of others related to driver, vehicle, traffic, and environmental conditions. Among the many roadway-related features of importance—estimated by one 1978 study to total at least 50 *(1)*—three that are often underscored as being among those having the greatest impact include lane width, shoulder width, and shoulder type.

The purpose of this investigation was to critically review relevant literature and develop a model for estimating the effect of lane width, shoulder width, and shoulder type on motor vehicle accidents on two-lane, rural highways. Preliminary issues considered important to this task include *(a)* criteria for selecting and evaluating useful studies, and *(b)* definitional issues.

CRITERIA FOR SELECTING STUDIES

More than 30 articles and reports dated between the early 1940s and the mid-1980s were reviewed. The conclusions of these studies were often not only inconsistent, but, in many cases, totally contradictory. For example, some studies concluded that wider shoulders result in an *increased* number of accidents, whereas others found that shoulder width had little or no effect on accidents (or only influenced accident frequency for specific levels of traffic volume). Still other studies revealed significantly fewer accidents on roadways with paved or widened shoulders than on those with unpaved or narrow shoulders, or both.

Because of this disparity in research findings, considerable selectivity was demanded in determining which studies should be considered among the most reliable. Such a task had been considered in detail by Zegeer and Perkins relative to the following study elements *(2)*: *(a)* type of data analysis and statistical testing, *(b)* reliability of the accident data sample, *(c)* characteristics of roadway sections, and *(d)* types of accidents analyzed. Criteria used herein to determine the major strengths and weaknesses of each source are given as follows:

Criteria related to data reliability

- Is the study data reasonably current or is it outdated?
- Did the author collect a sufficient sample for establishing reliable results?
- Was adequate detail maintained in the collection of important data variables?
- Did the author adequately control for possible data errors?
- What data biases exist in terms of state, geographic region, section lengths, roadway classes, and so forth? (It should also include the zero-accident sections.)

Criteria related to data analysis and results

- Were adequate control variables used?
- What accident types (rear-end, run-off-road, etc.) and units (frequencies, rates, etc.) were used in the analysis and were they properly handled?
- What assumptions were made in conducting the analysis and were they valid?
- Were appropriate analysis techniques and statistical tests applied?
- Did the author correctly interpret the analysis results?

Basic principles outlined in the Federal Highway Administration (FHWA) *Accident Research Manual* and the user's manual on *Highway Safety Evaluation* were also considered in the critical review *(3, 4)*.

Initial review of the 30 articles revealed numerous major flaws in many of the older (pre-1960) accident studies including the following:

- Specific attention was not focused on the types of accidents likely to be affected by lane and shoulder conditions.
- No measure of vehicle exposure was used in comparing accident experience for various lane and shoulder widths.
- The full effects of lane and shoulder conditions were obscured because the study was limited to straight, level, tangent sections.
- Because few or no "control variables" were used, relationships between lane or shoulder conditions and accidents were influenced in unknown ways by other roadway features.
- Although several studies incorporated appropriate statistical analysis techniques, others made gross or unsupported assumptions or used inappropriate tests for data analysis.

In addition to these flaws, use of data from older studies was considered undesirable for the following reasons:

- Current accident data bases are likely to be more reliable than older ones.
- Important safety-related vehicle characteristics have changed through the years, including such features as acceleration and braking ability, truck sizes and weights, availability of occupant restraints, and many others.
- The use of pavement delineation, signing, and other traffic control practices also differs today compared with earlier years.

As a result of these considerations, all pre-1960 studies were excluded from this critical assessment of the literature. Many post-1960 studies were also dismissed because of flaws, questionable study procedures, or other critical study limitations. Only nine studies, identified in Table 1, survived preliminary screening. Of these nine, the study by Rinde dealt with shoulder widening, whereas studies by Dart and Mann, Shannon and Stanley, and Zegeer et al. involved analyses of both lane and shoulder widths. Studies by Heimbach et al., Turner et al., and Rogness et al. involved only shoulder type, whereas studies by Foody and Long and Jorgensen analyzed lane width, shoulder width, and shoulder type *(1–9)*.

TABLE 1 Summary of Selected Studies

						Type of Analysis		
			Cross Sectional Elements Analyzed				Comparative Analysis	
Author	Date	States Included	Lane Width	Shoulder Width	Shoulder Type	Before/ After	No Predictive Equation	Predictive Equation
Dart and Mann	1970	Louisiana	X	X				X
Heimbach, Hunter, and Chao	1974	North Carolina			X		X	
Foody, Long	1974	Ohio	X	X	X			X
Shannon, Stanley	1976	Idaho Washington	X[a]	X[a]				X
Rinde	1977	California		X		X		
Jorgensen & Associates	1978	Washington[b] Maryland	X	X	X			X
Zegeer, Mayes, Deen	1979	Kentucky	X	X			X	
Turner, Fambro, Rogness	1981	Texas			X		X	
Rogness, Fambro, Turner	1982	Texas			X	X		

[a]In this study, pavement width was the variable used in the analysis, which included total paved width (lanes plus shoulders).
[b]New York State was used for initial analysis, but excluded for development of accident relationships.

The studies by Rinde and Rogness et al. were before-and-after studies of completed shoulder widening projects in which the authors controlled for external factors *(5, 11)*. The remaining seven studies were comparative analyses, which developed accident relationships with one or more geometric variables. Of these seven, three used regression analysis to develop predictive accident models.

To select the most reliable and complete information available, data and information from the nine studies were carefully analyzed. Data were desired that covered a wide range of lane- and shoulder-width and shoulder-type combinations. Also, data showing accident experience for the specific accident types most related to lane and shoulder deficiencies was considered most useful. Ultimately, data were selected from four of the nine studies to develop the general effects of these elements on safety. The studies included Zegeer et al., Kentucky; Foody and Long, Ohio; Rinde, California; and Rogness et al., Texas *(5, 8, 11, 12)*. Data from the Kentucky and Ohio studies *(8)* were used in the development of mathematical models that represent the most likely relationships between the rate of related (run-off-road and opposite-direction) accidents and combinations of lane width, shoulder width, and shoulder type.

DEFINITIONAL ISSUES

In the critical review, the following definitional issues had to be addressed:

- When comparing paved versus unpaved shoulders, what type of surfaces are included in the unpaved category (stabilized, gravel, grass, dirt)?
- How wide are the paved shoulders, and does the term "unpaved shoulders" imply that trees and other fixed objects may be located within 2 to 10 ft of the roadway?
- How much of the roadbed width is considered to be the lane and how much is considered to be the shoulder?

Attempts to resolve these and other issues required telephone contacts with the authors or others familiar with the studies and the data bases, or the use of unpublished research reports. Considerable clarification resulted from these followup investigations. For example, in a Texas study of shoulder effects, the term paved shoulder was defined as "any one of a wide range of all-weather surfaces—bituminous surface-treated shoulders, bituminous aggregate shoulders, full-depth asphalt shoulders, and portland cement concrete shoulders. They are constructed next to main line pavements of equal or better type" *(13)*.

Considerable variations were found among definitions used in the studies. Generally, a paved shoulder was considered to be an all-weather bituminous treatment. However, in studies comparing paved versus unpaved shoulders, a paved shoulder generally implied an 8- to 10-ft surface, whereas unpaved typically implied a grass or dirt shoulder free of obstructions for approximately 10 ft.

Citing another example, the North Carolina study by Heimbach et al. considered unpaved shoulders to be gravel, dirt, or grass surfaces on which obstructions generally do not exist for approximately 10 ft or more from the pavement edge *(9)*. Thus, unpaved shoulders may be considered to be driveable surfaces (except when wet), readily distinguishable from "no shoulder" situations. The study in Ohio by Foody and Long used several categories of shoulder—paved, stabilized, unstabilized, and other *(12)*. Unstabilized shoulders consisted of slag, gravel, soil, or grass. Although no clear definition is given for the "other" category, it was later learned that this represented situations in which no specific treatment was provided beyond the roadway edge.

In studies of the effect of shoulder width on accidents, variations were again found in the definition of width. In most studies, width apparently refers to all-weather paved or stabilized shoulders, or both. Such studies made a distinction between lane and shoulder width by comparing different surface types and noting a definite break between the roadway and the paved shoulder. However, in the study by Shannon and Stanley *(7)* and Rinde *(5)*, the authors refer to the entire pavement width, including the paved lane width and shoulders, even though the stated goal of the Rinde study involved the specific analysis of shoulder widening.

For use in developing accident relationships and predictive models in this paper, lane width is defined as the width of the travel lane, which is the width from the center of the roadway to one of the following points: *(a)* the edgeline, *(b)* where a visible joint separates the lane from the shoulder (if no edgeline is present), or *(c)* where the paved surface ends (if no paved shoulder exists). A shoulder is the area provided on some roadways intended primarily for emergency stopping or as a recovery area for vehicles leaving the travel lane. Paved shoulders are considered to be the width of bituminous or concrete material next to the travel lane. Stabilized shoulders are considered to consist of a mixture of bituminous material with gravel, so the surface is generally more smooth and compacted than loose gravel alone. Unstabilized shoulders (for the purpose of the accident model) are constructed of slag, gravel, crushed stone, grass, or soil, which are generally free of trees and most other roadside obstacles.

CRITICAL REVIEW AND ANALYSIS OF THE LITERATURE

Review and analysis of the nine most reliable studies addressed four specific questions related to the most likely relationships between accident experience and lane width and shoulder width and type:

- What dependent variables (i.e., accident measures) are most appropriate for expressing the relationships between safety and the three variables of primary interest?
- What other independent variables (e.g., widths, curvature, volume groups, roadside condition) should and can be included in developing accident relationships?
- What studies and data results are the most complete and reliable for determining the expected accident relationships?
- What is the most likely relationship between accident experience and lane width, shoulder width, and shoulder type?

Selection of Dependent Variable

The first major issue was to determine the types of accidents that are related to lane width, shoulder width, and shoulder type. Although total accidents had been commonly used in past accident studies, unrelated accident types influence the data base and mask the true effects of the lane or shoulder improvement. The importance of careful selection of the dependent safety variable has been emphasized in definitive procedural guides *(3, 4)*.

Of the nine studies selected following preliminary screening of the literature, three—Heimbach et al., Shannon and Stanley, and Jorgensen—analyzed total accidents or accidents stratified only by severity level *(1, 7, 9)*. Dart and Mann used total accidents stratified by severity, pavement wetness, and time of day, but did not separately analyze accident types such as rear-end, run-off-road, and the like *(6)*. Foody and Long analyzed only single-vehicle accidents, whereas Turner et al. analyzed run-off-road accidents, hit-other-car accidents, nondaylight accidents, total accidents, and accidents classified by severity level *(10, 12)*.

Detailed accident types were analyzed in the studies by Zegeer et al., Rinde, and Rogness et al. *(5, 8, 11)*. The seven categories of accidents analyzed by Zegeer et al. include run-off-road; opposite-direction; rear-end; passing vehicle; driveway and intersection; pedestrian, bicycle, animal, and train; and other or not stated *(8)*.

Only run-off-road (ROR) and opposite-direction (OD) accidents were found by Zegeer et al. to be associated with lane and shoulder width. The percentage of ROR and OD accidents ranged from more than 90 percent of total accidents for lane widths of 7 ft to as low as 31 percent for 13-ft lane widths (Table 2) *(8)*. It should be mentioned, however, that the sample size was small for both the 7-ft and 13-ft lane-width categories—123 and 135 accidents, respectively—and that 97 percent of the 16,000 mi of roadway in the data base included sections with 5,000 average daily traffic (ADT) or less.

Turner et al. found a higher frequency of run-off-road accidents on two-lane road sections with no shoulder *(10)*. Rates of hit-other-car accidents were also higher on these sections for certain volume levels. Unfortunately, head-on accidents were not separately analyzed.

Before-and-after studies by Rogness et al. and Rinde also analyzed specific accident types relative to shoulder improvement projects *(5,11)*. Rogness found that the frequency of single-vehicle accidents (run-off-road and fixed-object accidents) was reduced by adding shoulders on low-volume, two-lane roads (ADT levels of 1,000 to 3,000) *(11)*. For ADT levels of 3,000 to 5,000, shoulder additions reduced not only ROR accidents but multiple-vehicle accidents as well. However, the effect of head-on, multiple-vehicle accidents was not specifically addressed.

Rinde categorized accidents by accident type (head-on, rear-end, hit-object, overturn, and sideswipe) and also by movements after the collision *(5)*. As a result of pavement widening, head-on accidents were reduced by 50 to 60 percent, hit-object accidents by 27 to 53 percent, and rear-end accidents by 17 to 69 percent. Results were mixed for overturn and sideswipe accidents.

In summary, strong evidence exists that ROR and OD accidents are the primary accident types affected by lane or shoulder improvements, or both. This is particularly true for roads with low traffic volumes—ADT levels of 3,000 or less. Therefore, the rate of ROR and OD accidents was selected as the primary dependent variable for developing the accident relationships.

Selection of Independent Variables

Next, an examination was conducted of the possible need for adding to lane width, shoulder width, and shoulder type other interacting independent variables whose levels might influence the effect of lane and shoulder conditions on highway safety. Ideally, all independent variables chosen for inclusion in an accident model should interrelate with the three variables of concern in affecting the related accident types.

Previous literature has addressed the range of variables that may influence accidents on two-lane roads. For example, Jorgensen reviewed more than 400 reports and other

TABLE 2 Summary of Accident Frequencies by Type for Various Lane Widths *(8)*

Accident Frequencies by Type					Percent of Total Accidents		
Lane Width (ft)	Total Accidents	Run-off-Road	Opposite Direction	All Others	Run-off-Road	Opposite Direction	Run-off-Road and Opposite Direction
7	123	58	54	11	47.2	43.9	91.1
8	1,143	576	368	199	50.4	32.2	82.6
9	6,652	3,399	1,160	2,093	51.1	17.4	68.5
10	4,947	2,189	720	2,038	44.2	14.6	58.8
11	2,017	728	190	1,099	36.1	9.4	45.5
12	1,743	555	192	996	31.8	11.0	42.8
13	135	32	10	93	23.7	7.4	31.1
Total	16,760	7,532	2,694	6,534	44.9	16.1	61.0

publications on relationships between highway design elements and accidents *(1)*. Although more than 50 design features were found to affect safety, the authors emphasized that the validity of the various safety relationships had not been evaluated and noted that some of the relationships were contradictory. Although it is difficult to draw solid conclusions from a literature review of this type, it does provide evidence of the complexity of accident relationships and the possibility that numerous roadway factors may be significant.

Other studies confirm that dozens of roadway variables could affect highway safety and thus interrelate with the effects of pavement width, shoulder width, or shoulder type. Hundreds of such studies were compiled and summarized in a two-volume synthesis prepared for the FHWA in 1982 *(14)* but, like Jorgensen, they failed to critically assess the validity of suggested accident relationships.

Predictive accident models that account for interrelationships among roadway variables have been developed in a few studies. For example, Jorgensen developed a predictive model for total accidents based on independent variables such as pavement width, shoulder width, shoulder type, ADT, and horizontal curvature *(11)*. However, the R^2 value for that model was only 0.08, indicating that only about 8 percent of the accident variance was explained by the model. The predictive model of Dart and Mann also used total accident rate (accident rate per 100 million vehicle-mi) as the primary dependent variable and yielded a much better R^2 value of 0.46 (46 percent of accident variance explained) *(6)*. The independent variables in this model included various interactions among percent trucks, traffic volume ratio, cross slope, horizontal alignment, traffic conflicts, lane width, and shoulder width.

Based on a review of the publications identified in the preceding paragraph, as well as many others, the following general conclusions can be drawn:

- Numerous traffic, geometric, and roadway variables have an effect on the highway accident experience. Many of these variables interrelate, and certain variables—when combined—cause an unusually severe accident experience.
- The interrelationships of such variables and accidents are quite complex and have not yet been adequately quantified. There is strong evidence, however, that other independent variables (in addition to lane and shoulder widths and shoulder type) interrelate in affecting accidents on two-lane rural roads. These include roadside characteristics, horizontal and vertical curvature, volume level, access points, intersections, and others.
- Although the complete family of relationships cannot be developed here, it is desirable to determine the general or overall levels of expected accident experience associated with various combinations of pavement and shoulder widening or shoulder surfacing, or both, while controlling for the combined effects of other factors.

Selection of Data for Model Development

Data and information were carefully reviewed in each of the nine studies in order to select the most reliable accident relationships and the most complete information. Each study was characterized by strengths and weaknesses, necessitating constant judgment about the information that was the most reliable and complete. Five of the nine studies were not used to build the accident model for the following reasons:

- The Jorgensen study *(1)* quantified only the total accident experience, and the mathematical model explained only 8 percent of the variance in accidents.

- Although the Shannon and Stanley study *(7)* contained a rigorous statistical analysis of data from two states, it failed to analyze specific accident types and to provide accident experience for various lane- and shoulder-width combinations.
- The Dart and Mann relationships *(6)* explained a reasonable amount of the accident variance but only used total accidents as a dependent variable.
- The Heimbach et al. study *(9)* was one of the better studies on shoulder type and safety, but it did not include an analysis of specific accident types nor did it provide detailed accident rates.
- The Turner et al. study *(10)* presented composite run-off-road and total accidents but did not provide information on the rates for various combinations of lane and shoulder widths.

Although not perfect by any means, the four studies selected for development of most likely safety relationships were those by Zegeer et al., Foody and Long, Rinde, and Rogness et al. *(5, 8, 11, 12)*. The studies by Zegeer et al. in Kentucky and Foody and Long in Ohio were based on statewide data for two-lane roads *(8, 12)*. Data on approximately 16,000 mi of roadway (and nearly 17,000 accidents in one year) were used in the Kentucky study. The Ohio study also used approximately 16,000 mi of roadway (and more than 23,000 single-vehicle accidents in 2 years) in one phase of analysis and a 1,400-mi subfile for analyzing shoulder type. It was the only study that analyzed paved, stabilized, and unstabilized shoulder types separately. The Zegeer et al. study was the only one of the nine that had detailed accident rates for various combinations of lane and shoulder widths *(8)*. Adjustment factors from that study were used to adjust accident rates for the effects of other roadway features.

The studies by Rinde in California and Rogness et al. in Texas reported results of actual pavement or shoulder widening projects, or both *(5, 11)*. The Rogness study sampled 214 mi of roadway where paved shoulders had been added to two-lane highways *(11)*. Rinde studied 143 mi where total pavement widths were increased either to 28 ft (from initial widths of 20 to 24 ft), to 32 ft (from initial widths of 18 to 24 ft), or to 40 ft (from initial widths of 20 to 26 ft) *(5)*. Thus, for some sections of roadway in the Rinde study, lanes as well as shoulders were widened. Although such sample sizes would be small for many comparative analyses, the 357 mi were considered adequate for a before-and-after (with control) type of study, considering sample sizes indicated by the Poisson test as being necessary to detect significant change.

The studies by Rinde and Rogness et al. revealed reductions in both total accidents and in specific accident types *(5, 11)*. The Rinde study adjusted the after-accident experience on the basis of statewide accident trends to control for the external influences of the 55 mph speed limit, the energy crisis, and changes in traffic volume *(5)*. The Rogness study adjusted for changes in traffic volume *(11)*. Both studies used appropriate statistical tests to determine which accident reductions were statistically significant.

Accident Relationships and Reduction Factors

Average accident rates (accidents per million vehicle miles) from the Zegeer et al. study are given in Table 3 for all accidents and also for ROR and OD accidents for various combinations of lane and shoulder widths *(8)*. The interrelated effects of various combinations of lane and shoulder widths on unadjusted rates of ROR and OD accidents are shown in Figure 1 *(8)*. Note that rates generally decrease as lane and shoulder widths increase. However, the unadjusted accident rates were approximately the same (or slightly higher) for 12-ft lanes as for 11-ft lanes, possibly indicating in part the limit beyond which further increases in lane width are ineffectual.

TABLE 3 Average Accident Rates (per million vehicle miles) as a Function of Lane and Shoulder Width for Two-Lane Rural Roads in Kentucky *(8)*

	Shoulder Width (ft)									
	No Shoulder		1–3		4–6		7–9		10–12	
Lane Width (ft)	Accident Rate	No. of Sections[a]	Accident Rate	No. of Sections[a]	Accident Rate	No. of Sections[a]	Accident Rate	No. of Sections[a]	Accident Rate	No. of Sections[a]
All Accidents										
7	5.09	286	1.94	110		–[b]		–[b]		–[b]
8	3.60	2,460	4.06	344		–[b]		–[b]		–[b]
9	3.17	6,032	2.86	2,185	2.92	9	1.83	6		–[b]
10	3.01	1,384	2.73	1,080	3.11	23	2.96	8	2.54	12
11	1.86	382	2.71	275	2.21	31	0.85	21	2.21	38
12	1.91	168	2.43	87	2.26	27	1.82	34	1.86	26
Run-off-Road and Opposite-Direction Accidents										
7	4.70	286	1.71	110		–[b]		–[b]		–[b]
8	2.96	2,460	3.42	344		–[b]		–[b]		–[b]
9	2.22	6,032	1.92	2,185	1.34	9	1.22	6		–[b]
10	1.83	1,384	1.62	1,080	1.19	23	1.03	8	1.03	12
11	1.03	382	1.02	275	0.81	31	0.51	21	0.84	38
12	0.77	168	1.08	87	0.98	27	0.70	34	0.90	261

[a]Number of 1-mi sections used to calculate average accident rate.
[b]Fewer than five sections were available in test sample.

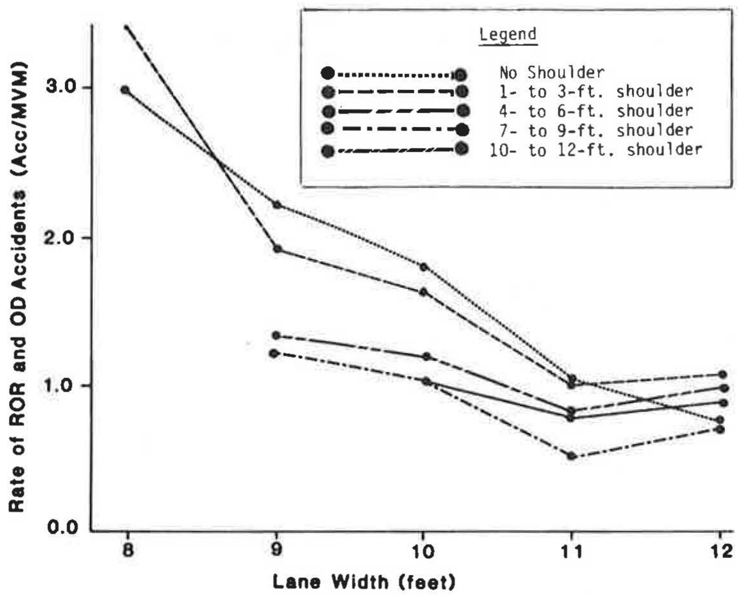

FIGURE 1 Relationship between accidents and lane and shoulder width in Kentucky (8).

Zegeer et al. adjusted these accident rates in an attempt to control for the effects of traffic and other roadway variables based on a plot of the unadjusted accident rates as a function of volume level (Figure 2) *(8)*. Although this was not an ideal method of control, the higher accident rates for low ADT groups (with sharp curves, poor roadsides, and other deficiencies) were clearly seen for different pavement-width classes. The authors then developed accident reduction factors that might realistically be anticipated as a result of lane and shoulder widening (Tables 4 and 5) *(8)*.

After other factors were controlled for, the expected reduction in ROR and OD accidents from shoulder widening projects ranged from 6 to 21 percent, depending on

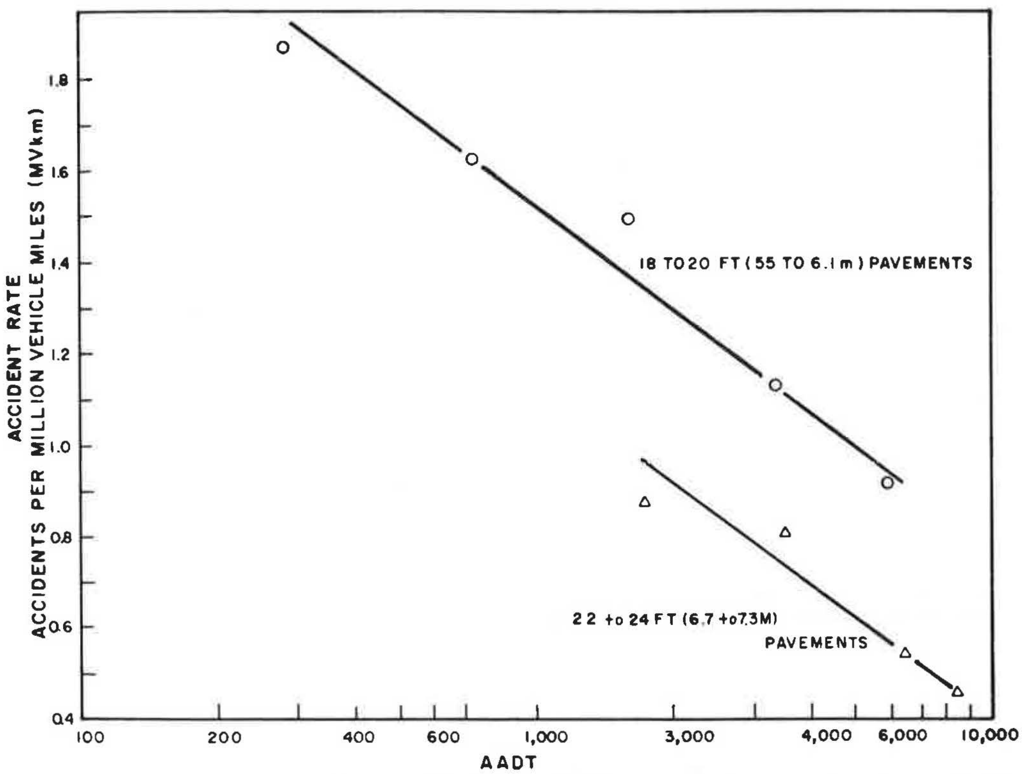

FIGURE 2 Rates of run-off-road accidents for various ADT groups and pavement widths in Kentucky (8).

TABLE 4 Percent Reduction in Run-off-Road and Opposite-Direction Accidents Due to Lane Widening *(8)*

Lane Width (ft)		Total	Percent Reduction
Before Widening	After Widening	Widening (ft)	in ROR and OD Accidents
7	8	2	10
7	9	4	23
7	10	6	29
7	11	8	39
8	9	2	16
8	10	4	23
8	11	6	36
9	10	2	10
9	11	4	29
10	11	2	23

TABLE 5 Percent Reduction in Run-off-Road and Opposite-Direction Accidents Due to Shoulder Widening *(8)*

Shoulder Width (ft)		Total	Percent Reduction
Before Widening	After Widening	Widening (ft)	in ROR and OD Accidents
None	1–3	4	6
None	4–6	10	15
None	7–9	16	21
1–3	4–6	6	10
1–3	7–9	12	16
4–6	7–9	6	8

the amount of widening. Lane widening was expected to cause greater accident reductions—10 to 39 percent after adjusting for other factors—again depending on the amount of widening *(8)*. Although this information is useful, it would have been more appropriate if accident reduction factors had been determined for various combinations of lane and shoulder widths. For example, what would be the expected accident reduction for shoulder widening from 0 to 3 ft for an existing lane width of 10 ft, as compared with similar shoulder widening for existing lane widths of 11 or 12 ft? Fortunately, this deficiency was found to be correctable in the current study.

Foody and Long performed several types of analyses for single-vehicle accidents, including an attempt to model such accidents by using data for 16,000 mi of roadway—an attempt that proved to be of only limited success *(12)*. The second phase of the study, however, was a detailed analysis of shoulder type for 1,400 mi of roadway sample data. Results of a series of analysis of variance (ANOVA) tests revealed that the mean rates of single-vehicle accidents were not significantly different for sections with paved shoulders compared with those with stabilized (tar with gravel) shoulders *(12)*. Subsequently, paved and stabilized shoulders were grouped into a single category termed "stabilized." Also, no significant differences were found in the mean rates of single-vehicle accidents for other types of shoulders. Accordingly, all such types were subsequently collected into one group, termed "unstabilized." Most important, however, the mean accident rate for stabilized shoulder sections was significantly less than that for sections having unstabilized shoulders *(12)*.

Mean rates of single-vehicle accidents are given in Table 6 for sections with both unstabilized and stabilized shoulders and for three pavement width categories—16 to 20 ft, 20 to 24 ft, and 24 to 28 ft. Note that these rates (or rate differences) are *not* adjusted for effects of other factors (curvature, ADT, etc.) because roadway width, shoulder quality, and roadside quality were the only independent variables used in the analysis.

These results indicate that shoulder stabilization or paving may be quite effective in reducing run-off-road accidents on narrow roadways, typically 20 ft or less in width, but have little effect on roads having widths of 24 ft or more. This finding basically agrees with data from the Zegeer et al. study *(8)*, which found a greater reduction in ROR and OD accidents as a result of shoulder widening for narrow lane widths as opposed to 12-ft lane widths.

Rogness et al. reported results of shoulder and roadway improvements that included 30 sections (214 mi) where paved shoulders had been added to two-lane roads *(11)*. Two years of accident data were analyzed for each of the before-and-after periods at each site. The effects of the treatments were analyzed for specific accident types within three ADT categories: 1,000 to 3,000, 3,000 to 5,000, and 5,000 to 7,000. The *t*-test was used (at the 90 percent confidence level) to determine whether changes in the accident pattern were statistically significant *(11)*.

TABLE 6 Rates of Single-Vehicle Accidents for Pavement Width and Shoulder Type Combinations in Ohio *(12)*

	Base Rate of SV Accidents (ACC/MVM)		
Pavement Width (ft) (excluding shoulder)	Unstabilized Shoulder	Stabilized Shoulder	Difference in Accident Rate (*D*)
16–20	3.57	1.11	2.46
20–24	2.04	1.40	0.64
24–28	1.02	0.98	0.04

NOTE: SV = single-vehicle; ACC/MVM = accidents per million vehicle miles.

TABLE 7 Accident Reductions as a Result of Adding Shoulders to Two-Lane Roadways in Texas (11)

Volume Range	Type of Accident	No. of Accidents Before	After[a]	Percent Change
1,000–3,000	Multivehicle	35	36.4	+4.0
	Single vehicle[b]	58	26.1	–55.0
	Other[c]	27	25.1	–7.0
	Total	120	87.6	–27.0
3,000–5,000	Multivehicle	68	53.9	–14.7
	Single vehicle[b]	67	52.9	–21.4
	Other[c]	29	36.7	+26.6
	Total	164	143.5	–12.5
5,000–7,000	Multivehicle	27	16.9	–37.4
	Single vehicle[b]	12	12.0	0
	Other[c]	6	8.2	+36.6
	Total	45	37.1	–17.6

NOTE: These include nonintersection accidents only.
[a]Adjusted for changes in average daily traffic.
[b]Run-off-road and hit-fixed-object accidents.
[c]Other single-vehicle accidents.

TABLE 8 Summary of Reductions in Total Accident Rates in California Due to Shoulder Widening (5)

Pavement Width[a] (ft)	AADT	Percent Change
28	<3,000	–16
32	<5,000	–35
40	>5,000	–29

[a]Pavement width refers to the paved width of lanes plus shoulders after widening.

Reductions in the frequency of single-vehicle accidents were found to be 55 percent for ADT levels of 1,000 to 3,000, 21.4 percent for ADTs of 3,000 to 5,000, and 0 percent for ADTs of 5,000 to 7,000 *(11)*. This trend appears consistent with other studies that have found greater accident reductions from lane and shoulder improvements on roads with lower ADT levels. No significant reductions were found for head-on accidents. The summary of the percent changes and accidents (Table 7) is for nonintersection accidents only. Accident numbers in the after period were adjusted by the authors to account for any volume differences between the before-and-after periods *(11)*.

The study by Rinde was a before-and-after evaluation of shoulder (pavement) widening for 37 projects representing 143 mi of two-lane, state-maintained highway in California *(5)*. Sections selected for evaluation had been constructed between 1964 and 1974 onexisting alignment, and the chi-square test (95 percent confidence level) was used to detect significant changes in various accident types. An attempt was made to control for the effects of external factors (estimated to account for only 4 to 6 percent of the reduction in accidents) during the analysis period. These effects were believed to primarily include the energy crisis and the resulting 55 mph speed limit. Statewide accident experience throughout the analysis period was used to determine the effect on these external factors, yielding adjustments of 4 to 6 percent *(5)*.

The summary given in Tables 8 and 9 shows reductions of 50 to 60 percent in head-on accidents *(5)*. Reductions of 27 to 53 percent were observed for hit-object accidents. The larger (53 percent) reduction for the middle (32 ft) category cannot be readily explained, except that such fluctuations are not uncommon in accident-based evaluations because of data instability or randomness, or both. These percent reductions included adjustments for volume changes but not for other external influences. After adjustments for

TABLE 9 Summary of Reductions in Accident Rates for Collision Types in California by Lane Width and Traffic Volumes *(5)*

Pavement Width (ft)	No. of Accidents Before	No. of Accidents After	Accident Rate Before	Accident Rate After	Percent Change
Head-on collision					
28 (<3,000 ADT)	3	2	0.10	0.05	–50
32 (<5,000 ADT)	32	19	1.04	0.50	–52[a]
40 (All)	29	14	0.14	0.06	–57[a]
Rear-end collision					
28(<3,000 ADT)	2	2	0.06	0.05	–17
32 (<5,000 ADT)	10	4	0.32	0.10	–69[a]
40 (All)	80	71	0.37	0.29	–22
Hit-object collision					
28 (<3,000 ADT)	37	35	1.19	0.87	–27
32 (<5,000 ADT)	34	20	1.10	0.52	–53[a]
40 (All)	137	112	0.64	0.46	–28[a]
Overturn					
28 (<3,000 ADT)	13	18	0.42	0.45	+7
32 (<5,000 ADT)	10	18	0.32	0.47	+47
40 (All)	61	41	0.29	0.17	–41[a]
Sideswipe					
28 (<3,000 ADT)	1	8	0.03	0.20	+567[b]
32 (<5,000 ADT)	14	14	0.45	0.37	–18
40 (All)	43	37	0.20	0.15	–25

[a]Statistically significant decrease.
[b]Statistically significant increase.

TABLE 10 Summary of Accident Reductions for Pavement Widening Projects *(5, 11)*

Type of Project	ADT Range	Expected Percent Reduction in Accidents: Total Accidents	Single-Vehicle Accidents	Head-On Accidents
Widening 20 to 24-ft pavement to 28 ft	0–3,000	16 (C)	22 (C)	45 (C)
Widening 18 to 24-ft pavement to 32 ft	<5,000	35[a] (C)	49[a] (C)	48[a] (C)
Widening 18 to 24-ft pavement to 40 ft	>5,000	29[a] (C)	22[a] (C)	51[a] (C)
Adding full-width paved shoulders to two-lane roads	1,000–3,000	27[a] (T)	55[a] (T)	Unknown
	3,000–5,000	12.5 (T)	21.4[a] (T)	Unknown
	5,000–7,000	17.6[a] (T)	0 (T)	Unknown

Notes: (C) indicates values from the Rinde study in California, and (T) indicates values from the Rogness et al. study in Texas. The single-vehicle and head-on accident percentages for California were adjusted by 4 to 6 percent to account for external effects. These adjusted percentages are now on the same basis as total accidents.

[a]These percent differences were significant at the 95 percent level of confidence for California sites (C) and 90 percent confidence level at the Texas sites (T).

other external influences had been made, the authors recommended percent reductions of 16, 35, and 29 percent in total accidents (for the three ADT groups) *(5)*.

Accident reduction factors for the Rinde and Rogness et al. studies are summarized for comparative purposes in Table 10 *(5, 11)*. These include percent accident reductions for total accidents with similar adjustments (for 4 to 6 percent) for single-vehicle accidents and head-on accidents in California. Reductions in total accidents ranged from 16 to 35 percent. Single-vehicle accidents dropped by as much as 55 percent as a result of widening but were unchanged in the 5,000 to 7,000 ADT group on Texas highways. Head-on accidents were reduced by 45 to 51 percent, based on the California data.

Several seemingly illogical patterns in the summary given in Table 10 warrant further discussion. For example, a reduction of 49 percent in single-vehicle accidents was found in California as a result of widening lanes to 32 ft, whereas only a 22 percent reduction was found as a result of widening lanes to 40 ft. In both cases, pavements were 18 to 24 ft in the before condition. Note, however, that projects involving widening to 32 ft included lower ADT levels (i.e., ≤ 5,000) compared with widening to 40 ft (i.e., ADT ≥ 5,000). Most research has indicated that a larger percentage of single-vehicle accidents are eliminated in the lower ADT groups because single-vehicle accidents are typically more of a problem on low-volume roads that have sharper curves, less forgiving roadsides, and so forth. Thus, the pattern observed in California, though counterintuitive at first glance, is not unreasonable.

Another interesting pattern is the reduction in total accidents as a result of the addition of full-width, paved shoulders in Texas. A 27 percent reduction was found for the low-volume (1,000 to 3,000 ADT) group, compared with 12.5 and 17.6 percent reductions for the 3,000 to 5,000 and 5,000 to 7,000 ADT groups, respectively. Although these reductions are not completely consistent, a plausible explanation is that widening projects are likely to be more effective on low-volume roads—which are more likely to have deficient roadways and roadsides—than on higher-volume roads. Random accident fluctuations may be responsible for the inconsistent upturn in the highest volume category.

Certainly differences are apparent between California and Texas data—possibly because of differences between the types of projects in the two states. For example, all of the projects in Texas involved adding paved, full-width shoulders to existing two-lane roads, whereas California projects involved differing amounts of total pavement widening. Nevertheless, the accident reduction factors in Table 10 represent the best information currently available on the effects of actual shoulder or pavement widening projects, or both.

DEVELOPMENT OF SAFETY RELATIONSHIPS

Although no satisfactory quantitative model relating accident rate to lane and shoulder conditions was found in the published literature, prior research has established the general effects of these elements on highway accidents. Qualitatively, these effects can be summarized as follows:

- Lane and shoulder conditions directly affect ROR and OD accidents. Other accident types, such as rear-end and angle accidents, are not directly affected by these elements.
- Rates of ROR and OD accidents decrease with increasing lane width; however, the marginal effect of lane-width increments is diminished as either the base lane width or base shoulder width increases.
- Rates of ROR and OD accidents decrease with increasing shoulder width. However, the marginal effect of shoulder-width increments is diminished as either the base lane width or base shoulder width increases.
- Lane width has a greater effect on accident rates than shoulder width.
- Nonstabilized shoulders, including those constructed of loose gravel, crushed stone, raw earth, and turf, exhibit larger accident rates than stabilized (e.g., tar with gravel) or paved (e.g., bituminous or concrete) shoulders.

Among numerous mathematical relationships capable of replicating these patterns, one of the simplest has the following form:

$$AR = (C_1)\ (C_2)^L\ (C_3)^S\ (C_4)^{LS}\ (C_5)^P\ (C_6)^{LP} \tag{1}$$

where

AR = number of ROR and OD accidents per million vehicle miles,
L = lane width in feet,
S = shoulder width in feet (including stabilized and unstabilized components),
P = width in feet of stabilized component of shoulder ($0 \le P \le S$: $P = 0$ for unstabilized shoulders and $P = S$ for full-width stabilization), and
C_i's = constants.

This model was calibrated using the best available data—presented earlier in Tables 3 and 6—taken from the Kentucky and Ohio studies *(8, 12)*. The first part of the two-part process involved a weighted, least-squares fit of Equation 1 to the data in Table 3. "No shoulder" data were excluded from this exercise because it actually contained data from highway sections having unstabilized shoulders of varying width. The calibrated model, reflecting only the effects of stabilized shoulders at this stage, was extended in the second part by data from Table 6. Only two data points were used: one indicating a 4 percent increase in accident rate for unstabilized as opposed to stabilized shoulders for wide pavements (e.g., 12-ft lanes with 8-ft shoulders), and the other indicating a 46 percent increase in accident rate for pavements of intermediate width (e.g., 10-ft lanes with 8-ft shoulders). Data for narrow pavements were excluded because of the apparently unreasonable accident rate for stabilized shoulders. In using the data in Table 6, the effect of shoulder stabilization on the rate of ROR and OD accidents was assumed to be the same as its effect on the rate of single-vehicle accidents.

The calibrated model, applicable only to lane widths between 7 and 12 ft and shoulder widths of 10 ft or less, is identified as follows:

$$AR = 40.290\ (0.7329)^L\ (0.8497)^S\ (1.0132)^{LS}\ (0.7727)^P\ (1.0213)^{LP} \tag{2}$$

Comparisons of estimates from Equation 2 with the actual data from which it was calibrated emphasize that the "fit" is far from perfect (Table 11). Nevertheless, the general trends are accurately reproduced: abnormalities in the available data bases cannot and should not be reproduced by any modeled relationship.

As a complication, the accident model reflects at this stage not only the effects of lane and shoulder conditions, but also the effects of other variables, such as curvature, sight distance, clear zones, sideslopes, and roadside obstacles. Because highways with inferior cross-sectional and roadside characteristics are also likely to have inferior geometrics, the modeled accident rates overstate the effect of safety gains resulting from improvements in lane and shoulder conditions alone. Actual accident reductions resulting from lane and shoulder improvements without accompanying improvements in other features may be as low as 50 percent of the reductions anticipated by the preceding model, according to information derived in the Kentucky study *(8)*.

Although available data bases do not provide an accurate guide for identifying the effects of these contributing factors, prior analysis of the Kentucky data provided a reasonable first approximation *(8)*. Central to this approximation is the hypothesis that when the difference between before-and-after accident rates (as estimated by Equation 2) is small, the confounding effects of the exogenous variables are also likely to be small. As a result, actual safety gains will be similar to modeled gains. As the modeled

TABLE 11 Comparison of Accident Model with Kentucky and Ohio Data

		Number of ROR and OD per MVM		Ratio of Accident Rates for Unstabilized and Stabilized Shoulders	
Lane Width (ft)	Shoulder Width (ft)	Kentucky Data	Accident Model[a]	Ohio Data	Accident Model[b]
7	1–3	1.7	2.6–3.8		
8	1–3	3.4	2.2–2.9		
9	1–3	1.9	1.8–2.2		
9	4–6	1.3	1.2–1.6		
9	7–9	1.2	0.9–1.1		
10	1–3	1.6	1.4–1.7		
10	4–6	1.2	1.1–1.3		
10	7–9	1.0	0.9–1.0		
11	1–3	1.0	1.2–1.3		
11	4–6	0.8	1.0–1.1		
11	7–9	0.5	0.9–1.0		
12	1–3	1.1	0.9–1.0		
12	4–6	1.0	0.9		
12	7–9	0.7	0.9		
8–10	4–8			3.22	1.21–2.04
10–12	4–8			1.46	1.02–1.46
12–14	4–8			1.04	1.02–1.04[c]

[a]Tabulated range in shoulder widths.
[b]Tabulated ranges in pavement and shoulder widths.
[c]For 12-ft lane only.

safety gains become larger, however, effects of the confounding variables become more pronounced, and actual gains are likely to represent a smaller fraction of modeled gains.

Such a relationship can be expressed in terms of accident reduction factors (ARF)—the expected percent reduction in accidents due to an improvement—as follows:

$$ARF_a = (ARF_m)^c \qquad (3)$$

where

ARF_a = an estimate of the accident reduction factor that can actually be achieved by lane and shoulder improvements;
ARF_m = the accident reduction factor resulting from application of Equation 2, which overstates the effect of lane and shoulder conditions; and
c = a calibration constant.

The constant, c, was calibrated by using data from the Kentucky study *(8)* (Table 12). Entries in Table 12 indicate the percent reduction in ROR and OD accidents expected to result from various widening projects. Zegeer et al. found the unadjusted differences (computed directly from the entries in Table 4) to overstate achievable gains because of the correlation, on Kentucky highways, between poor lane and shoulder conditions and poor geometric and roadside conditions *(8)*. The adjusted differences in Table 12 are a best estimate of the actual safety gains that can be achieved by widening, assuming that concurrent improvements in other roadway features are not made.

The last column of Table 12 provided the necessary information for calibrating Equation 3: a least-squares fit yielded an estimate of 0.4293 for c. The following model,

TABLE 12 Comparison of Adjusted and Unadjusted Differences in ROR and OD Accidents for Various Amounts of Pavement Widening *(8)*

Lane Width (ft)		Unadjusted Percent Differences[a]			Average Percent Difference (Unadjusted)	Adjusted AR Factor	Ratio of Adjusted to Unadjusted
Before	After	0–3-ft Shoulders (%)	4–6-ft Shoulders (%)	7–9-ft Shoulders (%)	(%)	(%)	
8	10	47	–	–	47	23	0.49
8	11–12	69	–	–	69	36	0.52
9	10	18/16[b]	–	–	17	10	0.59
9	11–12	51	–	–	51	29	0.57
10	11–12	41	33	–	37	23	0.62

Note: Dashes indicate insufficient data.
[a]From Table 4.
[b]Zero ft and 1 to 3 ft.

adjusted to remove unwanted effects of the confounding variables, is derived from the application of this exponent to Equation 2:

$$AR = 4.7918\ (0.8766)^{L}\ (0.9333)^{S}\ (1.0056)^{LS}\ (0.8964)^{P}\ (1.0090)^{LP} \quad (4)$$

Although Equation 4 generally conforms with the known qualitative effects of lane and shoulder conditions on accident rates, the effects of lane and shoulder increments for wide initial cross sections are questionably small. Only a 3 percent reduction in accidents is estimated by Equation 4 for an increase in lane width from 10 to 12 ft for roadways with 8-ft stabilized shoulders, or for an improvement from no shoulders to 8-ft stabilized shoulders for roadways with 12-ft lanes. In comparison, the addition of full-width paved shoulders in one instance has been found to reduce single-vehicle accidents by as much as 55 percent (Table 10).

Accordingly, further adjustment in Equation 4 was deemed desirable. Because of the absence of firm data, adjustments were largely intuitive. First, a 20 percent difference in the accident rates for 12-ft lanes with no shoulders and those with 8-ft stabilized shoulders was assumed. This is the approximate value observed within the Kentucky data (Table 3) after adjusting for external effects. Second, the comparative effect of stabilized versus unstabilized shoulders, as indicated by Equation 4, was generally considered to be valid for mid-range lane and shoulder widths. Third, the adjustment maintained the accident rates established by Equation 4 for 9-ft lanes. Shown in Figures 3 and 4 for stabilized and unstabilized shoulders, the final model is described as follows:

$$AR = 4.1501\ (0.8907)^{L}\ (0.9562)^{S}\ (1.0026)^{LS}\ (0.9403)^{P}\ (1.0040)^{LP} \quad (5)$$

APPLICATION OF RESULTS TO RRR PROJECTS

The purpose of this investigation was to develop, from published sources, a model for estimating the effect of lane and shoulder conditions on motor vehicle accidents on two-lane rural highways. Of the more than 30 articles reviewed, 9 studies were deemed most appropriate for detailed consideration, and information from 4 of the 9 was ultimately used in developing the most likely accident relationships.

The accident types found to be most related to lane and shoulder widths and shoulder type were run-off-road and opposite-direction accidents. Opposite-direction

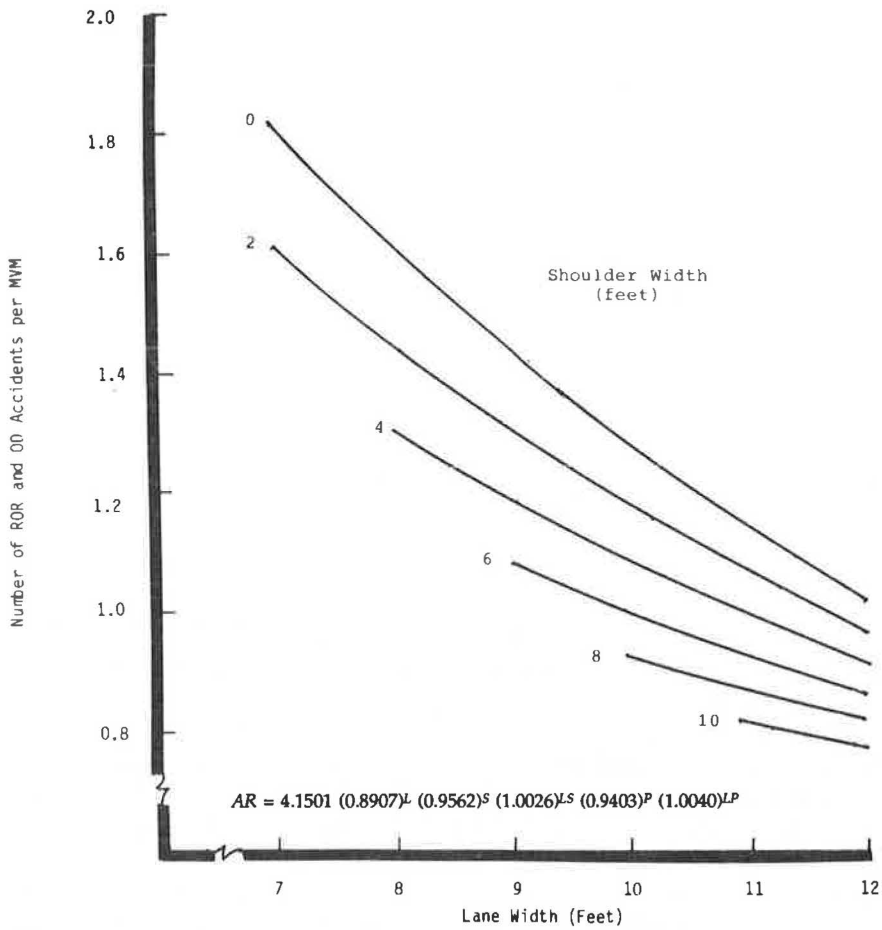

FIGURE 3 Adjusted rate of ROR and OD accidents for stabilized shoulders.

accidents include head-on and sideswipe accidents between vehicles traveling in opposite directions. Thus, the rate of ROR and OD accidents was considered to be the most appropriate dependent measure. The literature did not contain sufficient information to enable development of a complete group or family of accident relationships that incorporated traffic and other roadway effects as independent variables. However, it was possible to develop accident relationships that at least accounted for interrelationships among the variables of primary interest, namely, lane width, shoulder width, and shoulder type.

Of more than 30 research studies reviewed on accident effects of lane and shoulder conditions, the following 4 had supportable results and useful data for developing accident relationships:

- Zegeer et al. in Kentucky *(8)*;
- Foody and Long in Ohio *(12)*;
- Rinde in California *(5)*; and
- Rogness et al. in Texas *(11)*.

Primarily on the basis of the results of these four studies, lane width and shoulder width and type were found to have a significant impact on highway safety. Collectively, these studies indicated the following:

- Lane and shoulder conditions directly affect run-off-road and opposite-direction accidents. Other accident types, such as rear-end and angle accidents, are not directly affected by these conditions.
- Rates of ROR and OD accidents decrease with increasing lane width. However, the marginal effect of lane-width increments is diminished as either the base lane width or base shoulder width increases.
- Rates of ROR and OD accidents decrease with increasing shoulder width. However, the marginal effect of shoulder-width increments is diminished as either the base lane width or base shoulder width increases.
- Lane width has a greater effect on accident rates than shoulder width.
- Larger accident rates are exhibited on unstabilized shoulders, including loose gravel, crushed stone, raw earth, or turf, than on stabilized (e.g., tar plus gravel) or paved (e.g., bituminous or concrete) shoulders.

These qualitative relationships served in large part as the basis for developing a quantitative accident model. Data for calibration of the model were extracted from the 1979 Kentucky study *(8)* by Zegeer et al. and the 1974 Ohio study *(12)* by Foody and Long. Adjustments were made to remove unwanted effects of other confounding variables (such as curvature, ADT, roadside condition, etc.) and to assure appropriate consideration of shoulder-width effects for roadways having wider lanes.

The final model is defined as

$$AR = 4.1501\ (0.8907)^{L}\ (0.9562)^{S}\ (1.0026)^{LS}\ (0.9403)^{P}\ (1.0040)^{LP} \tag{6}$$

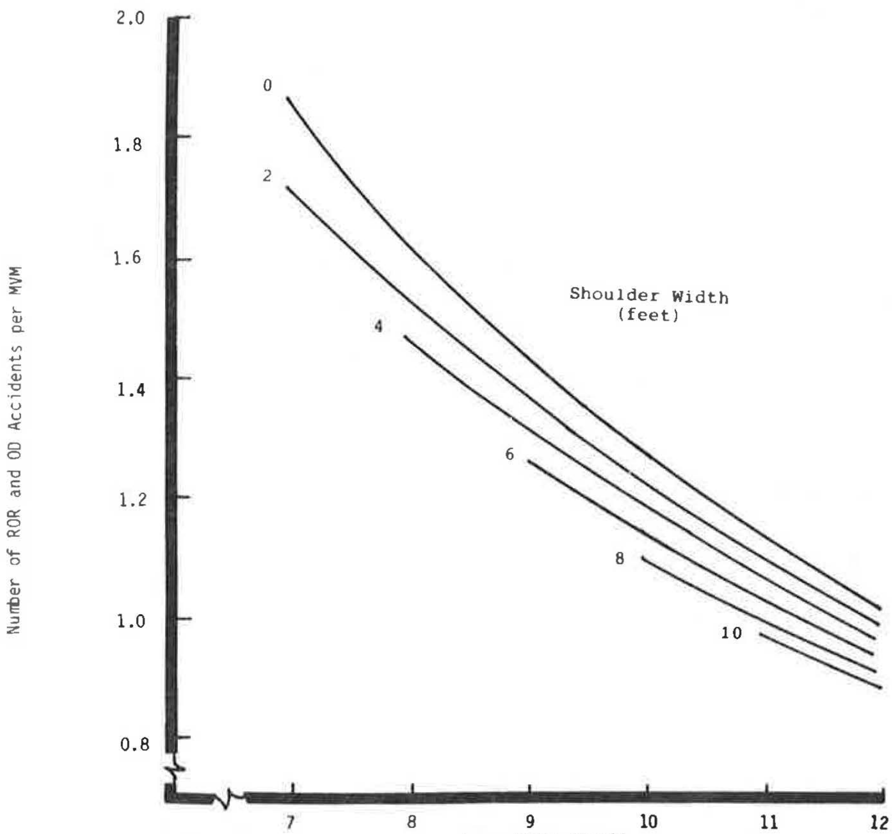

FIGURE 4 Adjusted rate of ROR and OD accidents for unstabilized shoulders.

where

AR = number of ROR and OD accidents per million vehicle miles,
L = lane width in feet,
S = shoulder width in feet (including stabilized and unstabilized components), and
P = width in feet of stabilized component of shoulder ($0 \leq P \leq S$).

Because of the many assumptions necessary in its development and the reliance on available data bases from only two states for its calibration and validation, this model is not considered to be a precise representation of the effects of lane and shoulder conditions on accident rates for all possible situations. However, when applied judiciously, it can serve as a useful first approximation of such effects. It does represent the best information currently available, and its most legitimate use is in the development of accident reduction factors that can be applied to actual accident rates to estimate likely reductions due to lane and shoulder improvements.

Limitations of the accident prediction model include the following:

- The model applies only to lane widths of 7 to 12 ft and shoulder widths of 0 to 10 ft. Furthermore, combinations of lane and shoulder widths that can be reasonably modeled are limited to those shown in Figure 3.
- The results relate to two-lane, two-way roads on state primary or secondary systems, or both.
- The results relate to rural, homogeneous roadway sections and generally exclude signalized intersections and corresponding intersection accidents.
- The results apply to paved roadways and include sections with curves and tangents and various types of terrain and roadway conditions.

This paper is strictly a critique of literature on the accident relationships of lane width, shoulder width, and shoulder type together with the development of most likely effects of pavement widening or shoulder paving, or both, on accidents. The economic impacts of widening pavements or improving shoulders were not addressed. Also, this review did not determine the pavement widths that should be used under various traffic conditions or roadway classes. Finally, no attempts were made to review literature or make judgments regarding the operational effects of lane and shoulder widths or shoulder type (e.g., effects on travel time or highway capacity).

ACKNOWLEDGMENTS

Charles V. Zegeer was employed by Goodell-Grivas, Inc., Southfield, Michigan, when this paper was written. Don Reinfurt of the University of North Carolina provided helpful technical and editorial comments on this paper.

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