

Accident Relationships of Roadway Width on Low-Volume Roads

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An analysis was performed to quantify the accident effects of lane and shoulder widths on rural roads carrying fewer than 2,000 vehicles per day. The primary data base used in the research contained accident and roadway characteristic information for more than 6600 km (4,100 mi) of two-lane roadway sections in seven states. Independent data bases from three states (Minnesota, Illinois, and North Carolina) for roadways totaling more than 86 000 km (54,000 mi) were selected to validate the accident relationships found in the primary data base. Analysis of covariance was used to quantify accident relationships on these low-volume roads. Single-vehicle and opposite-direction accidents were classified as *related* accidents because the accident rates for these two types were found to be related to differences in lane and shoulder widths. The rate of related accidents was also affected by roadside hazard, roadway terrain, the number of driveways per mile, and state differences. No differences in accident rates were found between roadways with paved and unpaved shoulders. For lane widths of at least 3.0 m (10 ft), related accident rates were lower when wide shoulders were present than when narrow shoulders were present. For a given shoulder width, wider lanes were found to be associated with lower accident rates. Somewhat counterintuitively the accident rate was higher for 3.0-m (10-ft) lanes with narrow shoulders than for 2.7-m (9-ft) lanes with narrow or wide shoulders. For traffic volumes of 250 vehicles per day or less, accident rates did not differ significantly between paved and unpaved roads. For traffic volumes of greater than 250 vehicles per day paved roads have significantly lower accident rates than unpaved (dirt and gravel) roads. The research findings indicate that on low-volume roads lane widths as narrow as 2.7 m (9 ft) may be acceptable from a safety standpoint under certain conditions. The 1995 draft AASHTO policy chapter on local roads includes revised roadway width guidelines that reflect many of the research findings presented.

Increasing concern has been expressed by safety professionals in recent years regarding the safety of low-volume roads [e.g., roads carrying fewer than approximately 2,000 vehicles per day (vpd)], since such roads constitute a major portion of the U.S. highway network. For example, of the 5.0 million km (3.1 million mi) of all two-lane rural roads, approximately 90 percent have average daily traffic (ADT) of less than 1,000 vpd. About 80 percent have ADT of less than 400 vpd, and 38 percent carry fewer than 50 vpd. Considering only the local and minor collector roads on the two-lane system, 90 percent have ADT of 2,000 vpd or less; more than 60 percent of minor rural arterials have ADT of 2,000 vpd or less (1).

Maintenance and reconstruction of the two-lane highway system have emerged as serious problems not only because of the extensive size of the system but also because significant portions of two-lane highways were designed and built to outdated stan-

dards not reflective of current design policy. For example, over one-quarter of the mileage of such roads have lane widths of 2.7 m (9 ft) or less, and two-thirds have shoulder widths of 1.2 m (4 ft) or less. In addition, 11.5 percent of two-lane highway mileage has no shoulders (1). These statistics are in contrast to the current design values given in the 1990 AASHTO policy, *A Policy on Geometric Design of Highways and Streets* (2). For all but extremely low-volume and low-speed highways, the current policy calls for 6.7- to 7.3-m (22- to 24-ft) roadways regardless of terrain or other conditions (2). Also a large portion of low-volume roads is unpaved, which presents maintenance problems in addition to safety concerns.

Controversy has existed over the optimal lane and shoulder widths for these low-volume roads with respect to whether existing roadways should be widened or new roadways constructed. Such decisions require the availability of quantifiable accident relationships on roadways with various lane and shoulder widths and types. Although numerous safety studies have been conducted in the past decade to address the safety effects of lanes and shoulders, few have focused exclusively on low-volume roads. Such an analysis was the focus of this study.

BACKGROUND SAFETY RESEARCH

During the past 25 years dozens of studies concerning the relative safety of various roadway widths have been conducted. One of the most comprehensive and more recent studies conducted to date on the safety effects of roadway width was a 1987 study by Zegeer et al. (3) for FHWA that involved an analysis of 7971 km (4,951 mi) of two-lane roadways in seven states. It included 7704 km (4,785 mi) of rural road and only 267 km (166 mi) of urban roadway. Accident prediction models were used to determine the expected accident reductions related to various geometric improvements. Accident types found to be most related to cross-sectional features (e.g., lanes, shoulders, and roadside condition) included run-off-the-road, head-on, and sideswipe (same direction and opposite direction) accidents. The roadway variables found to be associated with a reduced incidence of these related accident types were wider lanes, wider shoulders, better roadside condition, flatter terrain, and lower traffic volume (3).

For lane widths of from 2.4 to 3.7 m (8 to 12 ft), the predictive accident model showed that related accidents were reduced by approximately 12 percent for each 0.3 m (1 ft) of lane widening. For shoulder widths of between 0 and 3.7 m (0 and 12 ft), the percent reduction in related accidents as a result of the widening of paved shoulders ranged from 16 percent [for 0.6 m (2 ft) of widening] to 40 percent [for 1.8 m (6 ft) of widening]. Paved

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shoulders were slightly safer than unpaved shoulders. However approximately half of the roadways in that study sample had ADT of more than 2,000 vpd, there were no unpaved roads, and a minimal sample of roads with ADT values of less than 750 vpd was available (3).

Note that the results of that study (3) showing a constant percentage reduction for each foot of lane or shoulder widening are somewhat counterintuitive. That is, one might expect that widening of lanes from 2.4 to 2.7 m (8 to 9 ft) would result in a higher percentage reduction in accidents than widening from 3.4 to 3.7 m (11 to 12 ft). Although the model forms found in that study did not show this, it should be mentioned that the net number of accidents reduced would be greater for widening narrow [e.g., 2.4-m (8-ft)] lanes than for widening wider [e.g., 3.4-m (11-ft)] lanes, since, for example, the accident rate in the before condition is greater for 2.4-m (8-ft) lanes than for 3.4-m (11-ft) lanes. Thus a 12 percent accident reduction [per 0.305 m (1 ft) of widening] would represent more net accidents reduced on a road with narrow lanes (and a higher accident rate) than on a road with wider lanes.

A study that addressed low-volume rural roads in one state was a 1988 study by Griffin and Mak (4) that attempted to quantify the relationship between accident rate and roadway surface width on two-lane rural roads in Texas with ADTs of 1,500 vpd or fewer. Log-linear accident prediction models were developed for 58 306 km (36,215 mi) of roadway within several ADT categories. Multivehicle accident rates [number of accidents per 1.61 km (1 mi) per year] were not found to be related to surface width for any of the ADT groups tested. Single-vehicle accident rates were found to increase as roadway width decreased for ADT groups of between 401 and 1,500 vpd. Accident reduction factors were developed for various widening projects within these ADT ranges, and those accident reductions matched closely with those in the study of Zegeer et al. (3). On the basis of an economic analysis, widening was not found to be cost-beneficial for ADT values of less than 1,000 vpd (4).

Numerous other studies have also analyzed large state data bases to determine accident effects of lane and shoulder widths. These include studies by Foody and Long (5) in Ohio, Zegeer et al. (6) in Kentucky, Shannon and Stanley (7) in Idaho, and an NCHRP study by Jorgensen, Roy & Associates with data from Washington and Maryland (8), among others. Although those studies used a wide range of sample sizes and analysis techniques, all basically found that accident rates decreased as a result of wider lanes or shoulders, even though there was considerable variation in the exact amount of crash reduction.

Studies by Rinde (9) (California) and Rogness et al. (10) (Texas) involved evaluations of actual pavement-widening projects. Those results supported 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 magnitudes of the effects of widening. A 1974 study by Heimbach et al. (11) in North Carolina also found that paving 0.9- to 1.2-m (3- to 4-ft) unpaved shoulders results in significant reductions in accident frequency and severity.

RESEARCH OBJECTIVE AND APPROACH

Although past research laid the groundwork for what is currently known on the subject, there was a need to look more closely at

accident relationships for low-volume roads only, including paved and unpaved roads, and for roads in a variety of functional classifications (arterial, collector, and local) with varying roadway conditions, and to do so with a sample that included data from more than a single state. Also there was a need to determine what specific traveled way and shoulder width combinations provide reasonable levels of safety for various conditions.

The objective of the study was to quantify the accident effects of lane width, shoulder width, and shoulder type for a variety of traffic and roadway conditions for rural roads with traffic volumes of 2,000 vpd or fewer. Although ADT of 2,000 vpd or less does not constitute an official definition of low volume, it is the value used in AASHTO design guidelines for roadway width (2) and was chosen for use in the analysis in the present study. The study also involved an investigation of the safety of paved versus unpaved roadway surfaces for these lower-volume roads.

A detailed statistical analysis was conducted on a primary data base of approximately 6600 km (4,100 mi) of low-volume, two-lane roads in seven states. Adjusted accident rates were determined for various lane and shoulder widths by analysis of covariance. To validate and investigate these relationships further, three additional independent data bases for roadways totaling more than 87 000 km (54,000 mi) of low-volume, two-lane roads from three states (Illinois, Minnesota, and North Carolina) were analyzed. These validation data bases from Illinois and Minnesota were part of FHWA's Highway Safety Information System (HSIS), which consists of computerized accident, traffic, and roadway data files from five states. The accident effects of other roadway variables were also determined from the analysis. Note that the validation data bases did not include information on level of hazard of the roadside and did not include any sections used in the primary data base.

SELECTED DATA COLLECTION VARIABLES

Roadway and Traffic Variables

Crash experience on rural highways is a complex function of many factors, including those associated with physical aspects of the roadway, and many other factors related to driver, vehicle, traffic, and environmental conditions. On the basis of their relationships to accidents developed in past research, the traffic and roadway variables selected for data collection included

- Section information (section identification and length);
- Pavement type (paved or unpaved);
- Lane width, shoulder width, and type of shoulder (i.e., paved, gravel, or earth);
- General terrain (i.e., flat, rolling, or mountainous);
- Type of area and development;
- Design speed;
- Functional roadway class;
- Number of driveways (per kilometer or mile);
- Number of intersections (per kilometer or mile);
- Percent trucks;
- Speed limit;
- Average annual daily traffic (AADT);
- Horizontal alignment (i.e., percentage of the section with a curvature of greater than 2.5 degrees);
- Vertical alignment (i.e., percentage of the section with a grade of greater than 2.5 percent);

- Side slope ratio (2:1 and steeper, 3:1, 4:1, 5:1, 6:1, or 7:1 and flatter); and
- Measures of general roadside hazard (see below).

The two measures of roadside hazard used in the data collection and analysis were termed *roadside recovery distance* and *roadside hazard rating*. These measures were used in the 1987 FHWA study by Zegeer et al. (3) on two-lane rural roads and were both found to have a significant relationship to accidents. The ratings for the roadside hazard rating used in that study (and the current study) are based on a seven-point pictorial scale for rural highways. The data collectors chose the rating value (one through seven) that most closely matched the general roadside hazard level observed beside the roadway section in question.

In addition to the subjective roadside hazard rating, a measure termed *roadside recovery distance* also was determined for each section. This measure is relatively similar to the definition of a *clear zone*, in that it is the lateral distance from the edgeline (i.e., outer edge of the traffic lane) to the closest object that would cause a fixed-object or rollover collision, that is, the closest lateral distance to trees, utility poles, culvert head wall, bridge rail, steep slope (i.e., steeper than 3:1), and so on. Thus like the roadside rating, the roadside recovery distance basically measures the degree of forgiveness of the roadside.

Accident Variables

Although dozens of accident variables could have been chosen for analysis purposes, only those necessary for the analysis were selected. For each roadway section accident information included:

- Years of crash data (5 years in each case);
- Total number of accidents on the section;
- Number of accidents by severity (property damage only, A injury, B injury, C injury, and fatality);
- Number of people killed;
- Number of crashes by light condition (daylight or darkness);
- Number of accidents by pavement conditions (dry, wet, or icy); and
- Number of crashes by type (fixed-object, rollover, other run-off-the-road, head-on, opposite-direction sideswipe, same-direction sideswipe, rear-end, backing or parking, pedestrian or bike or moped, angle or turning, train-related, animal-related, and other or unknown types).

Selection of the Data Base

The data sample selected for analysis was a computer file consisting of sections of two-lane roads, each with its corresponding roadway, traffic, and accident characteristics. This type of data base allows a comparison of the accident experience associated with different roadway widths, paved versus unpaved roadway surfaces, and other roadway features. Ideally each roadway section should be of sufficient length to allow for calculation of accident rates in terms of the number of accidents per 1.61 million vehicle km [accidents per million vehicle mi (MVM)]. Section lengths of 1.61 km (1 mi) or greater were generally chosen to help ensure adequate crash data and thus stability of the rates, since very short sections can yield unstable accident rates. Note that even with

these longer section lengths some of the low-volume sections had no accidents in the 5-year analysis period.

Sample size requirements were computed to enable detection of at least a 10 percent difference in accident rate between roadway width groupings at a significance level of 0.05 (i.e., a 95 percent confidence level). The analysis revealed that a sample of at least 4025 km (2,500 mi) would be adequate. Ultimately a sample of 6661 km (4,137 mi) was available for use in the primary analysis. Independent samples of roadway sections also were used to validate these accident relationships, as discussed later.

The bulk of the data came from the data base on two-lane rural roads developed for TRB and FHWA in the study *Safety Effects of Cross-Section Design for Two-Lane Roads* (3). The data base developed for that earlier effort is perhaps the most complete multistate data base on two-lane roads in terms of roadway section representation, the amount of data sampled, and the wide variety of accident, traffic, roadway, and roadside variables for which data were collected.

The data base consists of a sample of 7971 km (4,951 mi) on paved, two-lane roads from Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia. Perhaps the most pertinent data variables collected in that study that are not available from standard state accident or roadway inventory files were those related to side slope and roadside hazard. However the FHWA cross-section data base provided only approximately 4300 km (2,700 mi) with ADT values of 2,000 vpd or less. Also it had no samples of unpaved roads and inadequate samples of roads with a local functional class and within a very low ADT range (particularly ADT values of less than 750 vpd). Thus other data sources were needed to fill these gaps.

Three state or local data bases (North Carolina, Utah, and Oakland County, Michigan) were selected to supplement the cross-section data base. Selection of additional sections in three of the seven cross-section states reduced the level of introduction of additional state biases resulting from different state reporting thresholds, state coding practices, or other factors. The wide variety of climates, driver characteristics, roadway design practices, and other factors contained within the seven states helped to ensure a diverse sample of roadway and traffic conditions. Within the three state or local data bases, roadway sections were selected as needed to fill the data gaps. The final primary data base thus contained 1,277 roadway sections with a total of 6661 km (4,137 mi) including 895 km (556 mi) of unpaved roads and 5765 km (3,581 mi) of paved roads. The average section length was 5.2 km (3.2 mi).

STUDY FINDINGS

Issue 1: Characteristics of Accidents on Low-Volume Roads

The question of most interest was how accidents on rural, low-volume roads differ from accidents on similar roads with higher volumes. The accident characteristics were first determined for the 5-year sample of 14,888 accidents that occurred on the 6661 km (4,137 mi) of low-volume roads, termed the *primary data base*, analyzed in the study. This was then compared with the full rural sample of 62,676 crashes on the 7704 km (4,785 mi) of rural two-lane roads in the data base from the earlier FHWA study (with a full range of ADT, including low-volume roads). With respect to

overall rates, the average accident rate for the total data base for low-volume roads was 3.5 accidents per 1.61 million vehicle km (MVM) in comparison with an overall rate of 2.4 accidents per 1.61 million vehicle km (MVM) for the higher-volume full sample.

With respect to accident types, a greater percentage of fixed-object crashes, rollover crashes, and other run-off-the-road crashes occurred on low-volume roads than on the full sample of rural roads (Table 1). Conversely the data showed a lower percentage of crashes involving rear-end collisions and angle and turning collisions for low-volume roads. This may be expected, because there are fewer other vehicles to strike on low-volume roads than on higher-volume routes.

Issue 2: Determining Related Accident Types

Analysis of covariance models were used to identify accident types that are associated with roadway width. The independent roadway variables included lane width, shoulder width, terrain, and roadside hazard rating. Accident rates were found to be significantly associated with varying lane and shoulder widths for

single-vehicle accidents and opposite-direction accidents. Rates of other accident types (angle, turning, etc.) were found not to be significantly related to lane or shoulder width. These findings agree closely with the 1987 study by Zegeer et al. (3) of rural, two-lane roads with all ADT ranges. However, that study not only related single-vehicle and opposite-direction accidents to roadway width but also found that same-direction sideswipe accidents were marginally significant, the latter finding was not confirmed in the present study for low-volume roads. In all of the remaining analyses, single-vehicle and opposite-direction accidents were combined and are referred to as *related accidents*.

Issue 3: Important Traffic and Roadway Variables

The traffic and roadway variables found to be significantly related to the rate of related accidents included

- Lane and shoulder width (or total roadway width);
- Roadside hazard rating and roadside recovery distance;
- Number of driveways per 1.61 km (1 mi);
- Terrain; and

TABLE 1 Summary of Accident Types and Characteristics for Low-Volume Road Sites

Accident Type	Primary Database on Low-Volume Roads		Cross-Section Database	
	Number of Accidents	Percent of Total Accidents	Number of Accidents	Percent of Total Accidents
Total	14,888	100.0	62,676	100.0
Property Damage Only	8,973	60.3	38,857	62.0
Injury	5,632	37.8	22,944	36.6
Fatal	283	1.9	875	1.4
Injuries*	8,768	N/A	37,321	N/A
Fatalities*	328	N/A	1,068	N/A
Daylight	8,050	54.1	37,402	59.7
Dawn/Dusk	820	5.5	2,888	4.6
Dark with Lights	160	1.1	2,770	4.4
Dark without Lights	5,809	39.0	19,496	31.1
Light Unknown	49	0.3	120	0.2
Dry	10,306	69.2	41,957	66.9
Wet	2,442	16.4	13,487	21.5
Snow/Ice	1,952	13.1	6,657	10.6
Unknown Pavement	188	1.3	575	0.9
Run-Off-Road - Fixed Object	4,017	27.0	12,091	19.3
Run-Off-Road - Rollover	1,999	13.4	4,245	6.8
Run-Off-Road - Other	2,287	15.4	2,840	4.5
Head-On	475	3.2	2,113	3.4
Opposite Direction Sideswipe	642	4.3	2,997	4.8
Same Direction Sideswipe	330	2.2	2,288	3.7
Rear-End	893	6.0	12,420	19.8
Parking/Backing	264	1.8	1,155	1.8
Ped/Bike Moped	117	0.8	655	1.0
Angle & Turning	1,773	11.9	14,730	23.5
Train	20	0.1	47	0.1
Animal	1,404	9.4	5,212	8.3
Other or Unknown	667	4.5	1,883	3.0

*The data for these variables represent the number of people injured or killed, and not the number of accidents.
N/A = Not applicable.

• State (grouped with respect to similar related accident rates): (a) Alabama, Montana, and Washington, (b) North Carolina and Michigan, and (c) Utah and West Virginia.

Variables for percent grade and curvature were not considered for further analysis, since they were available for only about half of the study sections. Instead the terrain variable was significant and served as a general measure of alignment for use as a control variable. The functional class variable was found to relate highly to roadway width (i.e., higher functional classes generally have wider roads) and state (i.e., some states tended to assign the same one or two functional class categories to all their low-volume roads, but such designations differed from state to state).

Variables that were found to not be associated significantly with accidents on low-volume roads were the number of intersections per 1.61 km (1 mi) (i.e., most sections had no major intersections), speed limit [i.e., most sections had 89-km/hr (55-mph) speed limits whether posted or not, regardless of the alignment or design speed], and the percentage of trucks (i.e., very few of the sections had a substantial volume of heavy trucks). The formulation of accident models was sensitive to these relationships.

It is also interesting to note that shoulder type (i.e., paved versus unpaved shoulders) was not found to affect significantly the number of accidents on low-volume roads. The 1987 study by Zegeer et al. (3) did find a small but significant reduction in the number of accidents on roadways with paved shoulders in comparison with the number on roadways with unpaved shoulders for a full range of traffic volumes. These findings may indicate that shoulder paving is more beneficial on higher-volume routes (e.g., those with more larger trucks) than on lower-volume routes.

Issue 4: Accident Effects of Lane and Shoulder Width on Paved Roads

Covariance models were used to estimate rates of related accidents as a function of lane and shoulder width while adjusting for roadside hazard rating, terrain, state, and the number of driveways per 1.61 km (1 mi). The following discussion of lane and shoulder width effects pertains only to paved roads on which shoulders are either paved or unpaved. The lane and shoulder width refer to the average width on one side. For example a shoulder width of 1.8 m (6 ft) refers to a 1.8-m (6-ft) shoulder on each side of the road. Because shoulder type was not found to significantly affect accident rate on low-volume roads, the shoulder width used in these analyses corresponds to the total width of each shoulder, regardless of the shoulder type. Unpaved roads will be considered later.

The results revealed that lane width and shoulder width each has a significant effect on the related accident rate. Six lane width categories [≤ 2.4 , 2.7, > 4.0 m (≤ 8 , 9, 10, 11, 12, ≥ 13 ft)] and five shoulder width categories 0, 1 to 2, 3 to 4, 5 to 6, and > 6 ft (0, 0.3 to 0.6, . . . > 1.8 m) were used. Some analyses were conducted for various combinations of lane and shoulder widths, termed *total roadway width*.

Two separate models were developed for related accident rate by total roadway width (Figure 1). Model I represents the estimated rate of related accidents for various widths of roadway (i.e., lanes plus shoulders) while controlling for state, terrain, roadside recovery distance, and number of driveways per 1.61 km (1 mi). For Model II state, functional class (local versus all others), ter-

rain, roadside hazard rating, and the number of driveways per 1.61 km (1 mi) were included as independent variables.

Both models have the same general shape, in which the rate of related accidents tends to decrease as roadway widths increase from 6.1 to 9.8 m (20 to 32 ft). However the rate for the most narrow roadway widths [5.5 m (18 ft) or less] was much lower than that for most wide roadways. Also no clear accident reduction was found for roadway widths of greater than 9.8 m (32 ft).

Because the models for total width do not provide details on the interaction of lane width with shoulder width, rates of related accidents were determined for various categories for lane and shoulder widths, as shown in Figure 2. Lane and shoulder width groupings were determined on the basis of the available sample sizes and by consideration of when significant accident differences exist. Data for only 134 km (83 mi) of roads with 2.4-m (8-ft) lanes were available, so a reliable accident rate could not be determined for roadways with that lane width. The resulting rate of related accidents for 2.7-m (9-ft) lanes was 1.69 accidents per 1.61 MV km (MVM) for shoulders of 1.2 m (4 ft) or less, and a rate of 1.56 for shoulders of 1.5 m (5 ft) or greater. Thus on roads with 2.7-m (9-ft) lanes, accident rates were not affected by wider shoulders.

One possible explanation for these findings is that vehicle speeds are lower on roads striped with 2.7-m (9-ft) lanes than on roads with wider lanes, regardless of the shoulder width. Somewhat unexpectedly the accident rate of 1.69 for roads with 2.7-m (9-ft) lanes with narrow [(0- to 1.2-m 0- to 4-ft)] shoulders was lower than the rate of 2.41 for roads with 3.1-m (10-ft) lanes with narrow shoulders. Roads with wider shoulders [greater than 1.5 m (5 ft)] and with 3.1-m (10-ft) lanes had lower accident rates (1.43), as shown in Figure 2. Further review of accident rates from several validation data bases was helpful in further examination of this somewhat surprising finding, as discussed later. No significant difference in accident rate was found between roads with 3.4- and 3.7-m (11- and 12-ft) lane widths, so data for roads with these lane widths were grouped together. The accident rate for roads with 4.0-m (13-ft) lanes and narrow shoulders was slightly lower (1.57) than the rate of 1.87 for roads with 3.3- and 3.7-m (11- and 12-ft) lanes.

Note that shoulder width categories were determined on the basis of actual accident rate differences and not set arbitrarily. Thus in terms of lane width effects, the initial analysis revealed that low-volume roads with 3.1-m (10-ft) lane widths with narrow or no shoulders have higher accident rates than low-volume roads with 2.7-m (9-ft) lane widths (of any shoulder width). Furthermore, for sections with narrow shoulders, accident rates were significantly lower for 3.4- and 3.7-m (11- and 12-ft) lanes than for 3.1-m (10-ft) lanes. Although roads with 4.0-m (13-ft) lanes with narrow shoulders had slightly lower accident rates than those with 3.3- and 3.7-m (11- and 12-ft) lanes, the sample size of roads with 4.0-m (13-ft) lanes with wide shoulders was small. Also, the practicality of providing 4.0-m (13-ft) lane widths for low-volume roads is questionable, and thus, 4.0-m (13-ft) lane widths were not considered further in the present study.

Validation of Analysis Results

The lower accident rate for roadways with 2.7-m (9-ft) lanes was unexpected and open to question and thus warranted further investigation with additional data bases of paved, low-volume roads

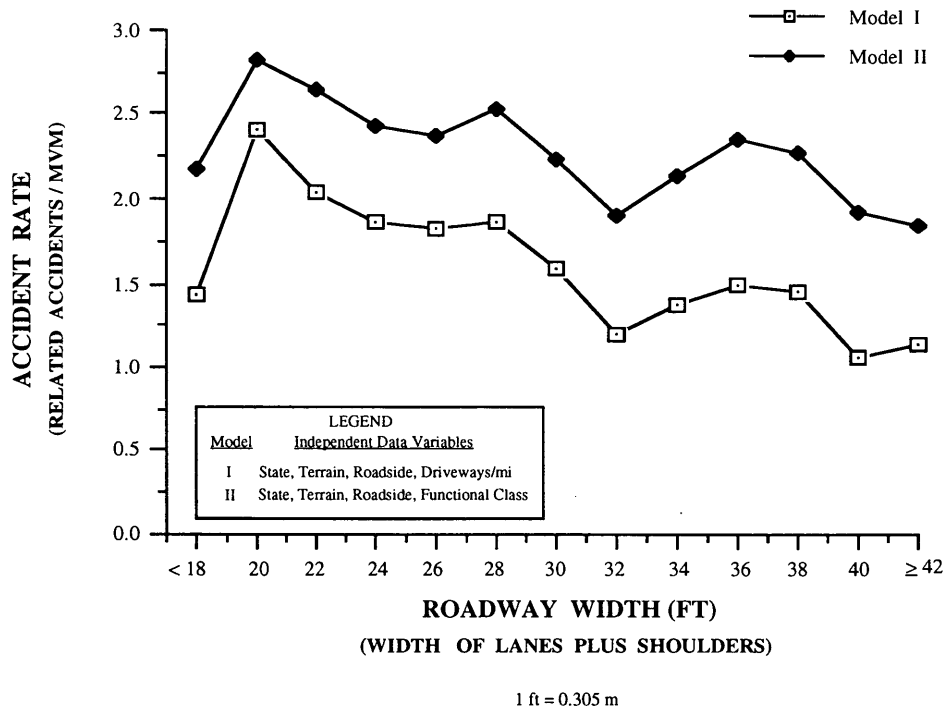


FIGURE 1 Rates of related accidents by roadway width from Models I and II.

from three states: Illinois [6104 km (3,791 mi)], Minnesota [39 121 km (24,299 mi)], and North Carolina [22 022 km (13,678 mi)]. Although detailed data on clear zone-roadside hazard were not available in these data bases, the other important variables were available.

On the basis of analysis of covariance models accident rates were computed for various lane and shoulder widths for the Illi-

nois and Minnesota data bases, as shown in Figure 3. As was found with the primary data base, accident rates were again found to be quite low for roads with 2.7-m (9-ft) lanes and increased for roads with 3.0-m (10-ft) lanes with narrow shoulders. Accident rates were considerably lower on roads with 3.0-m (10-ft) lanes with wider shoulders and leveled off for roads with lane widths of 3.3 and 3.7 m (11 and 12 ft). These results confirm the results

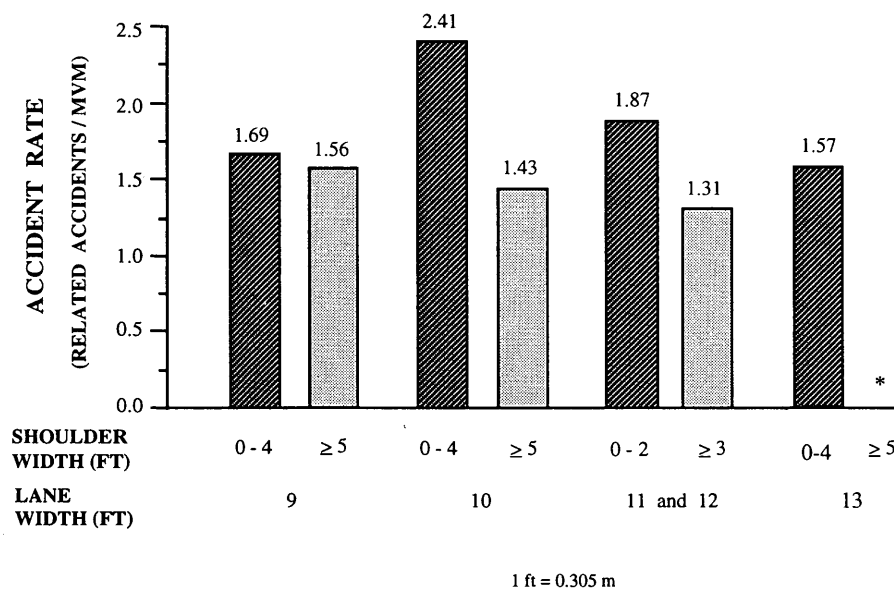


FIGURE 2 Rates of related accidents by lane and shoulder width from the data base for low-volume roads (the asterisk indicates inadequate sample size).

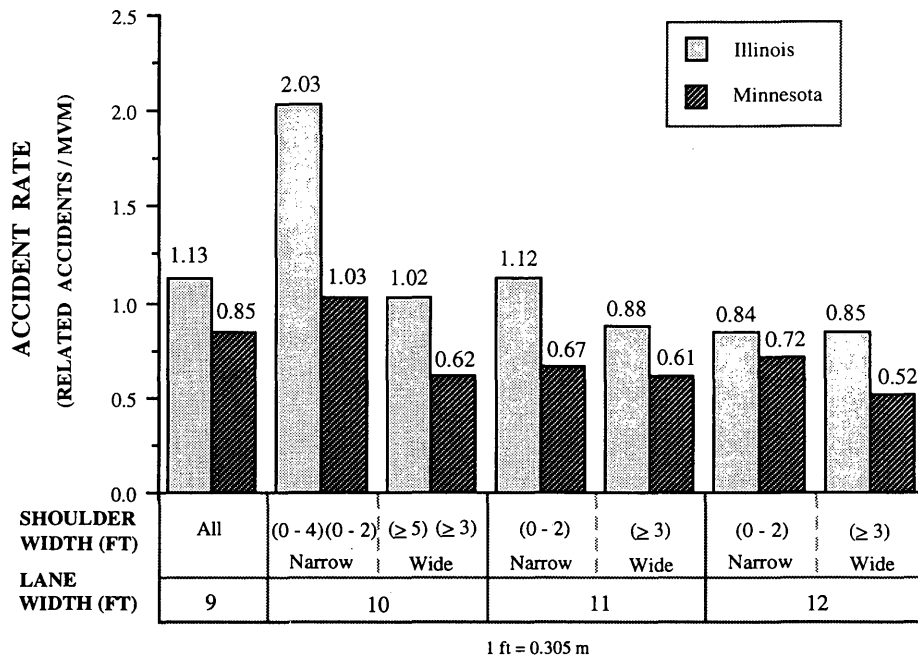


FIGURE 3 Rates of related accidents by lane and shoulder width in the Illinois and Minnesota data bases.

of the earlier analysis regarding lower accident rates for roads with 2.7-m (9-ft) lanes and higher rates for roads with 3.0-m (10-ft) lanes with narrow shoulders.

The North Carolina data showed rates of related accidents to be constant for roads with lane widths of 2.4 m (8 ft) or less and 2.7 m (9 ft), with rates of 1.95 and 1.94, respectively. In contrast to the other states and the primary data base, the rate then dropped to 1.73 for roads with 3.1-m (10-ft) lane widths and to 1.69 for roads with 3.4- and 3.7-m (11- and 12-ft) lane widths. Shoulder widths of 1.5 m (5 ft) or greater were associated with reduced accident rates. This could be due to roads with 2.7-m (9-ft) lanes in North Carolina being maintained by the state department of transportation in such a way to look like other, wider state roads (e.g., in terms of shoulder character, ditches, pavement striping), such that vehicle speeds on roads with 2.7-m (9-ft) lanes could be higher (and more likely to result in accidents) than those on roads with similar widths in other states.

It should also be mentioned that the North Carolina data supported the finding of the other data bases that increases in shoulder width reduced rates of related accidents, even though the important break points (or categories of shoulder width) varied for different lane widths and data bases. However the North Carolina data base did not show a lower accident rate for roads with 2.7-m (9-ft) lane widths than for roads with 3.1-m (10-ft) lane widths, after adjusting for shoulder width.

Discussion of Results

The results from the analysis of the primary and validation data bases have several important implications concerning safety effects of various lane and shoulder widths. First, on the basis of the data in primary data base, the presence of a wider shoulder is associated with a significant accident reduction for lane width cat-

egories of 3.0 m (10 ft) or greater. For roads with 3.1-m (10-ft) lanes, a shoulder with a width of 1.5 m (5 ft) or greater is needed to affect accident rate significantly. For roads with 3.4- and 3.7-m (11- and 12-ft) lane widths, shoulders with widths of 0.9 m (3 ft) or greater have significantly beneficial effects. For roads with lane widths of 2.7 m (9 ft), wider shoulders have a minimal, if any, safety benefit.

Second, with respect to lane width, data from two of the three validation data bases (Illinois and Minnesota) support the finding of a reduced accident rate for roads with 2.7-m (9-ft) lane widths in comparison with those for roads with 3.1-m (10-ft) lanes with narrow shoulders. Also the primary data base and the same two validation data bases both show that roads with 3.4-m (11-ft) lane widths have substantially lower accident rates in comparison with those for roads with 3.1-m (10-ft) lane widths, particularly where narrow shoulders exist. Furthermore, little if any real accident benefit can be gained from increasing lane widths from 3.4 m (11 ft) to 3.7 m (12 ft) on low-volume roads.

These analysis results generally agree with engineering intuition. Wider shoulders logically result in reduced accident rates, because drivers have more room to recover after encroaching over the edge line. Roads with lanes of 3.4 m (11 ft) or wider have lower accident rates than roads with 3.1-m (10-ft) lanes, which is again intuitively expected. The fact that 3.7-m (12-ft) lanes appear to offer minimal accident reduction in comparison with the number of accidents on 3.4-m (11-ft) lanes on low-volume roads agrees with results of a 1979 study by Zegeer et al. (6) of more than 16 000 km (10,000 mi) of rural, two-lane roads in Kentucky.

The main issue in question concerns the lower calculated accident rates for roadways with 2.7-m (9-ft) lanes in comparison with the accident rates for those with 3.1-m (10-ft) lanes. There are two possible explanations for this counterintuitive finding. First, the speeds on these narrower roadways may be lower, reflecting not only the effect of speed but also the effects of other

variables such as functional class and terrain. The majority of roads with such narrow lanes may be more local in character, carrying lower-speed, local traffic. (Note that no speed data were collected as part of the present study.) Roadways with 3.1-m (10-ft) lanes are commonly found on higher-class facilities, on which vehicles tend to operate at higher speeds than on roads with 2.7-m (9-ft) lanes.

The analysis results support the continued use of 2.7-m (9-ft) lanes on some roadways that have lower than average accident rates, as long as these narrow roadways do not have excessively high speeds. Widening of an existing roadway with 2.7-m (9-ft) lanes to provide 3.1-m (10-ft) lanes cannot be expected to improve its safety unless such widening is accompanied by a shoulder width of at least 1.5 m (5 ft). Widening of lanes from 3.1 m (10 ft) or less (which have little or no shoulders) to 3.4 m (11 ft) plus the provision of greater than 0.6-m (2-ft) shoulders would generally be effective in terms of reducing accident rates on the basis of the results of the present analysis. The authors conclude that these findings also support construction of new roadways with 2.7-m (9-ft) lanes in certain situations (e.g., very low traffic volume, low design speeds, local traffic, and minimal truck volumes).

Issue 5: Paved Versus Unpaved Road Surface

From the primary data base rates of related accidents were compared between paved and unpaved roadway sections from states where both types of sections were available. Three different accident rate models were used to compare the safety of paved versus unpaved roads. Again each analysis controlled for important traffic and roadway variables such as state, terrain, roadside recovery distance, and roadway width. For each of three lane width categories [≤ 2.7 , 3.0 to 3.4, 3.7 m (≤ 9 , 10 to 11, ≥ 12 ft)], unpaved roads had higher rates of related accidents than paved roads. This was also true using the rate of related injury accidents.

Next a comparison between rates of related accidents for paved and unpaved roadways for various ADT categories (i.e., <250, 250 to 400, and >400 vpd) was made to determine the levels of traffic at which paved surfaces provide safety benefits. On roadways with ADT of less than 250 vpd, accident rates did not differ significantly between paved and unpaved roads. However for ADT of more than 250 vpd, rates for unpaved roads were significantly higher than those for paved roads (except for the Minnesota validation data base). Thus the results of this analysis from the primary data base provide some indication that roadways with ADT of more than 250 vpd should be paved to provide reduced numbers of accidents.

Another question concerned how total roadway width on unpaved roads affects accidents, and here the findings were in contrast to the earlier findings for paved roads. By using data for the unpaved road samples from only the primary data base, the rates of related accidents per 1.61 million vehicle km (per MVM) were much lower on roadways with total widths of less than 5.5 m (18 ft) than on roadways with total widths of 6.1 to 6.7 m (20 to 22 ft) or 7.3 m (24 ft) or greater (i.e., rates of 1.72 versus 3.95 and 3.88, respectively). Similar trends were found by using rates of accidents resulting in injuries. Thus the increased width of unpaved roadways increases accident rates, which is the reverse of the finding for paved roads. Validation data from Minnesota indicated fluctuating rates for roads with widths of 5.5 to 9.2 m (18 to 30 ft), with some decrease in rate as widths increased over 9.2

m (30 ft). Minnesota data were used for this validation because of the large sample of unpaved roadways in that state.

As with the previous discussion of roads with very narrow lane widths, speed may be an explanation for what appears to be a counterintuitive finding. Vehicles on unpaved roads that are very narrow are probably driven at very low speeds. Wider, unpaved roads may appear safer and encourage higher speeds, even though roadway alignment is severe (e.g., sharp curves), thereby increasing the potential for accidents.

In summary roads with ADT values of more than 250 vpd should in general be surfaced to improve safety. Of course those making the final decision on which unpaved roadways should be surfaced should also consider the accident experience, traffic volumes, roadway alignment (in terms of which sections can handle higher speeds safely after surfacing) on each section, as well as priorities for surfacing under available funding levels.

Furthermore the results show that the width of unpaved roads also can affect accident rates. Although accident rates fluctuate considerably for narrow roadways, accident rates for roadway widths of 6.1 m (20 ft) or less are generally low on unpaved roads. This may occur as a result of reduced vehicle speeds on very narrow, unpaved roads. As widths increase to about 9.2 m (30 ft), accident rates increase, perhaps because of increases in vehicle speeds. As widths increase further to more than 9.2 m (30 ft), rates seem to decrease again, perhaps because vehicle speeds do not increase further for unpaved roadway widths of more than 9.2 m (30 ft).

CONCLUSIONS

The major research conclusions of the present study are given below.

1. Accident rates on paved, low-volume roads are significantly reduced by wider roadway width, improved roadside condition, flatter terrain, and fewer driveways per 1.61 km (1 mi). No differences in accident rates were found on roads with paved shoulders in comparison with the rates on roads with unpaved shoulders. Accident rates are most highly correlated with lane and shoulder widths for single-vehicle and opposite-direction accidents.

2. The presence of a shoulder is associated with significant accident reductions for roads with lane widths of 3.1 m (10 ft) or greater. For roads with lane widths of 3.0 m (10 ft), shoulders of 1.5 m (5 ft) or greater are needed to reduce accident rates. For roads with lane widths of 3.4 and 3.7 m (11 and 12 ft), shoulder widths of at least 0.9 m (3 ft) result in significant accident reductions in comparison with the numbers of accidents on roads with narrower shoulders.

The study also addressed roads with lane widths of 2.7 m (9 ft) in terms of their accident experience. For a combination of reasons there is no apparent benefit in terms of reducing the number of accidents from widening such lanes from 2.7 m (9 ft) to 3.1 m (10 ft) unless shoulders of 1.5 m (5 ft) or more are also added. Indeed the study produced evidence that existing roads with 2.7-m (9-ft) lanes with narrow or wide shoulders are preferable to roads with 3.1-m (10-ft) lanes with narrow shoulders, perhaps because of lower vehicle speeds on roads with 2.7-m (9-ft) lanes and thus lower numbers of accidents.

3. Accident experience does not appear to be significantly different for unpaved versus paved roadway surfaces at traffic volumes of 250 vpd or less. At traffic volumes greater than this, accident rates are significantly greater for unpaved roadways than for paved roadways, all else being equal. Therefore paving of rural roads with traffic volumes of 250 or more vpd will generally improve their safety. Accident rates increase on unpaved roads as width increases up to 9.1 m (30 ft), perhaps because of higher vehicle speeds on wider unpaved roads.

The results of the accident data analyses were used along with other considerations in the development of recommended changes to the AASHTO guidelines for roadway widths on low-volume roads. Details of those recommended guidelines are contained in the full report of the study (12). It should also be mentioned that all roadway features, including roadway width, roadside features, traffic control devices, and roadway alignment, should be considered for possible improvement as needed in conjunction with resurfacing, restoration, and rehabilitation projects and for major reconstruction projects.

APPLICATION OF RESEARCH RESULTS

The research reported here was part of a larger research effort funded by NCHRP. Project 15-12, Roadway Widths for Low Traffic Volume Roads, was conducted to answer basic questions about the cost-effectiveness of design values in current AASHTO policies (2) for rural roads with ADT volumes of less than 2,000 vpd. Other tasks performed as part of project 15-12 included construction cost modeling, a review and synthesis of operational considerations related to roadway widths (e.g., relationship of width to operation speeds, capacity and oversize vehicle operations, and analysis of functional shoulder widths, and analysis of design value consistency within the AASHTO policy.

The final report for NCHRP 15-12 identified revisions to design values for lane width and shoulder width as a function of design speed, functional classification, terrain, and traffic volume. The draft revisions to AASHTO roadway width guidelines reflected key accident relationships reported here

1. Lane widths of 2.7 m (9 ft) may be an appropriate standard for a wider range of operating speeds and traffic volumes than is reflected in the current policy.
2. Lane width-shoulder width combinations resulting in a total dimension of 9.2 to 9.8 m (30 to 32 ft) are cost-effective for a greater range of traffic volumes than is reflected in current design policy.
3. Justification of full-width [3.7-m (12-ft)] lanes and shoulders [3.1 m (10 ft)] as a basic standard is evident only for roads with

higher design speeds, roads with traffic volumes of more than 1,500 vpd, and roads with a significant proportion of heavy vehicle traffic.

The net effect of recommended changes to AASHTO policy design values would be a downsizing, particularly for highways with lower design speeds and with traffic volumes in the range of 400 to 1,000 vpd. As of the date of this paper's submission for publication, recommended revisions to the 1995 draft AASHTO policy chapter on local roads have been made. Those revisions reflect many of the research findings. Revisions to design values in the collectors and arterials chapters are also expected.

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