NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 362

Roadway Widths for Low-Traffic-Volume Roads

Transportation Research Board
National Research Council

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report 362

Roadway Widths for Low-Traffic-Volume Roads

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

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FOREWORD

By Staff
Transportation Research Board

This report is recommended to persons involved in highway design, safety, maintenance, and administration. It describes the results of comprehensive safety, operational, and economic analyses regarding minimum roadway widths for low-volume roads. It is believed that this report provides useful information, documents a detailed research approach, describes a useful model for investigating many facets of low-volume roads, and presents recommendations for revisions to the design standards presented in the American Association of State Highway and Transportation Officials' (AASHTO) *Policy on Geometric Design for Highways and Streets*, 1990 Edition (referred to in this report as *Policy* or Green Book).

The AASHTO Green Book established minimum roadway widths for new construction and major reconstruction of roadways according to road classification, traffic volume, and design speed. These minimum roadway widths were based on limited research findings augmented with engineering judgment. The impact of using these minimum widths was highlighted in the results of a recent research effort conducted by the Transportation Research Board that was published in *TRB Special Report 214*, "Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation" (1987). That report indicated that acceptable operational and safety experience can be found on low-traffic-volume (less than 2000 ADT) roadways having widths narrower than the minimum roadway widths specified in the Green Book. This implies that designs for new construction and major reconstruction of low-traffic-volume roadways may be excessive. Because about 1.3 million miles of rural roadways (or one-third of the total rural mileage) in the United States fall within the low-traffic-volume category, a reduction in the roadway-width requirements could have a major impact on the state programs.

The objectives of this research were to develop an engineering analysis procedure for determining optimum roadway width for the construction and reconstruction of low-volume roadways. This procedure was then to be used to develop "minimum width of traveled way and shoulder" recommendations for consideration by the Geometric Design Task Force of the AASHTO Highway Subcommittee on Design.

This project consisted of (1) a critical review of all pertinent literature dealing with safety, operations, and geometrics of low-volume roads as they pertain to roadway width; (2) development of a plan for acquiring and analyzing data on traffic volume, vehicle speed, percent trucks, roadway functional classification (arterial, collector, and local), level of service, accidents, and other information; (3) extensive data collection and analyses to assess safety, operational, and economic aspects; (4) development of an engineering analysis procedure for optimizing roadway width, considering the costs and safety benefits; (5) comparison of the recommended roadway widths to current width criteria for low-traffic-volume roadways to determine the safety, operational, and economic impacts that

would be associated with adopting recommended standards; and (6) preparation of a final report documenting the efforts and findings of the research.

This project was highlighted by (1) the use of the Highway Safety Information System (HSIS), which allowed the analyses of thousands of miles of low-volume, two-lane roadways; (2) extensive field investigations to obtain or verify critical information on the widths, cross sections, and roadside conditions for these roadways; (3) thorough analyses of the data leading to the formulation of a model for the analysis of traffic and roadway design conditions that affect the safety and operation of low-volume roads; and (4) an extensive economic analysis using data gathered from the states and case studies of actual low-volume roadway improvement projects that had been completed over the last 5 years. These analyses revealed that narrower roadways could function safely and effectively in some situations, allowing highway improvement funds to be stretched over a greater proportion of the two-lane road network. The results cover most low-volume roadways because the sample included paved and unpaved roadways, roadways in various terrains, a range of traffic volumes and mix, and roadways from different regions of the nation. Recommendations for changes to the AASHTO Green Book are presented in the report.

CONTENTS

1 SUMMARY

5 CHAPTER ONE Introduction and Research Approach
- Problem Statement, 5
- Current AASHTO Width Criteria, 6
- Background Safety Research, 9
- Research Objective and Scope, 10
- Research Approach, 10

11 CHAPTER TWO Study Findings
- Analysis Issues, 11
- Analysis of Highway Safety Issues, 11
  - Development of the Primary Accident and Roadway Database, 11
  - Statistical Testing and Results, 14
- Highway Operational Considerations Related to Design, 21
  - Functional Classification, 21
  - Design Speed, 22
- Roadway Design Requirements, 26
  - Cost-Effectiveness and Width-Related Sensitivities, 26
  - Comparison of 10-Ft Lanes with 5-Ft Shoulders to 10-Ft Lanes with 2-Ft Shoulders, 31
  - Comparison of 11-Ft Lanes with 4-Ft Shoulders to 11-Ft Lanes with 2-Ft Shoulders, 31
  - Comparison of 12-Ft Lanes with 4-Ft Shoulders to 12-Ft Lanes with 2-Ft Shoulders, 32
  - Comparison of 11-Ft Lanes with 2-Ft Shoulders to 10-Ft Lanes with 2-Ft Shoulders, 32
  - Comparison of 10-Ft Lanes with 6-Ft Shoulders to 11-Ft Lanes with 2-Ft Shoulders, 33
  - Comparison of 11-Ft Lanes with 4-Ft Shoulders to 10-Ft Lanes with 5-Ft Shoulders, 33
  - Comparison of 12-Ft Lanes with 3-Ft Shoulders to 11-Ft Lanes with 4-Ft Shoulders, 34

39 CHAPTER THREE Results, Interpretation, Appraisal, and Application
- Comparison of Recommended Widths to Current AASHTO *Policy*, 39
  - Format, 39
  - Local Road Design Values, 39
  - Collector Design Values, 43
  - Arterial Design Values, 46
- Application to 3R Design Problems, 46
  - Guidelines for 3R Design Problems, 46
  - Procedures for Evaluation of Low-Volume Road Design Options, 46
- Evaluation of Case Studies, 47
  - Case Study No. 1: *US 62 and 281—Widening and Reconstruction; Caddo County, Oklahoma*, 47
  - Case Study No. 2: *State Highway 46—Reconstruction; Gooding and Camas Counties, Idaho*, 47
  - Case Study No. 3: *Oak Harbor Southeast Road—Resurfacing; Ottawa County, Ohio*, 48
  - Case Study No. 4: *Grande Ronde River Road 51—Reconstruction; La Grande, Oregon*, 48
  - Summary of Case Studies, 48

50 CHAPTER FOUR Conclusions
Accidents on Low-Volume Roads, 50
Accident Effects of Lane and Shoulder Width, 50
Accident Effects of Paved vs. Unpaved Surfaces, 50
Accident Effects of Large Trucks, 50
Accident Benefits of Widening Low-Volume Roads, 50
Capacity and Level-of-Service Effects on Width of Low-Volume Roads, 50
Speed-Related Widths, 51
Shoulder Functions Related to Width, 51
Truck Operations Related to Width, 51
Costs of Construction of Low-Volume Roads, 51
Cost-Effective Width Combinations, 51
Recommended Standards, 51

52 REFERENCES

54 APPENDIX A Cost-Effectiveness Guide for Design Improvements to Roadway Cross Sections on Low-Volume Rural Roads

64 APPENDIX B Critical Review of Literature

72 APPENDIX C Analysis of Low-Volume Roads Data

90 APPENDIX D Survey of Construction Costs—Two-Lane Rural Highways

100 APPENDIX E Derivation of Consistency Between Lane Width, Shoulder Width, Functional Class, and Volume

105 APPENDIX F Guidelines for Derivation of Consistency Between Design Speed and Lane Width

ROADWAY WIDTHS FOR LOW-TRAFFIC-VOLUME ROADS

SUMMARY

In recent years, maintaining and reconstructing the two-lane highway system has emerged as a serious problem. A primary problem results from the extensive size of the system. A 1983 study estimated that there are approximately 3.1 million miles of two-lane highways in the United States, which represent 97 percent of the rural mileage and 80 percent of the total U.S. highway mileage. Further, much of this mileage has relatively low traffic volumes. For example, of the 3.1 million miles of two-lane rural roads, approximately 90 percent (2.8 million miles) have an average daily traffic (ADT) of less than 1,000 vehicles per day (vpd). About 80 percent have ADTs of less than 400 vpd, and 38 percent carry less than 50 vpd.

A great proportion of the two-lane rural road system is 30 years old or more, necessitating investment to replace pavement, repair shoulders, and address other problems. The age of the system adds another dimension to the problem. Significant mileage of two-lane highways was designed and built to standards that are outdated compared with current design policy. For example, over one-quarter of the mileage of such roads have lane widths of 9 ft or less, and two-thirds have shoulder widths of 4 ft or less. In addition, 11.5 percent of two-lane highway mileage (356,500 miles) have no shoulders. These statistics contrast with current design values shown in the 1990 American Association of State Highway and Transportation Officials (AASHTO) *Policy on the Geometric Design of Highways and Streets* (henceforth referred to as *Policy* or Green Book). For all but extremely low-volume and low-speed highways, the current *Policy* calls for 22- to 24-ft roadways (11- to 12-ft lane widths) regardless of terrain or other conditions (AASHTO, 1990).

There are insufficient funds to reconstruct the entire two-lane system to design values implied by the 1990 AASHTO *Policy*. At the same time, abandoning roads or allowing continued, long-term deterioration are not viable options. Thus, state and local highway agencies find their engineers confronted with difficult choices related to repaving or reconstructing (to AASHTO design standards). The impacts can be dramatic if, for example, an agency's budget allows for either 20 miles of roadway repavement or 12 miles of roadway reconstruction.

Of course, both repairs and reconstruction would be expected to produce different levels of safety and operational quality. Yet, as currently written, the AASHTO *Policy* does not offer the flexibility to consider the safety, operations, and cost trade-offs on either a statewide programming or site-specific basis. Indeed, many design engineers perceive the

Policy as a hindrance to arriving at the most cost-effective design solution. This is because there are many miles of two-lane rural highways considered "substandard" (with respect to the current AASHTO *Policy* values) that have acceptable safety experience. Furthermore, in many cases, accident problems that do exist may be attributable to variables other than those cited in the AASHTO *Policy* (i.e., the width of traveled way and shoulder), such as roadside conditions and horizontal or vertical alignment. However, once a decision is reached to reconstruct rather than resurface or maintain a highway, the current AASHTO *Policy* applies, which calls for certain minimum cross-sectional dimensions. There is no current evidence that such dimensions produce significant safety benefits, but they do generally have major cost implications. Revision to the values shown in the AASHTO *Policy*, reflecting greater sensitivity to safety and construction cost trade-offs, could offer the opportunity for agencies to increase the safety return on their reconstruction investment.

The objectives of this study were to (1) develop an engineering analysis procedure that would allow for the determination of optimum roadway widths for construction and reconstruction of low-volume roadways (ADT less than 2,000 vpd) and (2) use the analysis procedure to develop recommendations for "minimum width of traveled way plus shoulder." These recommendations would be considered by the design task force of the AASHTO highway subcommittee on design, for inclusion in future editions of the Green Book. The efforts in this study relate to paved or unpaved two-lane rural roads with ADT volumes of 2,000 vpd or less. Functional classifications studied included arterial, collector, and local roadways.

The basic approach to this research involved first reviewing current AASHTO Green Book values on roadway width, as well as other proposed guidelines, and the roadway factors considered to be important in the formulation of such standards. Next, a detailed review of safety literature was conducted to determine what is currently known about accident effects of roadway width and other traffic and roadway features on two-lane rural roads. Safety effects of numerous features, in addition to roadway width, were considered important because no single data item alone is the sole factor in resulting crashes. Instead, the interaction among several roadway elements, and perhaps driver and vehicle factors, can affect the frequency and/or severity of accidents.

The literature review revealed that in addition to lane and shoulder width, other factors found to affect safety on two-lane rural roads include shoulder type, roadside slope, roadside obstacles (placement, number, and rigidity), horizontal alignment, vertical alignment, traffic volume (and mix of traffic), narrow bridges, and location of intersections and driveways, among others. The identification of such safety relationships was useful in formulating a data collection and analysis plan. This plan identified the important variables for the analysis of the interaction of the factors that affect roadway design. For example, increasing lane width can reduce shoulder width and recovery area, if limited right of way is available. If shoulders are widened, then roadside slopes may need to be steepened, possibly leading to more severe crashes. Clearly, the trade-offs that exist from what seems to be a simple and logical increase in lane width must be studied together to determine optimal lane widths from a safety perspective.

To maximize the extent of the safety, operational, and economic analyses in this project, existing databases that offered adequate detail were used to the extent possible. The primary data source selected was a database of approximately 2,400 miles of two-lane road from seven states (with ADT of 2,000 vpd or below) from two previous FHWA studies (see References 5 and 7). This database was supplemented with data from approximately 1,700 miles of paved and unpaved two-lane roadway (mostly local and collector streets) from North Carolina, Utah, and Michigan, for a total of approximately 4,100 miles. Field data were collected on these supplemental sections to provide information on roadside conditions, intersections, driveways, and terrain to match the other database.

A detailed statistical analysis was conducted on the primary database, and accident rates were determined for various lane and shoulder widths. To validate the findings and to investigate these relationships further, three independent databases totaling more than 54,000 miles of low-volume, two-lane roads were obtained from three states (Illinois, Minnesota, and North Carolina) and analyzed.

A project cost analysis methodology was developed for roadway widening projects for existing roadways and also for comparing roadway width effects on new road construction costs. An economic analysis analyzed the cost and benefit relationships for the different lane and shoulder width combinations in various situations. Economic benefits of accident reductions were estimated using research by others that established societal costs of motor vehicle injuries and fatalities. The research approach used FHWA's recommended methodology for tabulating such costs, resulting in a recommended value of $60,000 per low-volume road accident. This value was used to estimate benefits of accident reductions. A construction cost model, based on a comprehensive survey of state design engineers and practices, was used to investigate the sensitivities of variable lane and shoulder width designs, as well as other relevant factors such as terrain on total construction costs. The accident and construction cost models were used to evaluate the cost-effectiveness of various combinations of lane and shoulder width.

Design standards for highways are based on more than safety performance. The research investigated the operational requirements and effects of different roadway and shoulder widths. Issues investigated included capacity; speed; highway level of service; consideration of wider, larger vehicles; and compatibility with alignment and other design standards and criteria published in the *Policy*. A central theme of the study was that width-related design standards should be compatible with primary design policy controls such as design speed and functional classification.

The safety, operational, and economic analyses covering all facets of low-volume roads resulted in a number of conclusions. Specific conclusions from the safety analyses included the following:

- Low-volume roads were found to experience a slightly higher percentage of injury accidents than the full sample of rural roads. Single-vehicle accidents (fixed object, rollover, run-off-road) are greater proportionately and multivehicle accidents (rear-end, angle, turning) lesser proportionately on low-volume roads than on all two-lane rural roads. The studies found that low-volume road accidents are affected primarily by roadway width, roadside hazard, terrain, and driveways per mile. Accident rates are significantly associated with varying lane and shoulder widths for single-vehicle and opposite-direction accidents.
- The presence of a shoulder is associated with significant accident reductions for lane widths of at least 10 ft. For lane widths of 11 and 12 ft, shoulder widths of at least 3 ft have significant effects. For a combination of reasons, some perhaps relating to lower vehicle speeds on narrow roadways, there is no apparent accident benefit of widening lanes from 9 ft to 10 ft. Indeed, the study produced evidence that 9-ft lanes with wide shoulders may be preferable to 10-ft lanes with narrow shoulders. Roadways with lane widths of 11 or 12 ft have significantly lower accident rates than roadways with 10-ft lane widths.
- Accident experience does not appear significantly different for unpaved versus paved roadway surfaces at traffic volume levels of 250 vpd or less. Above this volume, accident rates are significantly greater for unpaved roads, which provides evidence for paving roadways with traffic volumes above 250 ADT for safety reasons.

The study produced a linear model that was used to estimate expected accident effects of various combinations of lane width and shoulder width. For 10-ft lanes, accident rates

were lower by 0.98 per million vehicle miles (MVM) when accompanied by shoulders of greater than 4 ft versus shoulders of 4 ft or less. For 11- and 12-ft lanes, shoulder widths of 3 ft or greater produced accident rates 0.56 per MVM lower than with shoulder widths less than 3 ft. The accident model produced identical accident benefits for 11- and 12-ft lanes.

Specific conclusions derived from the analysis of operational issues included the following:

- Based on known operational effects of lane and shoulder widths, capacity requirements should influence design standards for certain terrain conditions and traffic composition. For designing roadways with ADT of 1,500 vpd or more, combinations of lane and shoulder width in excess of those required merely for safety are necessary to produce levels of service compatible with AASHTO design policy guidelines.
- Lane widths should produce operating speeds compatible with the selected design speed. Wider lane widths (say, 11- or 12-ft) on roadways designed with lower design speeds (say, 40- or 50-mph) may be undesirable. Such widths may promote operating speeds above those for which the alignment was intended to accommodate.
- It was concluded that for certain combinations of functional classification, traffic volume, and composition, shoulder widths in excess of those required solely for safety are necessary. For the upper range of traffic volumes (greater than 1,500 vpd), this study recommended minimum shoulder widths of 6 ft to 8 ft depending on the functional class of the facility.
- It was concluded that, where longer, wider vehicles can be expected to operate, providing incrementally greater lane and/or shoulder widths is desirable to accommodate the off-tracking and encroachment problems associated with these vehicles.

The economic analysis led to the following specific conclusions:

- Cost per mile of construction was found to be greatly influenced by terrain, total roadway width, and lane width.
- "Breakeven" ADT levels were computed to determine when widening appeared justified.

Finally, based on the accident, operational, and economic analyses results, revised width guidelines were developed for new or reconstructed low-volume roads. Guidelines also were developed for evaluation of 3R projects. This study concluded that there are opportunities to refine current lane and shoulder width standards for low-volume roads. A major conclusion of this exercise was that width combinations narrower than those called for by current AASHTO *Policy* appear appropriate. In particular, where total roadway widths (i.e., lanes plus shoulders) currently exceed 30 ft, there are many cases where narrower widths could be employed at lower cost with no apparent degradation in safety. Also, the cost-effectiveness analysis demonstrated that less variation in widths for the range in traffic volumes is appropriate compared to current AASHTO *Policy*. Revised design values based on the safety studies, operational analyses, and cost-effectiveness evaluations would produce meaningful savings in construction and reconstruction costs associated with the low-volume rural system.

The major objective of the research—to develop recommended design values for lane and shoulder width for low-volume roads—was accomplished. This research also recommended revisions to the format of design standards as well as to the values for the range of relevant condition. Overall, the research supports conclusions of earlier work from *TRB Special Report 214*; therefore, narrower width combinations for lanes and shoulders on low-volume roads should be considered in subsequent editions of the AASHTO *Policy*.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT

In recent years, maintaining and reconstructing the two-lane highway system has emerged as a serious problem. The problem primarily results from the extensive size of the system and the fact that significant mileage of two-lane highways was designed and built to outdated standards not reflective of current design policy. Also, a large portion of low-volume roads is unpaved, which presents maintenance problems in addition to safety concerns.

A 1983 study estimated that there are approximately 3.1 million miles of two-lane highways in the United States, which represents 97 percent of the rural mileage and 80 percent of the total U.S. highway mileage. Further, much of this mileage has relatively low traffic volumes. For example, of the 3.1 million miles of two-lane rural roads, approximately 90 percent (2.79 million miles) have an average daily traffic (ADT) of less than 1,000 vehicles per day (vpd). About 80 percent have an ADT of less than 400 vpd, and 38 percent carry less than 50 vpd. Of all local and minor collector roads on the two-lane system, 90 percent have an ADT of 2,000 vpd or less; more than 60 percent of minor rural arterials have an ADT of 2,000 vpd or less (*1*). Thus, in terms of their extensive mileage, low-volume roads are clearly an important component of the highway transportation system.

A great proportion of the two-lane rural road system is 30 years old or more, necessitating investment to replace pavement, repair shoulders, and address other problems. The age of the system adds another dimension to the problem. Significant mileage of two-lane highways was designed and built to standards that are outdated compared with current design policy. For example, over one-quarter of the mileage of such roads have lane widths of 9 ft or less, and two-thirds have shoulder widths of 4 ft or less. In addition, 11.5 percent of two-lane highway mileage (356,500 miles) has no shoulders. These statistics contrast with current design values shown in the 1990 American Association of State Highway and Transportation Officials *A Policy on the Geometric Design of Highways and Streets* (henceforth referred to as *Policy* or Green Book) (*2*). For all but extremely low-volume and low-speed highways, the 1990 AASHTO *Policy* calls for 22-ft to 24-ft roadways (11-ft to 12-ft lane widths) regardless of terrain or other conditions (*2*).

Over the last 50 years, design criteria for all highways have evolved to reflect changes in vehicle width and performance, greater understanding of driver behavior, and advances in material and construction techniques. Cross-section values in the AASHTO policies from 1940 to the present have gradually changed to the point where, except for extremely low-volume and low-speed highways, AASHTO policy criteria specify a 22-ft to 24-ft traveled way (i.e., 11-ft to 12-ft lanes) for all terrain and other conditions.

Much of the existing rural mileage was designed to criteria that prevailed more than 30 years ago. Indeed, there is undoubtedly significant mileage of low-volume roads that may not ever have been "designed" in the conventional sense. Such roads evolved over the years, beginning as horse paths and eventually being upgraded over time to a paved surface. What evolved was functional for the type and level of traffic that prevailed locally, yet might not have met any formal criteria for highway design.

There are insufficient funds to reconstruct the entire two-lane system to design values implied by the 1990 AASHTO *Policy*. At the same time, abandoning roads or allowing continued, long-term deterioration is not a viable option. Thus, state and local highway agencies find their engineers confronted with difficult choices. Should a highway merely be repaved within its existing cross section, or should reconstruction to values shown by AASHTO be considered? For example, assume that a given highway budget may enable repaving of 20 miles of facility in need of repair; if the latter approach—reconstruction—is taken, only 12 miles may be built for the same money.

Of course, both repairs and reconstruction would be expected to produce different levels of safety and operational quality. Yet, as currently written, the AASHTO *Policy* does not offer the flexibility to consider the safety, operations, and cost trade-offs on either a statewide programming or site-specific basis. Indeed, many design engineers perceive the *Policy* as a hindrance to arriving at the most cost-effective design solution. This is because there are many miles of two-lane rural highways considered "substandard" (with respect to the current AASHTO *Policy* values) that demonstrate acceptable safety records. Furthermore, in many cases, accident problems that do exist may not be attributable necessarily to the variables that describe the cross section in the AASHTO *Policy* (i.e., the width of traveled way and shoulder), but to other factors such as the roadside or horizontal or vertical alignment. However, once a decision is reached to reconstruct rather than resurface or maintain a highway, the current AASHTO *Policy* applies, which calls for certain minimum cross-sectional dimensions. There is no current evidence that such dimensions produce significant safety benefits; generally, they do have major cost implications.

Recent research concerning resurfacing, restoration, and rehabilitation (3R) practices [*TRB Special Report 214*, (*3*)] has suggested that acceptable safety and operational experience could be expected on low-volume roadways with lane widths that are somewhat narrower than those proposed in the AASHTO *Policy*. If this result could be demonstrated through carefully conducted research, the implications would be significant. Revision to the values shown in the *Policy*, reflecting greater sensitivity to safety

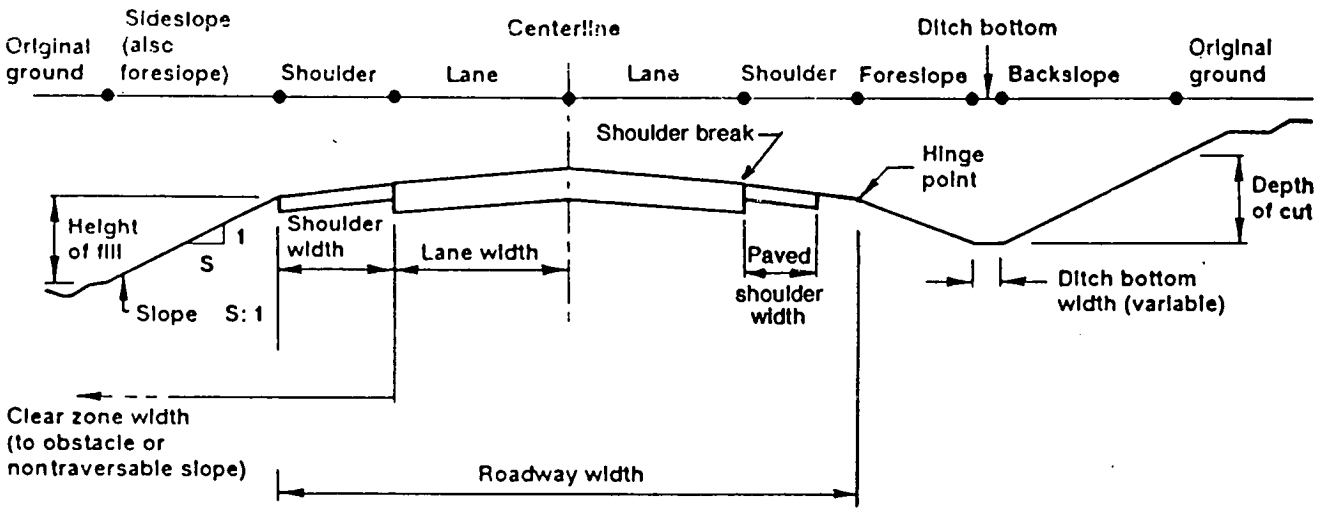


Figure 1. Elements of rural highway cross sections.

and construction cost trade-offs, could offer the opportunity for agencies to increase the safety return on their reconstruction investment.

Of course, the findings implied by *TRB Special Report 214* are somewhat tentative in nature at this point, because there have been very few well-conducted studies of lane-width-related crashes for low-volume roadways. Instead, much of the information currently available is based on data collected on higher volume roadways where accidents per mile are greater. There is also a need to establish the effects of lane width on crash rates for low-volume roads and, more specifically, to relate this information to the issue of widening existing narrow pavements on low-volume roads when reconstruction is done. No optimum set of lane and shoulder width values has yet been established for various traffic or geometric conditions on low-volume roads.

CURRENT AASHTO WIDTH CRITERIA

Width-related elements of rural highway include roadway features (lanes and shoulders) as well as roadside features (foreslopes, ditches, backslopes). Figure 1 describes those individual elements of interest in rural cross-section design.

The 1990 AASHTO *Policy* (Green Book) design values for width of traveled way for new construction or roadway reconstruction are given in Tables 1, 2, and 3 for arterial, collector, and rural local roads, respectively. The values in these tables generally are quite stringent for many roadway situations. For example, a 24-ft traveled way width (i.e., two 12-ft lanes) is suggested for nearly all design traffic volumes and design speeds on rural arterial streets, except for some combinations of lower design speed (i.e., 40 or 50 miles per hour (mph)) and design traffic volumes (i.e., design hourly volumes of less than 200 vpd). On rural collector streets, 24-ft widths are specified for design hourly volumes (DHV) over 400 vpd, with 20-ft to 22-ft widths specified for other situations. On rural local roads, traveled-way-width requirements range from 18 ft to 24 ft, with 24-ft widths specified again for DHV of 400 vpd and above, and 18-ft traveled-way widths (9-ft lanes) permitted only for roads with ADT of less than 250 vpd with design speeds of 20 or 30 mph.

Shoulder width requirements for rural arterials range from 4 ft to 8 ft of usable shoulders (each side of pavement), where such usable shoulders should be paved. For rural collector and local roadways, gravel shoulders of 2 ft to 8 ft are specified, depending on design traffic volume.

The 1990 AASHTO width values incorporate several revisions since the 1984 Green Book. For example, the 1984 *Policy* did not include a 40-mph design speed category for rural arterials. Also, the 1984 criteria for rural arterials specified design traffic volume categories with DHV of 200 to 400 vpd and DHV above 400 vpd, which now are combined into one category (DHV 200 vpd or above) in the 1990 *Policy*. Further, the 1990 *Policy* allows 22-ft traveled-way widths on reconstructed rural arterials in cases where alignment and safety records are satisfactory. Finally, on rural local roads with DHV of 200 to 400 vpd, the 1990 Green Book specifies a 6-ft shoulder width, compared to an 8-ft width in the 1984 version.

In recent years, standards less stringent than implied by Green Book values have been proposed for lane and shoulder widths. For example, AASHTO 3R design values have minimum lane widths of 10 ft or 11 ft and 2-ft minimum shoulder widths (see Table 4). These values are independent of ADT but do consider percent trucks for average running speeds over 40 mph (*TRB Special Report 214,* 1987).

The roadway width standards proposed in 1978 by the Federal Highway Administration (FHWA) generally fall somewhere between the AASHTO 1990 *Policy* and AASHTO 3R values discussed previously in terms of minimum width requirements (see Table 5). These standards generally call for minimum lane widths of 10 ft to 12 ft. However, for minor roads, 9-ft lanes are allowed on routes with ADT below 400 vpd and less than 10 percent trucks (*TRB Special Report 214,* 1987). Minimum width shoulders of 2 ft to 3 ft are specified based on various combinations of ADT, design speed, and design trucks.

In *TRB Special Report 214,* the authors modified the 1978 FHWA values based on cost-effectiveness and practicality of

TABLE 1. Minimum width of traveled way and usable shoulder for rural arterials

Design Speed (mph)	Width of Traveled Way (feet)[a]			
	Current ADT Under 400 vpd	Current ADT 400 vpd & Over	DHV 100-200	DHV Over 200
40	22	22	22	24
50	22	24	24	24
60	24	24	24	24
70	24	24	24	24
	Width of Usable Shoulder (feet) on Each Side of Pavement[b]			
All Speeds	4	6	6	8

[a]Width of traveled way may remain at 22 feet on reconstructed highways where alignment and safety records are satisfactory.
[b]Usable shoulders on arterials should be paved.
Source: AASHTO. 1990. *Geometric Design of Highways and Streets.*

TABLE 2. Minimum width of traveled way and graded shoulder for rural collector roads

Design Speed (mph)	Width of Traveled Way (feet)				
	Current ADT Under 400 vpd	Current ADT 400 vpd and Over	DHV 100-200	DHV 200-400	DHV Over 400
20	20	20	20	22	24
30	20	20	20	22	24
40	20	22	22	22	24
50	20	22	22	24	24
60	22	22	22	24	24
70	22	22	22	24	24
	Width of Graded Shoulder——Each Side of Pavement				
All Speeds	2[a]	4	6	8	8

[a]Minimum width is 4 feet if roadside barrier is utilized.
Source: AASHTO. 1990. *Geometric Design of Highways and Streets.*

TABLE 3. Minimum width of traveled way and graded shoulder for rural local roads

Design Speed (mph)	Width of Traveled Way (feet)					
	Current ADT Under 250 vpd	Current ADT 250-400 vpd	Current ADT Over 400 vpd	DHV 100-200	DHV 200-400	DHV Over 400
20	18	20	20	20	22	24
30	18	20	20	20	22	24
40	20	20	22	22	22	24
50	20	20	22	22	24	24
60	20	22	22	22	24	24
	Width of Grade Shoulder——Each Side of Pavement					
All Speeds	2	2	4	6	6	8

Source: AASHTO. 1990. *Geometric Design of Highways and Streets.*

TABLE 4. AASHTO roadway width standards for 3R projects

Average Running Speeds (mph)	Percent Trucks	Minimum Widths (ft)	
		Lane	Shoulder
40 or less	All	10	2
Over 40	15 or less	10	2
	Over 15	11	2

NOTE: The standards specify a range of widths for all cases. Only the minimums are reported here.

TABLE 5. FHWA roadway width standards (1978)

Current Traffic (ADT)	Design Speed (mph)	Width (ft)			
		10 Percent or More Trucks		Less Than 10 Percent Trucks	
		Lanes	Shoulders	Lanes	Shoulders
1-400	50 or less	10	2	9[a]	2
	Over 50	10	2	10	2
401-4,000	50 or less	11	2	10	2
	Over 50	12	3	11	3
Over 4,000	All	12	4	11	4

NOTES: The 1978 FHWA proposed standards were actually defined in terms of lane width and total roadway (lane plus shoulder) width. The standards are shown here in terms of lane and shoulder width so that they can be more easily compared with AASHTO standards. In the actual standard, 11-ft lanes and a 1-ft shoulder are permitted where 10-ft lanes and 2-ft shoulders are specified in the table.
[a]"Minor roads" only; otherwise 10-ft lanes.

Source: Transportation Research Board. *Special Report 214.* 1987.

TABLE 6. FHWA standards revised by TRB

Design Year Volume (ADT)	Average Running Speed (mph)	Width (ft)			
		10 Percent or More Trucks		Less Than 10 Percent Trucks	
		Lanes	Shoulders	Lanes	Shoulders
1-750	Under 50	10	2	9	2
	50 or more	10	2	10	2
751-2,000	Under 50	11	2	10	2
	50 or more	12	3	11	3
Over 2,000	All	12	6	11	6

NOTES: Shoulders may be 1 ft less for highways in mountainous terrain. The standards were actually defined in terms of lane width and total roadway (lane plus shoulder) width. They are given here in terms of lane and shoulder width for easier comparison with AASHTO standards. For the purpose of simplicity, weighted average design speed was used for average running speed in the analysis.

Source: Transportation Research Board. *Special Report 214.* 1987.

use. As given in Table 6, the authors also used ADT, average running speed, and percent trucks as criteria in their suggested guidelines. They further provided for shoulders to be 1 ft less in mountainous terrain than those width values given in Table 5. The revised table (Table 6) eliminated "minor road" as a criterion for 9-ft lanes, and substituted "average running speed" in place of design speed, perhaps because the term "minor road" is vague and design speed was considered difficult to determine for an existing highway. *TRB Special Report 214* also discusses various roadway width standards.

In 1979, Glennon developed minimum roadway width requirements for roads with ADT of 400 vpd and below (*4*). As given

TABLE 7. Glennon roadway width requirements for low-volume roads

Design Speed (mph)[c]	Total Road Width Requirements (ft) [a] [b]			
	Lower % Busses & Trucks (as specified below)		Higher % Busses & Trucks (as specified below)	
	< 28% for 0- 50 ADT < 12% for 51-100 ADT < 7% for 101-200 ADT NA for 201-400 ADT		≥ 28% for 0- 50 ADT ≥ 12% for 51-100 ADT ≥ 7% for 101-200 ADT All% for 201-400 ADT	
	Infrequent Trips by Farm Machinery[d]	Frequent Trips by Farm Machinery[d]	Infrequent Trips by Farm Machinery	Frequent Trips by Farm Machinery
20 mph	18 ft.	22 ft.	20 ft.	24 ft.
25	20	24	22	26
30	20	24	22	26
35	22	24	24	26
40	22	26	24	28
45	26	26	26	28
50	30	30	30	30

[a] 1 ft = .305 m
[b] Widths above 24 ft. (7.3m) include appropriate shoulder widths.
[c] 1 mph = 1.61 kph
[d] The determination of "frequent" and "infrequent" are at the discretion of the designer.

in Table 7, criteria for minimum widths included design speed, percent buses and trucks, ADT groups below 400 vpd, and frequency of use of farm machinery. Recommended minimum widths range from 18 ft to 30 ft. For design speeds of 40 mph or less, higher percentages of buses and trucks require 2 ft of additional width.

A review of such other proposed width standards provides insight into the roadway criteria (e.g., design speed, running speed, ADT, design hourly volume, percent trucks) considered in these standards, as well as the roadway width requirements that are proposed. To date, much of the development of current or proposed width standards has been based on "reasonableness" and, in some cases, partly on expected safety and operational relationships.

This report builds on previous work, focusing on the determination of accident relationships with roadway width on low-volume roads, as well as on other highway operational requirements considered essential to width standards.

BACKGROUND SAFETY RESEARCH

Over the past 20 years, many studies have been conducted concerning the relative safety of various roadway widths. For example, one of the most comprehensive and more recent studies conducted to date on safety effects of roadway width was a 1987 study by Zegeer, et al., for the FHWA (*5*), which involved an analysis of 4,951 miles of two-lane roadway in seven states. Statistical testing was used along with an accident prediction model to determine the expected accident reductions related to various geometric improvements.

Accident types found in the Zegeer, et al. study to be most related to cross-section features included run-off-road, head-on, and sideswipe (same direction and opposite direction) accidents (*5*). The roadway variables found to be associated with a reduced incidence of these related accident types (and included in the predictive model) were wider lanes, wider shoulders (paved shoulders were found to be slightly safer than unpaved shoulders), better roadside condition, flatter terrain, and lower traffic volume. For lane widths between 8 and 12 ft, the predictive accident model showed that related accidents were reduced by 12 percent for 1 ft of lane widening (for example, 10-ft lanes to 11-ft lanes), 23 percent for 2 ft of lane widening, 32 percent for 3 ft of lane widening, and 40 percent for 4 ft of lane widening. The study also modeled the effects of shoulder widening on related accidents for paved and unpaved shoulders. For shoulder widths between 0 and 12 ft, the percent reduction in related accidents resulting from widening paved shoulders was predicted to be 16 percent for 2 ft of widening, 29 percent for 4 ft of widening, and 40 percent for 6 ft of widening. Predicted accident reductions resulting from adding unpaved shoulders were slightly less than reductions for adding paved shoulders (*5*).

Another study that addressed low-volume rural roads was one by Griffin and Mak (*6*), which attempted to quantify the relationship between accident rate and roadway surface width on two-lane rural roads in Texas with ADT of 1,500 vpd or less. Log-linear accident prediction models were developed for 36,215 miles of roadway within several ADT categories. Multivehicle accident rates (accidents per mile 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 between 401 and 1,500 vpd. Accident reduction factors were developed for various widening projects within these ADT ranges. Based on an economic analysis, widening was not found to be cost-beneficial for ADT below 1,000 vpd (*6*).

It is interesting to note that accident reduction factors developed by these two studies for lane widening generally were quite similar. The studies were reviewed in detail along with

approximately 70 other accident studies to better understand such accident relationships (see Appendix B for a complete literature review). Considerable variation in results was observed, however, for some of the older studies. While past research has laid the groundwork for what is currently known on the subject, there is a need to look more closely at accident relationships for low-volume roads (i.e., ADT of 2,000 vpd or less) including paved and unpaved roads, and for roads in a variety of functional classifications (arterial, collector, and local) with varying roadway conditions. Also, there is a need to determine what specific traveled way and shoulder width combinations provide reasonable levels of safety for various conditions.

RESEARCH OBJECTIVE AND SCOPE

The objective of this research was first to develop an engineering analysis procedure that would allow for the determination of optimum roadway widths for construction and reconstruction of low-volume roadways (ADT less than 2,000 vpd). Based on the analysis performed in this effort, recommendations should be developed for "minimum width of traveled way plus shoulder" (for consideration, by the design task force of the AASHTO highway subcommittee on design, for inclusion in future editions of the Green Book).

Thus, this study involved producing two separate, but related, products. One product was a set of design tables specifying minimum width values for lanes and shoulders based on certain roadway factors (e.g., design speed, ADT, roadway classification) to modify and expand the tables now found in the AASHTO Green Book for ADT below 2,000 vpd. These tables should provide suggested minimum lane and shoulder widths for at least three ADT classes below 2,000 vpd.

To produce these numbers, another study output included technical background and a framework for estimating the effects of various roadway widths on safety and operations. This should enable informed judgments by design engineers in applying the research findings to 3R-type problems or in assessing situations where unusual conditions may warrant design exceptions.

The efforts in this study relate to paved or unpaved two-lane rural roads with ADT volumes of 2,000 vpd or less. Functional classifications studied include arterial, collector, and local roadways.

RESEARCH APPROACH

The basic approach to this research involved first reviewing current AASHTO Green Book values on roadway width, as well as other proposed guidelines, and the roadway factors considered to be important in the formulation of such standards. Next, a detailed review of safety literature was conducted to determine what is currently known about accident effects of roadway width and other traffic and roadway features on two-lane rural roads. Safety effects of numerous features, in addition to roadway width, were considered important, because no single data item alone is the sole factor in resulting crashes. Instead, the interaction among several roadway elements, and perhaps driver and vehicle factors, can affect the frequency and severity of accidents.

The literature review revealed that in addition to lane and shoulder width, other factors found to affect safety on two-lane rural roads include shoulder type, roadside slope, roadside obstacles (placement, number, and rigidity), horizontal alignment, vertical alignment, traffic volume (and mix of traffic), narrow bridges, and location of intersections and driveways, among others.

The identification of such safety relationships was useful in developing an accident study plan. For this study plan, it is important to select appropriate variables for data collection. For example, increasing lane width can decrease shoulder area and recovery area if limited right of way is available. If shoulders are widened, roadside slopes may be steepened, possibly leading to more severe crashes. Clearly, the trade-offs that exist from what seems to be a simple and logical increase in lane width must be studied together to determine optimal lane widths from a safety perspective.

Analysis issues identified for this study relate primarily to safety, operational, and cost issues of various roadway widths. To address these issues, existing databases were reviewed to select those that would enable the development of accident relationships with important roadway variables, so that expected accident benefits could be computed for various roadway width alternatives. The primary data source selected was a database of approximately 2,400 miles of two-lane road from seven states (with ADT of 2,000 vpd or below) from previous FHWA studies (*5, 7*). This database was supplemented with data from approximately 1,700 miles of paved and unpaved two-lane roadway (mostly local and collector streets) from North Carolina, Utah, and Michigan, for a total of approximately 4,100 miles. Field data were collected on these supplemental sections, including information on roadside safety, intersections, and driveways, as described later. The resulting database subsequently is termed and referred to as the "primary database."

A detailed statistical analysis was conducted on the primary database, and accident rates were determined for various lane and shoulder widths. To validate and to investigate these relationships further, three independent databases totalling more than 54,000 miles of low-volume, two-lane roads were obtained from three states (Illinois, Minnesota, and North Carolina) and analyzed. A project cost methodology was developed for roadway widening projects for existing roadways and also for comparing roadway width alternatives on new road construction.

Finally, based on the accident analyses results, cost estimates, and other operational considerations, revised width guidelines were developed for new or reconstructed low-volume roads. Guideline also were developed for an evaluation of 3R design problems. Additional evaluations of the operational effects of variable widths were performed. Issues investigated include speed related to lane width; width effects on highway level of service; consideration of wider, larger vehicles; and compatibility with alignment and other design standards and criteria.

CHAPTER 2

STUDY FINDINGS

ANALYSIS ISSUES

The analysis in this study was aimed at determining appropriate design values for roadway width on rural roads carrying less than 2,000 vpd. Accomplishing this objective required quantifying the safety effects of various widths on such roads, and identifying and controlling for other important traffic and roadway variables that, with roadway width, affect accident experience. The results of this accident analysis should be used along with project cost information (for roadway widening), vehicle operations, capacity of roadway designs, and other considerations in the development of appropriate roadway width design values.

Thus, the specific issues addressed in this study include the following: *Issue 1*—What are the characteristics of accidents on low-volume, two-lane roads? *Issue 2*—What accident types are related to roadway width? *Issue 3*—What traffic and roadway variables have a significant effect on accidents on low-volume, two-lane roads? *Issue 4*—What are the relationships between accidents and various combinations of lane and shoulder width for paved, low-volume roads (i.e., roads with ADT below 2,000 vpd)? *Issue 5*—How are accident frequencies and severities affected by having a paved road surface versus an unpaved road surface? *Issue 6*—How does the presence of trucks influence operations and safety for various roadway widths on low-volume roads? *Issue 7*—What are the expected accident benefits (i.e., accident reduction factors) on low-volume roads for various amounts of roadway widening as a function of ADT groups, percent trucks, vehicle speed, and other roadway features?

In addition to safety, other operational and design requirements should play a role in the formulation of width standards. Issues 8 through 14 address these additional requirements, as well as the manner in which all inputs are used to develop appropriate width-related standards: *Issue 8*—How do roadway width combinations influence capacity and level of service on low-volume roads? *Issue 9*—How does vehicle speed (i.e., design speed versus running speed) influence accidents and vehicle operations on different roadway widths for low-volume roads? *Issue 10*—What are the width-related operational requirements for shoulders on low-volume roads? *Issue 11*—What are the width-related operational effects of wide trucks? *Issue 12*—What are the construction and maintenance costs associated with roadway widening in different terrain and for other conditions? *Issue 13*—What roadway widths are most cost-effective relative to expected safety benefits on low-volume roads? *Issue 14*—What combinations of lane width and shoulder width are appropriate for design standards for low-volume roads?

ANALYSIS OF HIGHWAY SAFETY ISSUES

The data analysis was structured to address the safety-related issues listed previously, and an appropriate database was developed for use in statistical testing. Then, appropriate analyses were conducted to quantify safety consequences of roadway width and other roadway features. Details of these topics are discussed next.

Development of the Primary Accident and Roadway Database

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. One 1978 study, for example, estimated that at least 50 roadway-related features could have an effect on accidents (*8*). Note, however, in typical accident analyses, there are often relatively few important traffic and roadway variables that show individually significant relationships with accidents.

Needed Roadway and Traffic Variables

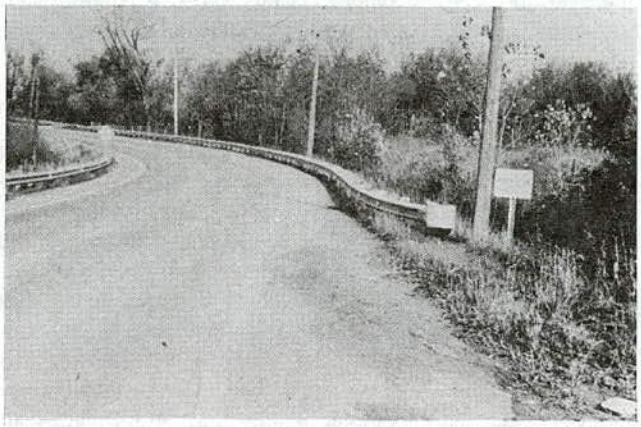
On the basis of their relationships to accidents developed in past research, the traffic and roadway variables selected for data collection included section information (section identification and length); pavement type (paved or unpaved); lane width, shoulder width, and type of shoulder (i.e., paved, gravel, or earth); terrain; type of area and development; design speed; functional roadway class; number of driveways (per mile); number of intersections (per mile); percent trucks; speed limit; average annual daily traffic (AADT); horizontal alignment (i.e., percent of the section with curvature greater than 2.5 deg.); vertical alignment (i.e., the percent of the section with grade greater than 2.5 percent); sideslope 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 discussion 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. (*5*) on two-lane rural roads, and were both found to have a significant relationship to accidents. The researchers developed a seven-point roadside hazard scale based on a literature review and on the results of a workshop involving highway and roadside safety professionals. The roadside hazard rating developed for the study was a subjective

Roadside hazard rating of 1

Roadside hazard rating of 2

Roadside hazard rating of 3



Roadside hazard rating of 4

Figure 2(a). Sample photographs of the roadside hazard scale: hazard ratings 1, 2, 3, and 4.

measure of the hazard associated with the roadside environment. The rating values indicated the accident likelihood and damage severity expected to be sustained by errant vehicles on a scale from one (low likelihood of an off-roadway collision or overturn) to seven (high likelihood of an accident resulting in a fatality or severe injury).

The ratings for the roadside hazard rating used in this study are based on a seven-point pictorial scale for rural highways (see Figures 2(a) and 2(b)). The data collectors chose the rating value (one through seven) that most closely matched the roadside hazard level for the roadway section in question. In many cases, the roadside hazard along a section varied considerably, so that an "average" value was selected to represent the general roadside hazard rating of that section. For example, if ratings generally range from four to six along a section, a rating of five was chosen to represent the roadside hazard rating of the section.

In addition to the subjective roadside hazard rating, a measure termed "roadside recovery distance" also was determined for each section along with detailed data on the number of roadside obstacles by type and distance from the roadway. Although this measure is relatively similar to a "clear zone" definition, 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, which is the closest lateral distance to trees, utility poles, culvert headwall, bridge rail, steep slope (i.e., 3:1 or steeper), and so forth. Thus, like the "roadside rating," the roadside recovery distance basically measures the degree of "forgiveness" of the roadside.

Note that the foregoing list of variables includes measures of lane and shoulder width and shoulder type, which are of primary concern in the development of roadway width values. Also included are other variables currently included in AASHTO width values, such as functional class, design speed, and traffic volume (ADT). The list also contains other important variables that research has shown to affect accidents on two-lane roads, such as horizontal and vertical alignment, roadside conditions, number of intersections and driveways, and others. These other important variables must be included in the accident analysis and predictive models to obtain a more accurate assessment of the true effects of roadway width on accidents.

Needed Accident Variables

Although many 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

Roadside hazard rating of 5

Roadside hazard rating of 6

Roadside hazard rating of 7

Figure 2(b). Sample photographs of the roadside hazard scale: hazard ratings 5, 6, and 7.

of accidents on the section; number of accidents by severity (property-damage only, A-injury, B-injury, C-injury, and fatal); number of people killed; number of crashes by light condition (daylight or darkness); number of accidents by pavement condition (dry, wet, or icy); and number of crashes by type (fixed object, rollover, other run-off-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).

Sample Size Requirements

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 database allows a comparison of the accident experience associated with different roadway widths, paved versus unpaved roadway surfaces, and so on. Ideally, each roadway section should be of sufficient length to allow for calculation of accident rates in terms of accidents per million vehicle miles (accidents per MVM). Section lengths of one mile or greater were chosen to help ensure data stability because very short sections can yield unstable accident rates. Note that even with these longer section lengths, many of the low-volume sections would have zero accidents in a given 5-year time 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 approximately 2,500 miles to 3,000 miles would be adequate. Ultimately, a sample of 4,137 miles was chosen for use in the primary analysis. Independent samples of roadway sections also were used to validate these accident relationships, as discussed later.

Selection of the Database

The criteria used for selecting and developing a database for the analysis were as follows: *Criterion 1*—The database should consist of roadway sections that can be merged with corresponding traffic and accident data. *Criterion 2*—The database should have a substantial sample of unpaved as well as paved roads, and all sections should have ADT below 2,000 vpd; also, a wide range of roadway widths was needed to fulfill the sampling

requirements. *Criterion 3*—The accident data should be of good quality in terms of location accuracy, with a reasonably low reporting threshold. *Criterion 4*—Accurate computerized data should be available for lane width, shoulder width, ADT, terrain, and other needed roadway variables; also, data on percent trucks and design speed should be available or be easy to obtain.

A detailed review was made of several existing databases on rural two-lane roads, including those developed for national safety research studies (i.e., FHWA safety research), as well as available computer databases from many state highway agencies and transportation departments. No single database was sufficient by itself for the purposes of this analysis. Thus, several databases were obtained and were supplemented with field and other data collection for this analysis.

The bulk of the data came from the database on two-lane rural roads developed for the Transportation Research Board (TRB) and FHWA in the study, "Safety Effects of Cross-Section Design for Two-Lane Roads" (*5*). The database developed for this earlier effort is perhaps the most complete multistate database on two-lane roads, in terms of roadway section representation, the amount of data sampled (4,137 miles of two-lane roadway sections in seven states), and the wide variety of accident, traffic, roadway, and roadside variables for which data were collected.

The FHWA database consists of a large sample of mileage 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, which are not available from standard state accident or roadway inventory files, were those related to sideslope and roadside hazard. Such variables not only are important in assessing safety on two-lane roads, but they also are expensive and time-consuming to collect.

While the cross-section data file provided a valuable source for the required analysis file, it alone was not sufficient. The analysis in the current study is concerned only with two-lane roads with 2,000 vpd or less, and the FHWA cross-section database provided only approximately 2,700 miles of the 4,137-mile sample in this lower ADT range. Also, it had no samples of unpaved roads, and inadequate samples of roads with "local" functional class and within a very low ADT range (particularly ADT below 750 vpd). Thus, other data sources were needed to fill these gaps.

Three state/local databases were selected to supplement the cross-section database: State of North Carolina, State of Utah, and Oakland County (Michigan) database.

Each of these databases contained a substantial sample of unpaved and low-volume sections with "mergeable" data files and good-quality data. They also contained many of the needed roadway, accident, and traffic data variables. These three states also had provided data to the FHWA cross-section database.

Selection of additional sections in three of the seven "cross-section" states prevented additional state biases to be introduced from different state reporting thresholds, state coding practices, or other factors. The wide variety of climate, driver characteristics, roadway design practices, and other factors contained within the seven states were considered to ensure a diverse sample of roadway and traffic conditions.

Within the three supplemental computerized databases, roadway sections were selected as needed to fill the data "gaps." This resulted in sample sizes for the primary database, as shown in Table 8. The primary database contained 1,277 roadway sections with a total of 4,137 miles, including 556 miles of unpaved and 3,581 miles of paved roads. The average section length was 3.24 miles.

The selected roadway sections from the four databases contained many, but not all, of the needed data variables. Therefore, field surveys were conducted on all of the supplemental sections in Michigan, Utah, and North Carolina to obtain data on roadside condition (i.e., roadside hazard rating and roadside recovery distance), the number of driveways and intersections, and the width and type of pavement and shoulder. Also, for these sections, state and local files and records were used to obtain data on ADT, percent trucks (where available), speed limit, and accident data. For the seven-state cross-section database, state files also were used to obtain functional class and percent trucks and speed limit. However, design speed data were only available for sections in Montana.

In summary, a computer data file consisting of 4,137 miles, which was created as described in the foregoing, represented the "primary database" used for developing accident relationships with roadway width and other variables. Three other independent state databases also were selected to validate the accident relationships found with the primary database. These included computerized databases from Illinois, Minnesota, and North Carolina (mileage in North Carolina excluded sections used for the primary database for analysis and model building). These three validation databases did not contain roadside data, number of driveways and intersections, and some other variables that were contained in the primary database; however, they did contain ADT, accident data, width and type of pavement and shoulder, and many other valuable variables.

The validation databases were analyzed separately in detail, and their accident relationships were compared to those of the primary database as discussed later.

Sample sizes of the validation databases were 3,791 miles in Illinois, 36,247 miles in Minnesota, and 14,134 miles in North Carolina. A substantial sample of unpaved roads was available from Minnesota (11,948) with a lesser amount from North Carolina (455 miles). Thus, a total of 58,309 miles of roadway was analyzed, which included 21,827 total sections. The primary database contained numerous detailed roadway variables (i.e., roadside data and number of intersections and driveways) not available on the validation databases.

Statistical Testing and Results

The data analysis focused on addressing each of the analysis issues listed earlier. The results are summarized in the following discussion. More details of analysis activities are given in Appendix C.

Issue 1—Characteristics of Accidents on Low-Volume Roads

The total sample of accidents that occurred on the primary sections in a 5-year period is given in Table 9, along with accident summaries by type, severity, light conditions, and pavement conditions. A total of 14,888 accidents was noted on the 4,137.19-mile primary database, which included 8,973 property-damage-only accidents (60.3 percent of the total); 5,632 nonfatal injury

TABLE 8. Summary of sample sizes for primary and validation databases

Database	Number of Miles			Number of Sections		
	Paved	Unpaved	Totals	Paved	Unpaved	Totals
Primary	3,581.05	556.14	4,137.19	1,113	164	1,277
Illinois (Validation)	3,790.86	0	3,790.86	1,795	0	1,795
Minnesota (Validation)	24,298.92	11,948.58	36,247.50	8,911	4,900	13,811
North Carolina (Validation)	13,678.30	455.40	14,133.70	4,708	236	4,944
Totals	45,349.13	12,960.12	58,309.25	16,527	5,300	21,827

TABLE 9. 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[a]	8,768	N/A	37,321	N/A
Fatalities[a]	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
ROR - Fixed Object	4,017	27.0	12,091	19.3
ROR - Rollover	1,999	13.4	4,245	6.8
ROR - 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

[a]The data for these variables represent the number of people injured or killed, and not the number of accidents.
N/A = Not Applicable.
ROR = Run-off-Road.

accidents (37.8 percent); and 283 fatal accidents (1.9 percent). A total of 8,768 people were injured and 328 people were killed in these 14,888 accidents. A comparison was made of the percentage of crashes by severity between the 4,137 miles of low-volume roads versus the full sample of 4,785 miles of rural two-lane roads in the database from the earlier FHWA study (with a full range of ADT). The sample of low-volume roads had a slightly higher percentage of injury accidents (37.8 versus 36.6

percent) and fatal accidents (1.9 versus 1.4 percent) than the full sample.

Similar comparisons also were made between low-volume roads and the full cross-section rural sample for other accident variables, as shown in Table 8. Both samples showed high percentages of accidents when no roadway lighting was present; low-volume roads had a higher percent of nighttime, no-lighting accidents than the higher volume, cross-section sample (39.0 versus 31.1 percent). The greater difficulty in driving on low-volume roads at night, because there are fewer opportunities for "caravaning," could have contributed to this result. Also, there may typically be a reduced level of nighttime visibility on low-volume roads associated with less delineation and less-frequent overhead lighting compared to higher volume roadway sections. The low-volume sample also showed a slightly higher proportion of snow and ice accidents than the full rural sample (13.1 versus 10.6 percent), possibly because of better snow removal operations on higher volume routes.

In terms of accident types, low-volume roads have a greater percentage of fixed-object crashes (27.0 versus 19.3 percent), rollover crashes (13.4 versus 6.8 percent), and other run-off-road crashes (15.4 versus 4.5 percent) than the full sample of rural roads. This may be expected because there are fewer other vehicles to strike on low-volume roads than on higher volume routes. Conversely, the data showed a lower percentage of crashes involving rear-end collisions and angle and turning collisions for low-volume roads (6.0 versus 19.8 percent and 11.9 versus 23.5 percent, respectively).

The average accident rate for the total primary database was 3.47 accidents per MVM; the rates for paved sections and unpaved sections were 2.86 and 7.59 accidents per MVM, respectively. The average number of accidents per mile per year was 0.79 for the total sample, and was somewhat higher for paved sections (0.84) than for unpaved sections (0.69), due to higher traffic volumes on paved roads than on unpaved roads (and, consequently, a greater number of opportunities for crashes).

Issue 2—Determining Related Accident Types

The next analysis issue concerned the identification of specific accident types that are related to roadway width. This issue is important in that wider roadways may logically be expected to reduce some accident types (head-on or run-off-road crashes) but not necessarily others (rear-end or angle). For example, if widening lanes on low-volume, two-lane roads does not affect rear-end collisions, the rear-end accident type should be excluded before developing relationships between accidents and roadway width.

The following accident types were considered in the investigation of what types may be related to roadway width: single-vehicle accidents (fixed-object, rollover, and other run-off-road); opposite-direction accidents (head-on and opposite-direction sideswipe); angle accidents (vehicles on the main roadway striking at an angle with turning vehicles or vehicles from driveways or intersections); same-direction accidents (sideswipe and rear-end); and other accident types (vehicle strikes pedestrian, bicycle, animal, or train; backing or parking collisions; and others). All accident rates for each accident type were expressed in terms of accidents per MVM.

Analysis of covariance accident models was used to identify accident types that are associated or related significantly to roadway width. The independent roadway variables used in the analysis were lane width, shoulder width, terrain, and roadside hazard rating.

Accident rates were found to be associated significantly with varying lane and shoulder widths for single-vehicle accidents and opposite-direction accidents. Rates of other accident types were found to not be significantly related to lane or shoulder width. These findings agree closely with the 1987 study by Zegeer et al. of rural, two-lane roads—that is, all ADT ranges in that study, not just for ADT of 2,000 vpd or below (*5*). 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.

In virtually all of the remaining analyses, single-vehicle and opposite-direction accidents were combined and were referred to as "related accidents." To investigate accident severity questions, certain types of injury accident rates (for all injury accidents on a section) also were analyzed.

Issue 3—Important Traffic and Roadway Variables

The next issue involved identifying what traffic and roadway variables have a significant effect on accidents for low-volume, two-lane roads. This question was important for two major reasons.

First, correctly quantifying the accident effect of roadway width requires that all other important traffic and roadway variables (confounding variables) also be accounted for or controlled. For example, assume that wider roadways and safer roadsides are both associated with lower accident rates. Also assume that wider roadways (higher class roads) typically have safer roadsides as well. If one simply tries to find the relationship between roadway width and accidents without controlling for roadside condition, the results will show an exaggerated, erroneous effect. In other words, the computed accident benefit of wider roadways would, in fact, be the combined accident benefit of wider roads plus better roadsides. Thus, the effect of roadside hazard (or other important traffic and roadway variables) must be accounted for in the analysis to provide an accurate indication of roadway width effects on accidents.

The second reason for determining effects of other roadway variables (besides roadway width) on accidents is to gain a better understanding of how safety can be improved on low-volume rural roads. For example, it would be important to know that roadside hazard, horizontal alignment, or other roadway features affect accidents, in addition to roadway width. This would allow engineers and designers to have more justification for considering improvements to roadsides (i.e., cutting trees near the road, flattening steep slopes), improving horizontal curves (i.e., improving superelevation), and other improving roadway features on low-volume, two-lane roads in addition to (or instead of) roadway widening (i.e., as a part of 3R or major reconstruction improvements).

The traffic and roadway variables found to be significantly related to the rate of "related" accidents (i.e., rate of single-vehicle plus opposite-direction accidents) included lane and shoulder width (or total roadway width); roadside hazard rating and roadside recovery distance (which were essentially inter-

changeable, with only one being used in a particular analysis); number of driveways per mile; terrain, with values of 1 for flat, 2 for rolling, and 3 for mountainous terrain; and state—which consists of three discrete values representing the following three groups of states (states within a group were similar with respect to related accident rate): (1) Alabama, Montana, and Washington; (2) North Carolina and Michigan; and (3) Utah and West Virginia.

Variables for percent grade and curvature were not considered for further analysis because they were available for only about half of the study sections. The terrain variable was significant and served as a general measure of alignment for use as a control variable.

Variables that were not found to be associated significantly with accidents on low-volume roads were intersections per mile (i.e., most sections had no major intersections), speed limit (i.e., most sections had 55-mph speed limits whether posted or not, regardless of the alignment or design speed), and percent trucks (i.e., very few of the sections had a substantial volume of heavy trucks). 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). Thus, the accident effect of functional class actually resulted from state and width effects.

It is also interesting to note that shoulder type (paved versus unpaved shoulders) was not found to affect accidents significantly on low-volume roads. The 1987 study by Zegeer, et al., did find a small (generally less than 10 percent) but significant accident reduction from paved shoulders compared to unpaved shoulders on higher volume, two-lane roads. These two seemingly different findings may actually be explainable for several reasons. First, because higher volume roads (i.e., typically higher class) tend to carry more of the heavy truck traffic than lower volume roads, paved shoulders would logically be more beneficial on higher volume roads to handle truck encroachments over the edgeline. Also, because higher volume roads typically have better alignment and, subsequently, higher speeds than lower volume roads, paved shoulders may be particularly beneficial to assist higher speed vehicles that run over the roadway edge. It is also interesting that AASHTO criteria for roadway width specify paved shoulders for higher class roadways (typically higher volume), but allow unpaved shoulders on lower class roads (typically lower volume).

In summary, the results of these analyses indicate that accidents on low-volume roads are affected primarily by roadway width, roadside hazard, roadway terrain (i.e., alignment), and the number of driveways per mile.

All of these roadways features should be considered for possible improvement, as needed, in conjunction with 3R or major reconstruction projects. State differences also can affect accident rates, perhaps because of accident reporting differences, driver differences, weather differences, roadway maintenance practices, or other differences.

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

A detailed analysis was conducted on the primary database to quantify the relationships between lane and shoulder width and accidents. An analysis of covariance models was used to estimate rates of related accidents as a function of lane and shoulder width, while adjusting for roadside hazard rating, terrain, state, and driveways per mile. The following discussion of lane and shoulder effects pertains to paved roads only, where shoulders are either paved or unpaved. The lane and shoulder width refer to average width on one side of the road. For example, a shoulder width of 6 ft refers to a 6-ft shoulder on each side of the road. Because shoulder type was not found to affect accident rate significantly on low-volume roads, shoulder width as used in these analyses corresponds to the total width of each shoulder, regardless of the shoulder type.

The results revealed that lane and shoulder width each has a significant effect on related accident rate. The lane width categories used were 8 ft or less, 9 ft, 10 ft, 11 ft, 12 ft, and 13 ft or more. Shoulder widths were combined into five categories: 0 ft, 1 to 2 ft, 3 to 4 ft, 5 to 6 ft, and greater than 6 ft. Some analyses were conducted for various combinations of lane and shoulder width, termed "total roadway width."

Two separate models were developed for related accident rate by total roadway width, as shown in Figure 3. Model I represents the estimated rate of related accidents for various widths of roadway (lanes plus shoulders) while controlling for state and terrain as class variables, and roadside recovery distance and number of driveways per mile as continuous variables. For Model II, state and two levels of functional class (local versus all others) were taken as class variables, while terrain, roadside hazard rating, and driveways per mile were included as continuous variables. Note that both models have the same general shape for related accident rate by roadway width. Also, the rate of related accidents tends to decrease as roadway widths increase from 20 ft to 32 ft for both models. However, the rate for the most narrow roadway widths of 18 ft or less was much lower than that for most wider roadways. Also, no clear accident reduction was found for roadway widths greater than 32 ft.

The adjusted rate of related accidents was next determined for various categories of roadway width, as shown in Figure 4. The rate for roadways of 18 ft or less was 1.43 compared to 1.90 for 19-ft to 24-ft roads, 1.41 for widths of 29 ft to 39 ft, and 1.10 for greater than 40-ft roadway widths.

Next, accident relationships (rates of related accidents) were determined for various categories of lane and shoulder widths. Lane and shoulder width groupings were determined on the basis of available sample sizes and by considering where significant accident differences exist. The resulting rates are shown in Figure 5. Lane widths of 8 ft and 9 ft were grouped together for all shoulder widths, and the resulting accident rate was 1.66. This was lower than the rate for 10-ft lanes with narrow (zero to 4 ft) shoulders, which had a rate of 2.41. Related accidents per MVM for wider shoulders (greater than 5 ft) with 10-ft lanes resulted in a rate of 1.43. Note that the sample size of 8-ft lane widths was very small in the primary database. Further review of accident rates from several validation databases was helpful, as discussed next.

No significant difference was found between 11-ft and 12-ft lane widths; therefore, these lane widths were grouped together. Rates of related accidents on 11-ft or 12-ft lanes were 1.87 for narrow (2 ft or less) shoulders and 1.31 for wide (3 ft or greater) shoulders. Lane widths of 13 ft resulted in rates of 1.57 for narrow (0 to 4 ft) shoulders and 0.76 for wider (5 ft or greater) shoulders.

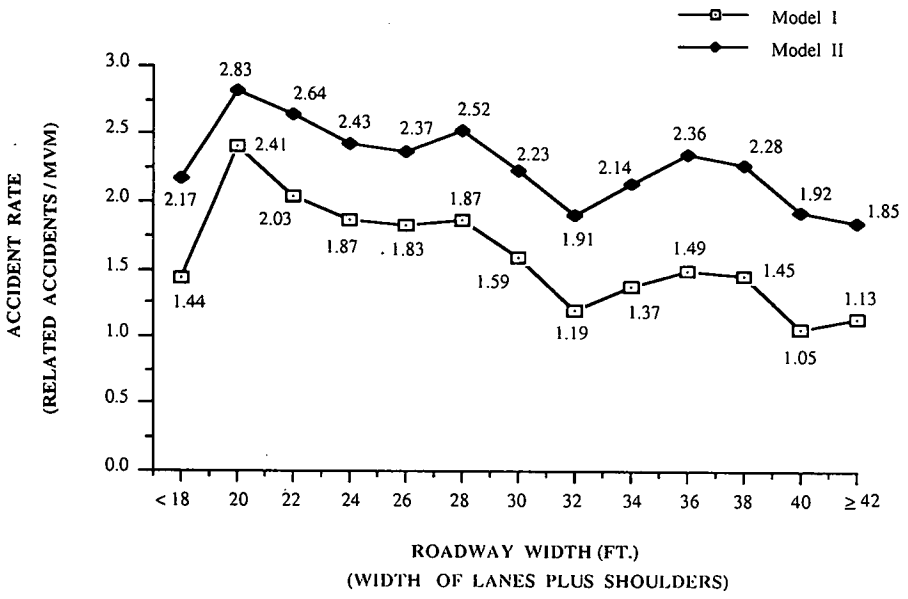


Figure 3. Accident rates by roadway width from two different models.

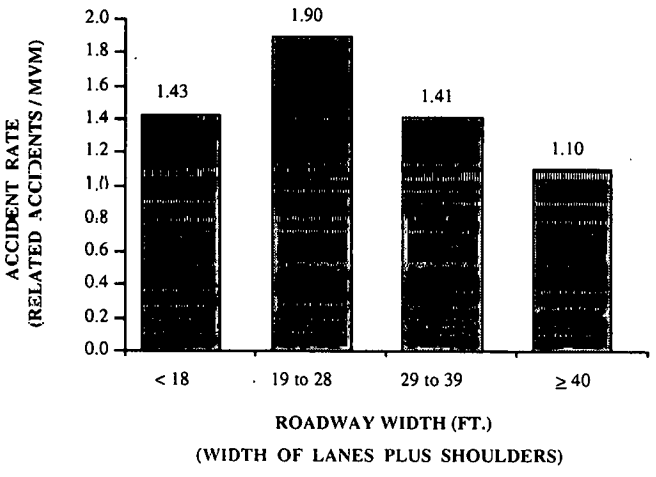


Figure 4. Least-squares mean accident rates by roadway widths.

Note that different width values were used for narrow and wide shoulders, depending on specific lane width categories. This is because shoulder width categories were determined based on actual accident rate differences. Selecting uniform shoulder width categories (e.g., 0 to 4 ft = narrow, 5 ft or greater = wide) for all lane width categories would be subjective in nature and would not reflect where actual differences occur.

Validation of Analyses Results. In terms of lane width effects, the analysis revealed that 10-ft lane widths with narrow or no shoulders have higher accident rates than 9-ft lane widths on low-volume roads with any shoulder width. The 8-ft lane widths showed similar low rates as 9-ft lane widths, although the sample sizes were smaller. Further, for sections with 0- to 4-ft shoulders, accident rates are significantly lower for 11-ft and 12-ft lanes than they are for 10-ft lanes, with only a slight accident reduction for lanes of 13 ft or wider.

The lower accident rate for roadways with 8-ft and 9-ft lanes was unexpected, open to question, and thus warranted further investigation using other independent databases. These investigations included a similar analysis of related accident rates by lane and shoulder width categories using "validation" databases of paved, low-volume roads from three states—Illinois (3,791 miles), Minnesota (24,299 miles), and North Carolina (13,678 miles).

Illinois data showed trends in accident rates similar to the primary database, by lane and shoulder width, for lane widths of 9 ft to 13 ft or greater. Lower accident rates were found for 9-ft lane widths (all shoulder widths) compared to 10-ft lanes with narrow shoulders (rates of 1.13 versus 2.03 accidents per MVM, respectively). However, 8-ft lane widths in the Illinois database had a much higher rate (3.57 accidents per MVM) than other lane width categories. Accident rates then decreased for roads with lane widths (narrow shoulders) greater than 10 ft.

The results of the Minnesota analysis revealed trends similar to those noted for the Illinois data. Again, rates of related accidents were highest (2.32 accidents per MVM) for 8-ft lane widths (for all shoulder widths), dropped to 0.85 for 9-ft lanes, and increased to 1.03 for 10-ft lanes with narrow shoulders. The accident rate again dropped for lane widths of 11 ft (0.67 accidents per MVM) with narrow shoulders, with no further decrease in rate for lane widths of 12 ft to 13 ft. Again, for a given lane width, wider shoulders were associated with reduced accident experience.

The North Carolina data showed rates of related accidents to be constant for lane widths of 8 ft or less (1.95 accidents per MVM) and 9 ft (1.94 accidents per MVM). The rate then dropped to 1.73 for 10-ft lane widths, and to 1.69 for 11-ft and 12-ft lane widths. Shoulder widths of 5 ft or greater were associated with reduced accident rates.

Discussion of Results. The results from the analysis of the

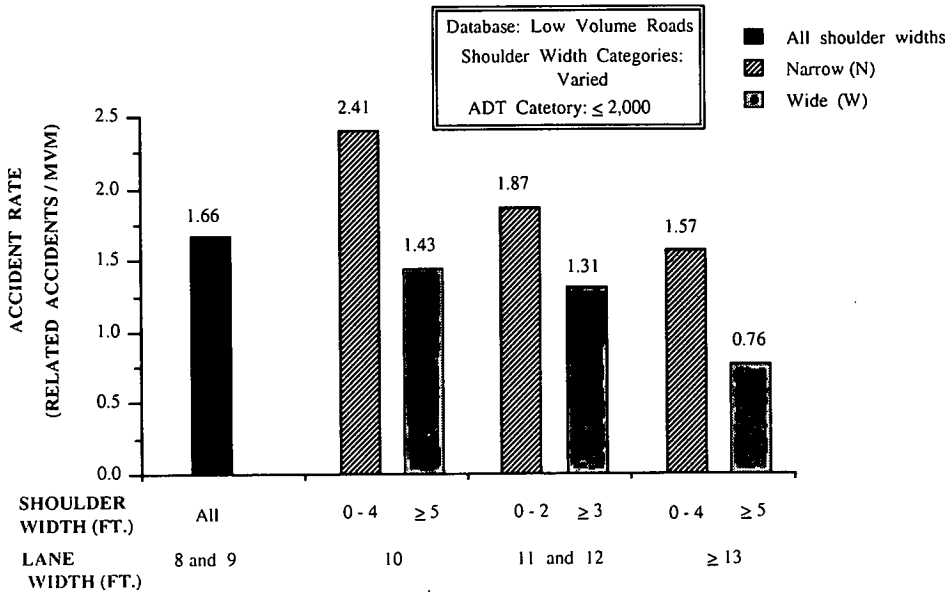


Figure 5. Rates of related accidents by lane and shoulder width from the low-volume roads database.

primary and validation databases have several important implications concerning safety effects of various lane and shoulder widths. First, based on the primary database, the presence of a shoulder is associated with a significant accident reduction for various lane width categories, particularly for shoulder widths of at least 3 ft to 4 ft. This was found to be true for lane widths of between 10 ft and 13 ft or greater. For 10-ft lanes, a shoulder of 5 ft or greater appears to be needed to affect accident rate significantly. For 11-ft and 12-ft lane widths, shoulders of 3 ft or greater have significantly beneficial effects. For lane widths of 8 ft and 9 ft, the shoulder width relationship is less clear. An inadequate sample of 8-ft lane widths was available within the primary database. Eight-foot lane widths were, therefore, combined with those of 9 ft for analysis purposes. Because the overall sample of 9-ft lanes and narrow shoulders had a lower accident rate than the 10-ft lanes, it may be concluded that roads with 9-ft lane widths also may contain narrow shoulders.

With respect to lane width, two of the three validation databases (Illinois and Minnesota) support the finding of a reduced accident rate for 9-ft lane widths compared to 10-ft lanes with narrow shoulders. However, these two databases differ from the primary database analysis in the findings for 8-ft and 9-ft and wider lane widths, for which the 8-ft lane widths had substantially higher rates. Inasmuch as the primary database had a very low sample of 8-ft lanes (83 miles), the low rate is not considered reliable. Also, the primary database and the same two validation databases both show that 11-ft lane widths have substantially lower accident rates compared to 10-ft lane widths, particularly where narrow shoulders exist. It is also clear from those databases that little, if any, real accident benefit can be gained from having lane widths wider than 11 ft on low-volume roads.

The North Carolina database revealed some similar trends, but also some conflicting trends. For example, North Carolina data supported the finding of all other databases 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 databases. However, only the North Carolina database did not show an accident rate lower for 9-ft lane widths than for 10-ft lane widths, including adjustments for shoulder width.

The effects of lane width on accident experience using the four databases (the primary database plus the three state validation databases) were compared with the findings from the 1987 FHWA study by Zegeer, et al., of two-lane rural roads (all ADT ranges). The results in that 1987 study used a mathematical model that indicated a "smoothed" relationship of reduced accident experience for wider lanes (for lane widths between 8 ft and 12 ft) and shoulders. This model resulted in an assumed reduction of 12 percent in related accidents for 1 ft of widening between 8 ft and 12 ft. However, a more in-depth analysis of the four low-volume roads databases indicates that high accident rates exist for roads with 8-ft lanes from the Illinois and Minnesota databases. Note that the sample size of paved 8-ft lanes is small (43 miles) for these two States. The low-volume databases also show that accident rates level off at a lane width of 11 ft, with little additional reduction for lanes of 12 ft or greater (primary and validation databases). Also, the low-volume databases show that 10-ft lanes with narrow or no shoulders produce accident rates that are higher than rates for 9-ft lanes with the range of shoulder widths. Although the 1987 study did not show this finding, the study did confirm the safety benefits of wider shoulders (with regard to accidents).

The analysis results of these four low-volume databases generally agree with engineering intuition. Wider shoulders logically result in reduced accident rates because drivers have more room to recover after encroaching over the edgeline. Lanes of 11 ft or wider produce lower accident rates than 10-ft lanes, which is again intuitively expected. The fact that 12-ft and 13-ft lanes appear to offer minimal accident reduction compared to 11-ft lanes on low-volume roads agrees with results of a 1979 study

by Zegeer et al. (*9*) of over 10,000 miles of rural, two-lane roads in Kentucky.

The main issue in question concerns the lower calculated accident rates for roadways with 9-ft lanes compared to those with 10-ft lanes. There are two possible explanations for this counter-intuitive finding. First, speeds on these narrower roadways may be lower, reflecting not only the width effect of speed, but also 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 this study.) Roadways with 10-ft lanes are commonly found on higher class facilities, which tend to operate at higher speeds.

A second possible explanation also is related to functional class. It may be that many of the roadways with 9-ft lanes are of the local, very low-volume nature (i.e., with ADT of 200 vpd or less). Nominal traffic volume data for such roads could be more variable and less reliable than for the rest of the study sample.

Accident rate trends for roadways with 8-ft lanes are not entirely clear. There is an indication from two databases (Illinois and Minnesota) that 8-ft lane widths are associated with considerably higher rates than lane widths of 9 ft or 10 ft. This finding, however, is based on a small sample of 8-ft lane widths in those States. Two other databases (primary and North Carolina) show the rate on 8-ft lanes to be similar to the rate for 9-ft lanes. The primary database, however, contained only a small sample of 8-ft lane widths and, therefore, was not considered very reliable. The true effect of these "very narrow" lane widths (8-ft or less) probably relates to many factors, such as volume of nonlocal and truck traffic, roadway alignment, roadside conditions, presence of roadway delineation, and so on. These factors could not be explored any further with the primary database.

In any case, the analysis results would tend to support the continued use of 9-ft lanes on some roadways that have acceptable accident rates. It appears that widening an existing roadway with 9-ft lanes to provide 10-ft lanes can not be expected to improve its safety, unless such widening is accompanied by a shoulder width of at least 5 ft. Widening lanes from 10 ft or less (particularly those that have little or no shoulders) to 11 ft plus greater than 3-ft shoulders appears effective in terms of expected reduced accident rates.

Issue 5—Paved Versus Unpaved Road Surface

The next question involved comparing accident experience on low-volume roads for paved versus unpaved roadway surfaces. From the primary database, rates of related accidents were compared between paved and unpaved sections from the same three states where both types of sections were available (Michigan, Utah, and North Carolina). 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.

Accident rates were found to be greater for more severe terrain. Roads in mountainous terrain had greater rates than those in rolling terrain, all other variables being held constant or controlled. Similarly, roads in rolling terrain had greater accident rates than those in flat terrain. The analysis also showed that

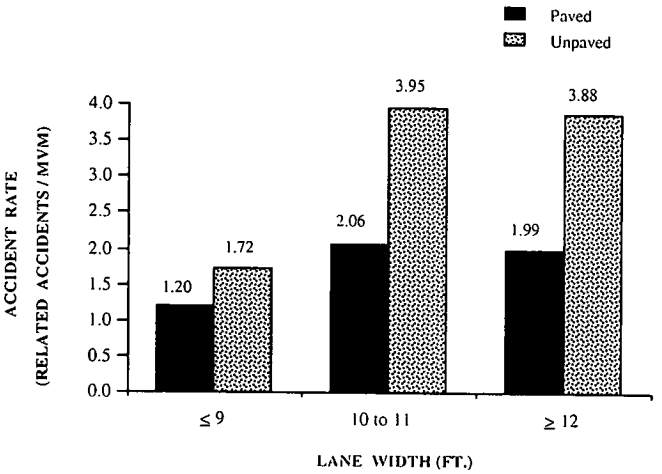


Figure 6. Rate of related accidents for paved versus unpaved roads by lane width.

rates were higher for roads with less roadside recovery distance, and with more narrow roadway widths.

For each of three lane width categories (less than 9 ft, 10 ft to 11 ft, and 12 ft or greater), unpaved roads had higher rates of related accidents than paved roads (see Figure 6). This was also true using rate of injury accidents.

A separate comparison of various lane and shoulder widths also was made using the rate of total injury accidents (where all accident types were included involving an injury or death, not just "related" accident types). Models were fit to three types of injury rates, including total injury accidents per MVM (i.e., injury rate), accidents resulting in K, A, or B injuries per MVM (i.e., KAB rate), and accidents involving K or A injuries per MVM (i.e., KA rate). The original 29 lane and shoulder width categories were used in the model along with state, terrain, clear recovery distance, and driveways per mile.

The pattern found in the variation of injury rates across lane and shoulder width categories was similar to the pattern noted for rate of related accidents. This similarity suggests that lane and shoulder width do not affect the distribution of accident severity. This result may be because narrow low-volume roads may have basically the same type of accidents as wider low-volume roads (primarily fixed-object, rollover, head-on), even though a higher rate of these accident types occurs for some of the more narrow width categories (particularly 10-ft lane widths with narrow shoulders). This would explain the fact that roadway width has a similar effect on rate of related accidents and rate of injury accidents.

Next, a comparison was made between paved and unpaved roadways for various ADT categories to determine the levels of traffic at which paved surfaces were most beneficial. Rates of related accidents were computed for paved and unpaved roadways for three ADT groups: ADT less than 250 vpd, ADT between 250 and 400 vpd, and ADT greater than 400 vpd. Again, adjustments were made for important roadway variables. On roadways with ADT less than 250 vpd, accident rates did not differ significantly between paved and unpaved roads. However, for ADT above 250 vpd, rates for unpaved roads were significantly higher than for unpaved roads. Note that the top ADT

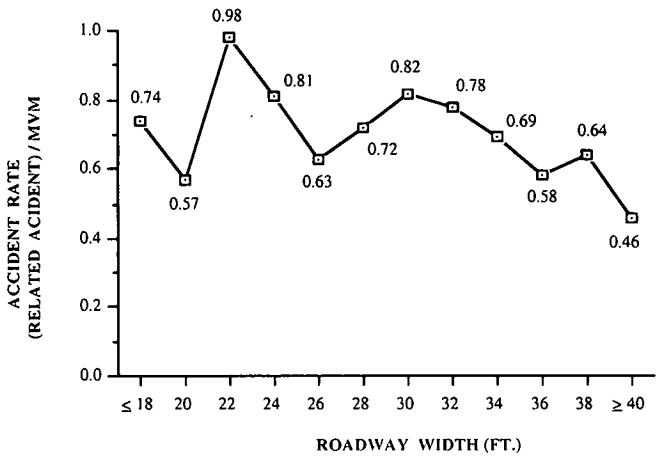


Figure 7. Relationship between accident rate and total roadway width for unpaved roads in Minnesota.

groups (between 250 and 400 vpd, and greater than 400 vpd) had to be combined because of small sample sizes in the greater than 400 vpd ADT group.

The results of this analysis from the primary database provide some indication that roadways with ADT above 250 vpd should be paved to provide reduced accident experience. However, to confirm this result, data from Minnesota also were used to compare the effect of pavement type (paved versus unpaved). This analysis made use of a large sample of paved (24,300 miles) and unpaved (11,900 miles) roads. The results, however, showed no significant effects of pavement on accident rate (p-value of 0.3980).

Another question concerned how total roadway width on unpaved roads affects accidents. Using the unpaved road samples from only the primary database, rates of related accidents were much lower on roadways with a total width of less than 18 ft (1.72 accidents per MVM) compared to roadways of 20 ft to 22 ft (3.95 accidents per MVM) or 24 ft or greater (3.88 accidents per MVM). Similar trends were found using rates of injury accidents. Thus, increased roadway width seems to have a negative effect, the reverse of the finding for paved roads.

As with the previous discussion of very narrow lane widths, speed may be an explanation for what appears to be a counter intuitive finding. Unpaved roads that are very narrow are probably driven at very low speeds. Wider, unpaved roads may encourage higher speeds, thereby increasing the potential for accidents.

A comparison also was made of the effect of width on unpaved Minnesota roadway using similar modeling techniques. As shown in Figure 7, the adjusted rates fluctuate considerably for roadway widths of less than 18 ft to 30 ft. This could be due to some extent to speed differences associated with various widths and, perhaps, to the condition of the surface, percent of local (familiar drivers), and other factors. The rate of related accidents tends to decrease as total roadway width (i.e., width of lanes plus shoulders) increases from 30 ft to greater than 40 ft (lane widths of 15 ft to 20 ft).

In summary, the effects of paved versus unpaved surface are somewhat unclear based on an analysis of the various databases. While there are indications from one database (the primary database) that paved surface can reduce accidents for roads with ADT above 250 vpd, no effect of pavement surfacing was found from a larger database (Minnesota). Thus, it appears that the decision to surface a roadway should be made on a case-by-case basis and should include consideration of surfacing and maintenance costs, ADT, accident experience on the roads, roadway alignment (in terms of whether it can handle increased speeds safely), and other considerations.

There is some indication that the width of unpaved roads also can affect accident rates. It appears that while accident rates can fluctuate considerably for narrow roadways, rates for roadway widths of 20 ft or less are low. This may occur as a result of reduced vehicle speeds on very narrow, unpaved roads. As widths increase to about 30 ft, accident rates can increase, perhaps with increases in vehicle speeds. As widths further increase above 30 ft, rates seem to decrease again.

Issue 6—Safety Effects of Large Trucks

The variable indicating the percent of truck traffic was not found to be significantly associated with related accident rate in any of the analyses of the primary database. Although this finding may, in part, result from the limited variation in the variable and the lack of detailed information concerning oversized trucks or truck type, it is also suspected that the quality of such data on lower volume roads may be less than for higher volume roads.

It is possible and, indeed, intuitive that roadway width is an important variable influencing truck accident experience in some situations. Discerning these effects or situations was beyond the capabilities of the database assembled for this study.

Issue 7—Expected Accident Benefits on Low-Volume Roads

The best linear accident model forms the basis for estimating expected accident effects of variable roadway widths on low-volume roads, as shown in Figure 5. Table 10 gives the accident rates from this model, compiled by lane width and shoulder width, that were used in the cost-effectiveness analysis. Annual accident benefits are calculated by taking the difference in rates implied by any two cells of Table 3, multiplied by the annualized traffic volume level being analyzed.

The rates reflect a sensitivity to terrain, which is considered an indicator of alignment quality. In other words, in more difficult terrain, horizontal and vertical alignment tend to be more severe, producing higher overall levels of accidents.

HIGHWAY OPERATIONAL CONSIDERATIONS RELATED TO DESIGN

Appropriate width values for design are related not only to safety, but also to other traffic operational considerations. These operational considerations include width effects on vehicle speeds, capacity and level-of-service implications of widths, vehicle composition and lane width effects, and shoulder functional requirements.

Current design policy established the framework within which both operational and safety concerns must fit. A highway's design is affected significantly by its functional classification and design speed.

Functional Classification

The concept of functional classification is central to the development of all highway design standards. As stated in the 1990 AASHTO *Policy:*

TABLE 10. Accident rates used for analysis of cost-effective widths on low-volume roads[a]

Lane Width (feet)	Shoulder Width (feet)	Accident Rates (Related Accidents per MVM)		
		Terrain		
		Level	Rolling	Mountainous
10	0-2	2.28	2.41	2.86
	3-4	2.28	2.41	2.86
	>4	1.30	1.43	1.88
11	0-2	1.74	1.87	2.32
	3-4	1.18	1.31	1.76
	>4	1.18	1.31	1.76
12	0-2	1.74	1.87	2.32
	3-4	1.18	1.31	1.76
	>4	1.18	1.31	1.76

[a]Values in this table are based on the accident model produced in the analysis of the primary database.

Under a functional classification system, standards and level of service vary according to the function of the highway facility. Volumes serve to further refine the standards for each class.

Arterials are expected to provide a high degree of mobility for the longer trip length. Therefore, they should provide a high operating speed and level of service. Since access to abutting property is not their major function, some degree of access control is desirable to enhance mobility. The collectors serve a dual function in accommodating the shorter trip and feeding the arterials. They must provide some degree of mobility and also serve abutting property. Thus, an intermediate design speed and level of service is appropriate. Local roads and streets have relative short trip lengths, and because property access is their main function, there is little need for mobility or high operating speeds. This function is reflected by use of a lower design speed and level of service.

The functional concept is important to the designer. Even though many of the geometric standards could be determined without reference to the functional classification, the designer must keep in mind the overall purpose that the street or highway is intended to serve. This concept is consistent with a systematic approach to highway planning and design (AASHTO, 1990, p. 16).

Design Speed

Design speed is one of the basic controls in establishing the design of any highway. According to the 1990 AASHTO *Policy:*

Design speed is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern. The assumed design speed should be a logical one with respect to the topography, the adjacent land use, and the functional classification of highway. Except for local streets where speed controls are frequently included intentionally, every effort should be made to use as high a design speed as practicable to attain a desired degree of safety, mobility, and efficiency while under the constraints of environmental quality, economics, aesthetics, and social or political impacts. Once selected, all of the pertinent features of the highway should be related to the design speed to obtain a balanced design.

The design speed chosen should be consistent with the speed a driver is likely to expect. Where a difficult condition is obvious, drivers are more apt to accept lower speed operation than where there is no apparent reason for it. A highway of higher functional classification may justify a higher design speed than a less important facility in similar topography, particularly where the savings in vehicle operation and other operating costs are sufficient to offset the increased costs of right-of-way and construction. A low design speed, however, should not be assumed for a secondary road where the topography is such that drivers are likely to travel at high speeds. Drivers do not adjust their speeds to the importance of the highway, but to their perception of the physical limitations and traffic thereon (AASHTO, 1990, pp. 63–64).

Table 11 provides general design speed guidelines for various combinations of highway type and terrain. Note that such speeds are irrespective of traffic volume levels.

Analysis issues 8 through 11 concern the relationships between roadway widths and highway operations. These issues are addressed in the following sections within the framework established earlier, in which functional classification and design speed serve as primary design controls.

Issue 8—Width Effects on Capacity and Level of Service

Both lane and shoulder widths affect the capacity of a two-lane roadway. Table 12, from the 1985 *Highway Capacity Manual,* shows that a roadway with 9-ft lanes and no shoulders has only two-thirds the capacity of a two-lane roadway with 12-ft lanes and 6-ft shoulders.

There is an additional relevant consideration regarding design standards and level of service. Consistent with the framework of functional classification, the current AASHTO *Policy* advises the use of guidelines given in Table 13 for design levels of service. Lower levels of service (i.e., "D") are considered acceptable on lower class highways and in more difficult terrain. For rural highways, however, in most cases the design should produce level-of-service B or C.

Recommended minimum standard widths for design of low-volume roads should be consistent with minimum AASHTO *Policy* requirements for level of service and with the known operational relationships between highway level of service and lane and shoulder width. Appendix E presents an evaluation of these relationships. Tables 14(a) and 14(b) summarize the results. The tables present the minimum required values for f_w (the capacity factor expressing the contribution of lane width and shoulder width) to produce the minimum level of service called for by

TABLE 11. Guidelines for selecting appropriate design speed

Highway Type	Design Speed (mph)		
	Rural		
	Level	Rolling	Mountainous
Freeway	80	70	60[a]
Primary Highway or Street	60-70	50-60	40-50
Local or Collector Highway or Street	30-60	30-50	20-40

[a]Special case, 50 mph
Source: AASHTO 1990 Geometric Design of Highways and Streets, (Derived from Tables V-1, p. 4, VI-1, p. 469, and p. 494).

TABLE 12. Adjustment factors for the combined effect of narrow lanes and restricted shoulder width

Usable[a] Shoulder Width (feet)	12-foot Lanes		11-foot Lanes		10-foot Lanes		9-foot Lanes	
	LOS A-D	LOS[b] E	LOS A-D	LOS[b] E	LOS A-D	LOS[b] E	LOS A-D	LOS[b] E
≥ 6	1.00	1.00	0.93	0.94	0.84	0.87	0.70	0.76
4	0.92	0.97	0.85	0.92	0.77	0.85	0.65	0.74
2	0.81	0.93	0.75	0.88	0.68	0.81	0.57	0.70
0	0.70	0.88	0.65	0.82	0.58	0.75	0.49	0.66

[a]Where shoulder width is different on each side of the road, use the average shoulder width.
[b]Factor applies for all speeds less than 45 mph.
Source: Transportation Research Board. *Special Report 209.* 1985. *Highway Capacity Manual.* pp. 8-9.

TABLE 13. Guidelines for selecting design levels of service

Highway Type	Type of Area and Appropriate Level of Service			
	Rural Level	Rural Rolling	Rural Mountainous	Urban and Suburban
Freeway	B	B	C	C
Arterial	B	B	C	C
Collector	C	C	D	D
Local	D	D	D	D

Note: General operating conditions for levels of service:
A——free flow, with low volumes and high speeds.
B——reasonably free flow, but speeds beginning to be restricted by traffic conditions.
C——in stable flow zone, but most drivers restricted in freedom to select their own speed.
D——approaching unstable flow, drivers have little freedom to maneuver.
E——unstable flow, may be short stoppages.

Source: AASHTO. 1990. *Geometric Design of Highways and Streets.* p. 92.

AASHTO (see Table 12), in typical design conditions. The following is concluded from the analysis:

1. At traffic volumes less than 1,500 vpd, capacity effects are not a factor in determining minimum values for lane and shoulder width for typical combinations of functional classification, terrain, and traffic composition.
2. At traffic volumes approaching 2,000 vpd, the known width

TABLE 14(a). Minimum required lane and shoulder width capacity factor (f_w) for low-volume two-lane highways[a] (trucks = 10% of ADT)

Rural Highway Type/Terrain	Average Daily Traffic Volume			
	400 vpd	750 vpd	1,500 vpd	2,000 vpd
Arterial				
— Level	0.12	0.22	0.43	0.58
— Rolling	0.18	0.34	0.68	0.91
— Mountainous	0.20	0.38	0.75	1.00
Collector				
— Level	0.07	0.13	0.26	0.35
— Rolling	0.10	0.18	0.36	0.49
— Mountainous	0.13	0.24	0.47	0.63
Local				
— Level	0.04	0.08	0.16	0.21
— Rolling	0.06	0.12	0.24	0.32
— Mountainous	0.13	0.24	0.47	0.63

[a]As determined in Appendix E. Values for f_w are representative of typical traffic and geometric conditions for a given highway type and terrain. See Table 12 for the relationship between f_w and lane widths and shoulder widths.

TABLE 14(b). Minimum required lane and shoulder width capacity factor (f_w) for low-volume two-lane highways[a] (trucks = 15% of ADT)

Rural Highway Type/Terrain	Average Daily Traffic Volume			
	400 vpd	750 vpd	1,500 vpd	2,000 vpd
Arterial				
— Level	0.12	0.23	0.46	0.61
— Rolling	0.21	0.39	0.78	1.04
— Mountainous	0.25	0.46	0.93	1.24
Collector				
— Level	0.07	0.14	0.28	0.37
— Rolling	0.11	0.21	0.42	0.55
— Mountainous	0.16	0.30	0.60	0.79
Local				
— Level	0.04	0.08	0.17	0.22
— Rolling	0.07	0.14	0.28	0.37
— Mountainous	0.16	0.30	0.60	0.79

[a]As determined in Appendix E. Values for f_w are representative of typical traffic and geometric conditions for a given highway type and terrain. See Table 12 for the relationship between f_w and lane widths and shoulder widths.

effects on level of service should begin to influence minimum lane and shoulder width design values, particularly for highways with significant truck volumes (greater than 10 percent), in rolling or mountainous terrain and on primary arterials. Justification of full lane and shoulder widths on the basis of their influence on capacity is evident for primary arterials with traffic volumes approaching 2,000 vpd. For collector and local roadways, justification based on capacity needs of total width dimensions of 22 ft for roads with low truck volumes, and dimensions of 28 ft to 30 ft for roads with higher truck volumes, is evident at 2,000 vpd. Refer to Appendix E.

Issue 9—Effect of Width on Vehicle Speeds

A number of studies have documented a lane width effect on free vehicle speeds. Glennon et al. (*11*) studied the free speeds of drivers negotiating curves and found that a 2-mph to 3-mph difference in mean speeds occurs for the same alignment for narrow roadways (i.e., with lane widths less than 10 ft) versus wide roadways (lane widths of 12 ft or greater).

Lamm and Choueiri (*12*) developed models from speed studies in New York to quantify the effect of lane width on 85th-percentile speeds (which are or should be close to the design speed). This research looked at speeds on curves, as well as speeds through varying continuous alignment. It was found that, for alignment typically occurring in level terrain, 85-percentile speeds on roads with 10-ft lanes are about 6 mph lower than speeds on roads with 12-ft lanes. The difference in speeds associated with lane width increases to almost 8 mph for alignment associated with mountainous terrain.

Appendix F presents an analysis of the relationship among vehicle operating speeds, lane width, and design speed based on the foregoing cited research. Its application to development of

TABLE 15. Acceptable shoulder width values for shoulder functions (values in feet)

Shoulder Function	Functional Classification	
	Arterial	Collector & Local
Shoulder Widths of 1 to 2 feet		
Roadway and Shoulder Drainage	1	1
Lateral Support of Pavement	1.5	1
Off-tracking of Wide Vehicles	2	2
Encroachment of Wide Vehicles	2	2
Errant Vehicles (Run off road)	—	2
Mail and Other Deliveries	—	2
Shoulder Widths of 3 to 4 feet		
Pedestrians	4	4
Bicycles	4	4
Errant Vehicles (Run off road)	3	—
Shoulder Widths of 6 feet		
Emergency Stopping	6	6
Mail and Other Deliveries	6	—
Garbage Pickup	6	6
Emergency Vehicle Travel	6	6
Routine Maintenance	—	6
Law Enforcement	—	6
Emergency Call Box Services	—	6
Shoulder Widths of 7 to 10 feet		
Parking		
Trucks	10	N/A
Residential	8	7
Commercial	10	8
Turning and Passing at Intersections	10	9
Routine Maintenance	8	—
Major Reconstruction and Maintenance	9	9
Slow-Moving Vehicles	10	9
Law Enforcement	8	—
Emergency Call box Services	8	—

Adopted From: Downs, Jr. H.G. and Wallace, D.W. "Shoulder Geometrics and Use Guidelines." NCHRP Report 254. Transportation Research Board, Washington, D.C. December 1982.

design standards focuses on identifying compatible (hence, appropriate) lane widths for given design speeds. It is concluded that 11-ft and 12-ft lane widths generally are appropriate (i.e., produce speeds compatible with the established design speed) for higher speed highways (those with design speeds of 60-mph and greater). Lane widths of 10 ft and 11 ft are appropriate for intermediate design speeds (50 mph), and lane widths of 10 ft are appropriate for lower design speeds (40 mph or less).

The analysis and its application to lane width design values presents an important research recommendation. Lane widths should be compatible with the terrain and design speed. Lane widths that are too wide for a given set of design conditions are undesirable. They may encourage higher speeds than those for which the alignment and roadside were designed.

Issue 10—Width-Related Shoulder Functional Requirements

Shoulders serve many functions, each of which requires a minimum acceptable width. An earlier NCHRP study by Downs and Wallace (*13*) catalogued the various shoulder functions and noted the required widths. Table 15, summarized from that research, shows the range in functions and widths. Table 15 indicates that there is a stepwise utility of shoulder widths. Minimum widths of 2 ft serve to drain the pavement, supply lateral support, and provide for off-tracking on sharp curves and encroachment of wide vehicles. An additional width of 4 ft offers little additional functional utility, other than the minimum space for pedestrians and bicycles. On most low-volume rural roads, providing additional shoulder width just for pedestrian and bicycle use is not normally justified by the added expense. At a width of 6 ft, the utility of shoulders improves significantly. A 6-ft width is acceptable for emergency stopping, mail and package deliveries, emergency vehicle travel, and routine maintenance (on lower class facilities). Shoulder widths of 8 ft or more generally have utility only for higher class, higher volume roads, where the effects of slowed vehicles, parked vehicles, and routine maintenance are more significant.

Issue 11—Operational Effects of Wider Trucks

As discussed earlier, the specific accident effects of large trucks on low-volume roads could not be properly quantified in this study because of data limitations. However, a previous re-

search study for FHWA has investigated the operational impacts of large trucks on rural two-lane roads. Specifically, tractor semitrailers with long trailers (e.g., 48 ft or longer) have been found to have problems with "off-tracking." As these long trucks travel around a left-hand curve, the trailers may encroach across the centerline. On a right-hand curve, the trailers may encroach off the shoulder. This off-tracking problem increases for narrow lanes and shoulders, and for sharper horizontal curves.

This recent study conducted for FHWA by Harkey et al. (*10*) recommended paved shoulders of 3 ft or more and minimum lane widths of 12 ft. This design handles the larger trucks allowed by the Surface Transportation Assistance Act (STAA) of 1982 (i.e., trucks 102 in. wide, twin 28-ft trailers, or semitrailers of 48 ft or greater), particularly, on roads with severe horizontal and vertical alignment.

To best accommodate trucks, it may be a useful design policy to differentiate between local, low-volume roads and higher facility types such as low-volume arterials. Such differentiation would involve knowing the percentage and volume of larger trucks. On local-type facilities with more local delivery trucks, single-unit trucks, and smaller trucks, lesser widths may in fact be sufficient. On the higher class, low-volume roads, the presence of the longer trucks may be sufficient justification for incrementally greater lane widths and paved shoulder widths.

ROADWAY DESIGN REQUIREMENTS

Cost-Effectiveness and Width-Related Sensitivities

Cost-effectiveness is the primary concern in establishing width-related design standards. Greater widths may be associated with safety and operational benefits, but they may also cost significantly more to build and to maintain. An important research task was to investigate the width-related sensitivities of construction and maintenance costs.

Issue 12—Construction and Maintenance Costs

The research team performed a comprehensive evaluation of construction cost values and cost estimating methodologies to uncover width-related sensitivities. The evaluation included a nationwide survey of state design agencies, development of a cost model, and calculation of typical per mile construction costs for the full range of reasonable lane and shoulder widths. The survey and analysis focused on identifying costs of new construction or reconstruction (4R).

Construction Cost Survey. All 50 state transportation agencies were surveyed to develop a methodology for estimating construction costs for rural highways. Appendix D, Tables D-1 to D-7, summarizes the survey findings resulting from a response rate of about 50 percent. The purpose of the survey was (1) data were sought for 1991 construction unit costs around the country; and (2) cost estimating assumptions or models were investigated for use or adaptation to the research.

The cost estimating model developed from the survey was structured to enable users to apply their own unit values or factors, or default values (derived from the survey). Figure 8 summarizes the construction cost model. It is based on the relatively common practice in preliminary or planning-level analyses of estimating quantities for the major construction items of pavement, earthwork, and shoulders, and applying factors or percentages for all other items. The result is a "cost per mile" that is representative of the typical conditions and unit values cited in the survey responses.

The following methodology and assumptions apply to the derivation of the cost model:

Item 1—Pavement. Quantities for 18-, 20-, 22-, and 24-ft traveled-way widths were calculated directly to produce square feet of pavement per mile. Unit costs of pavement were developed for two traffic-volume and two heavy-vehicle percentage ranges. Tables 16(a) and 16(b) summarize unit quantities and costs.

Item 2—Shoulders. Quantities for unpaved and paved shoulders were calculated to produce square feet of shoulder per mile (see Table 17(a)). The survey produced the recommended unit costs given in Table 17(b).

Item 3—Earthwork. Quantities of cubic yards of earthwork per mile were computed for typical cross-section designs in level, rolling, and mountainous terrain. For level and rolling terrain, 3:1 sideslopes were assumed. For mountainous terrain, 2:1 sideslopes were assumed. An evaluation of project cost and quantity data provided by the Colorado Department of Highways was performed to establish the average depth of earthwork as a function of terrain. This was determined to be 2.5 ft for level terrain, 3.0 ft for rolling terrain, and 4.5 ft for mountainous terrain. Table 18(a) shows per mile quantities of earthwork, with the foregoing assumptions, as a function of the full range of the traveled way and shoulder width. Unit costs suggested for use are given in Table 18(b). These costs were derived from the survey responses for average projects.

Item 4—Clearing and Grubbing. Survey responses were limited for this item. The Colorado cost information was used to establish unit costs (see Table 19(a)) for typical right-of-way values (see Table 19(b)).

Item 5—Utility Relocation. A unit cost of $40,000 per mile was derived from the survey responses.

Item 6—Drainage. Costs of drainage structures, ditches, and the like are related generally to the earthwork and pavement costs. From the survey, a unit value of 15 percent of the costs of Items 1 through 5 was derived. The net effect of this cost was tested against project data and found to be reasonable.

Other Items. Other minor, but necessary, cost items include signing, striping, and permanent traffic control (Item 7); appurtenances, such as guardrail (Item 8), and erosion control, environmental mitigation, and landscaping (Item 9). The survey responses resulted in the following recommended typical unit costs for these items: (1) permanent traffic control—1 percent of Items 1 through 5, (2) appurtenances—9 percent of Items 1 through 5, and (3) erosion control—4 percent of Items 1 through 5. Other costs (Items 10 through 14) typically are computed or estimated as a percentage of total cost. The results of the survey were used to develop typical percentages for costs of traffic control during construction; mobilization and contingencies; preliminary, final, and construction engineering; and other nonconstruction costs.

The model was developed to enable the use of substitute cost

Item	Cost per Mile
1. Pavement [see Tables 16(a) and 16(b)]	$_____
2. Shoulders [see Tables 17(a) and 17(b)]	$_____
3. Earthwork [see Tables 18(a) and 18(b)]	$_____
4. Clearing and Grubbing [see Tables 19(a) and 19(b)]	$_____
5. Utility Relocation——$40,000 per mile (suggested)	$_____
• Subtotal (Items 1-5)	
6. Drainage (15 Percent of Items 1-5*)	$_____
7. Signing, Striping, and Permanent Traffic Control (1 Percent of Items 1-5*)	$_____
8. Appurtenances (9 Percent of Items 1-5*)	$_____
9. Erosion Control, Other Environmental Mitigation, Landscaping, Seeding Sodding, etc. (4 Percent of Items 1-5*)	$_____
• Subtotal (Items 1-9) $_____	
10. Traffic Control During Construction (4 Percent of Items 1-9*)	$_____
11. Mobilization, Miscellaneous Costs, and Contingencies (15 Percent of Items 1-9*)	$_____
• Construction Subtotal (Items 1-11) $_____	
12. Preliminary and Final Engineering (9 Percent of Items 1-11)	$_____
13. Construction Engineering (10 Percent of Items 1-11)	$_____
14. Legal, Administrative, and Other Non-Construction Costs (5 Percent of Items 1-11*)	$_____
15. Total Estimated Cost per Mile for Project (Items 1-14)	$_____
Total Estimated Cost for Project	
Project Length _____mi.	
Project Cost per Mile x $_____/mi.	
TOTAL PROJECT COST	$_____

*Percentages other than those suggested may be used if desired.

Figure 8. Summary of construction cost model—cost estimating procedure for two-lane rural highways (new construction).

factors or unit values for the basic items. The cost-effectiveness analysis results presented here were based on the unit costs and percentages previously described.

Tables 20 and 21 present the resulting unit costs per mile for constructing two-lane highways by terrain, traffic volume, and roadway cross section, for ADT less than 400 vpd and greater than 400 vpd. The values were checked against typical project costs from various states and from the research team's information on other projects.

Tables 20 and 21 reveal the following: (1) roadways in mountainous terrain are significantly more costly than roadways in rolling terrain, and the cost difference between roadways in rolling and level terrain is less pronounced; (2) the incremental cost of an additional 4 ft of shoulder width (2 ft on each side of the roadway) varies from about $50,000 to $70,000 per mile, depending on terrain; and (3) the difference in costs between paved and unpaved shoulders varies from about $25,000 to $80,000 per mile, depending on width.

TABLE 16(a). Quantities for item 1—pavement

TRAVELED WAY WIDTH (ft.)	PAVEMENT AREA (sq. ft./mi)
18	95,040
20	105,600
22	116,160
24	126,720

TABLE 16(b). Suggested unit costs for item 1—pavement*

% HEAVY TRUCKS	AVERAGE DAILY TRAFFIC	
	< 400 vpd	> 400 vpd
< 10	$ 1.50 / sq.ft.	$ 1.90 / sq. ft.
> 10	$ 1.70 / sq.ft.	$ 2.20 / sq. ft.

* Other unit costs may be substituted if desired.

TABLE 17(a). Quantities for item 2—shoulders

SHOULDER WIDTH, EACH (ft.)	SHOULDER AREA (sq. ft./mi)
2	21,120
4	42,240
6	63,360
8	84,480
10	105,600

TABLE 17(b). Suggested unit costs for item 2—shoulders*

SHOULDER TYPE	UNIT COST
PAVED	$1.45 / sq. ft.
UNPAVED	$0.85 / sq. ft.

* Other unit costs may be substituted if desire

Calculation for Item 1: Pavement

sq. ft./mi. X $ _____ /sq. ft. _____ = $ ____/mi.

Calculation for Item 2: Shoulders

sq. ft./mi. X $ _____ / sq. ft. = $ _____/ mi.

Maintenance Costs Survey. A review of the literature uncovered no identifiable "width-sensitive" costs associated with maintenance. *TRB Special Report 214* notes that increased pavement maintenance costs, when considering a typical widening project for a two-lane highway, represent about 6 percent of annualized construction cost.

Issue 13—Cost-Effective Roadway and Shoulder Width Combinations Relative to Safety and Operational Benefits

A primary input to determination of cost-effective widths is an evaluation of the economic trade-offs involving costs versus safety and operational benefits. Costs include construction cost and annual maintenance costs. Theoretical benefits include travel-time savings and accident reductions. For low-volume roads (ADT less than 2,000 vpd), a number of simplifying assumptions are appropriate. These include treatment of traffic operational benefits and incremental maintenance costs.

Traffic Operational Benefits. Wider roadways promote higher speeds, which have a dual effect in terms of operating cost. Travel times are lowered (producing a benefit), but vehicle operating costs are increased (producing a cost). *TRB Special Report 214* includes an analysis of the net operational benefits of widening roads as a function of ADT. The findings show that user savings are less than 2 percent of the cost of widening for roads with ADT less than 1,000 vpd, and about 7 percent for roads with ADT less than 2,000 vpd (*3*). Such net benefits are considered negligible.

Maintenance Costs. For analysis purposes, incremental maintenance costs are considered inconsequential and are ignored.

For analysis purposes, then, the comparison of economic benefits and costs is restricted to a comparison of annualized construction costs and annual accident cost savings. Ignoring incremental traffic operational benefits and maintenance costs would, in total, have little or no effect on the analysis because the incremental benefits and costs (1) are minor in terms of their individual effect, and (2) tend to cancel each other out. (For example, wider cross sections have marginally greater operational benefits, but marginally higher maintenance costs.)

Cost Assumptions. Assumptions are required for the discount rate, traffic growth, useful life of improvements, and average accident costs.

Discount Rate. The 1977 AASHTO "Manual on User Benefit

TABLE 18(a). Quantities for item 3—earthwork (cu yd/mi)

TERRAIN	TRAVELED WAY (ft.)	SHOULDER WIDTH, EACH (ft.) 0	2	4	6	8	10
LEVEL	18	28,113	30,069	32,025	33,981	35,937	37,893
	20	29,091	31,047	33,003	34,959	36,915	38,871
	22	30,069	32,025	33,981	35,937	37,893	39,849
	24	31,047	33,003	34,959	36,915	38,871	40,827
ROLLING	18	34,619	36,967	39,315	41,663	44,011	46,359
	20	35,793	38,141	40,489	42,837	45,185	47,533
	22	36,967	39,315	41,663	44,011	46,359	48,707
	24	38,141	40,489	42,837	45,185	47,533	49,881
MOUNTAINOUS	18	51,920	55,440	58,960	62,480	66,000	69,520
	20	53,680	57,200	60,720	64,240	67,760	71,280
	22	55,440	58,960	62,480	66,000	69,520	73,040
	24	57,200	60,720	64,240	67,760	71,280	74,800

TABLE 18(b). Suggested unit costs for item 3—earthwork*

TERRAIN	UNIT COST
LEVEL	$ 3.50 /cu. yd.
ROLLING	$ 3.50 /cu. yd.
MOUNTAINOUS	$ 5.50 /cu. yd.

* Other unit costs may be substituted if desired.

Calculation for Item 3: Earthwork

cu. yd./mi. X $ /cu. yd. = $ /mi.

TABLE 19(a). Quantities for item 4—clearing and grubbing

TERRAIN	WIDTH OF CLEARING* (ft.)
LEVEL	80
ROLLING	80
MOUNTAINOUS	66

*Width of clearing may be changed if desired.

TABLE 19(b). Suggested unit costs for item 4—clearing and grubbing*

TERRAIN	UNIT COST
LEVEL	$ 170 / ft. width / mi.
ROLLING	$ 170 / ft. width / mi.
MOUNTAINOUS	$ 520 / ft. width / mi.

* Other unit costs may be substituted if desired.

Calculation for Item 4: Clearing and Grubbing

_____ ft. width X $_____ /ft. width/mi. = $ _____ /mi.

Analysis and Bus-Transit Improvements" recommends a 4-percent discount rate for low-risk investments (*14*). More recent research suggests a rate of 6 percent as appropriate for evaluation of highway improvements (*3*). For this research, a 6-percent discount rate is assumed.

Traffic Growth. No consideration of traffic growth is assumed for analysis purposes. For most low-volume roads, particularly with ADT less than 1,000 vpd, traffic growth is negligible, and existing or projected traffic is a rough estimate at best. Thus, economic analysis of width values for the purpose of testing standards assumes that the design traffic remains constant over the life of the improvements.

Useful Life of Improvements. A 20-year useful life of construction items is assumed.

Average Accident Costs. The determination of an appropriate dollar value for an average accident is, perhaps, the most significant step in the economic evaluation. Accident costs are a function of the severity distribution of accidents and costs that are considered to be reasonable for a fatal injury and property-damage-only accident.

A recent FHWA Technical Advisory suggests that the value of a typical accident on a rural road is $85,600 (*15*). This is based on the FHWA "willingness to pay" valuation of accidents, which is substantially higher than the values derived by the National Safety Council. Other recent research by the authors of this study, using the same FHWA approach, derived values of $53,700 to $59,000 per average accident on rural highways and rural highway curves, respectively.

Accident severity data used in this study do not provide the details to enable a rigorous derivation of a typical accident cost. Valuations in the $50,000 to $85,000 range appear appropriate. For analysis purposes, thus, it was decided that a value of $60,000 per accident is appropriate. This value is slightly higher than unit values derived in recent past studies (*5, 35*). Recent revisions to unit costs reflecting inflation are noted in Ref. 15. Accident severity on low-volume roads appears less, however, than in the earlier research. Note that a direct relationship exists between the selected accident valuation and breakeven traffic volume in cost-effectiveness analysis levels. For higher accident valuations, breakeven ADT levels that justify wider roadways will be lower.

Average accident rates from the best linear model were used in the economic analysis. These rates were summarized in Table 12. Annualized capital costs for comparison of two alternative designs were taken as the difference in construction costs per mile (from Tables 20 and 21) multiplied by a capital recovery factor of 0.08718 (for a 6-percent discount rate and 20-year life).

For example, for a roadway with a design ADT greater than 400 vpd, in rolling terrain with less than 10-percent trucks, the following are typical costs per mile (see Table 21): for a 20-ft traveled way (i.e., two 10-ft lanes) with 4-ft paved shoulders (producing a total roadway width of 28 ft), $870,290; and for a 22-ft traveled way (i.e., two 11-ft lanes) with 4-ft paved shoulders (producing a total roadway width of 30 ft), $916,304.

The incremental construction cost of the wider design is $46,014—the difference between the 30-ft roadway and the

TABLE 20. Estimated construction costs per mile—two-lane rural highways (ADT less than 400 vpd)

ADT < 400 vpd

ESTIMATED CONSTRUCTION COSTS -- TWO-LANE RURAL HIGHWAYS (DOLLARS)

			SHOULDER WIDTH (ft.)										
			0	2		4		6		8		10	
PERCENT TRUCKS	TERRAIN	TRAVELED WAY (ft.)	NO SHLDR	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED
< 10 %	LEVEL	18	560,693	632,019	607,897	703,344	655,101	774,669	702,304	845,994	749,508	917,319	796,711
		20	597,361	668,686	644,565	740,011	691,768	811,336	738,972	882,661	786,175	953,986	833,379
		22	634,029	705,354	681,232	776,679	728,436	848,004	775,639	919,329	822,843	990,654	870,047
		24	670,696	742,021	717,900	813,346	765,103	884,671	812,307	955,996	859,511	1,027,321	906,714
	ROLLING	18	604,039	677,975	653,854	751,912	703,669	825,849	753,484	899,785	803,300	973,722	853,115
		20	642,012	715,949	691,827	789,885	741,642	863,822	791,458	937,759	841,273	1,011,695	891,088
		22	679,985	753,922	729,801	827,859	779,616	901,795	829,431	975,732	879,246	1,049,669	929,062
		24	717,959	791,895	767,774	865,832	817,589	939,769	867,404	1,013,706	917,220	1,087,642	967,035
	MOUNTAINOUS	18	956,407	1,051,552	1,027,431	1,146,698	1,098,455	1,241,844	1,169,479	1,336,990	1,240,504	1,432,135	1,311,528
		20	1,004,985	1,100,130	1,076,009	1,195,276	1,147,033	1,290,422	1,218,057	1,385,568	1,289,082	1,480,713	1,360,106
		22	1,053,562	1,148,708	1,124,587	1,243,854	1,195,611	1,339,000	1,266,635	1,434,145	1,337,660	1,529,291	1,408,684
		24	1,102,140	1,197,286	1,173,165	1,292,432	1,244,189	1,387,578	1,315,213	1,482,723	1,386,238	1,577,869	1,457,262
> 10 %	LEVEL	18	596,876	668,201	644,079	739,526	691,283	810,851	738,486	882,176	785,690	953,501	832,894
		20	637,563	708,889	684,767	780,214	731,971	851,539	779,174	922,864	826,378	994,189	873,581
		22	678,251	749,576	725,455	820,901	772,658	892,226	819,862	963,551	867,066	1,034,877	914,269
		24	718,939	790,264	766,143	861,589	813,346	932,914	860,550	1,004,239	907,753	1,075,564	954,957
	ROLLING	18	640,221	714,157	690,036	788,094	739,851	862,031	789,666	935,968	839,482	1,009,904	889,297
		20	682,214	756,151	732,030	830,088	781,845	904,024	831,660	977,961	881,475	1,051,898	931,291
		22	724,208	798,145	774,023	872,081	823,839	946,018	873,654	1,019,955	923,469	1,093,891	973,284
		24	766,202	840,138	816,017	914,075	865,832	988,012	915,647	1,061,948	965,463	1,135,885	1,015,278
	MOUNTAINOUS	18	992,589	1,087,735	1,063,613	1,182,880	1,134,637	1,278,026	1,205,662	1,373,172	1,276,686	1,468,318	1,347,710
		20	1,045,187	1,140,333	1,116,211	1,235,478	1,187,236	1,330,624	1,258,260	1,425,770	1,329,284	1,520,916	1,400,308
		22	1,097,785	1,192,931	1,168,809	1,288,077	1,239,834	1,383,222	1,310,858	1,478,368	1,381,882	1,573,514	1,452,907
		24	1,150,383	1,245,529	1,221,408	1,340,675	1,292,432	1,435,821	1,363,456	1,530,966	1,434,480	1,626,112	1,505,505

TABLE 21. Estimated construction costs per mile—two-lane rural highways (ADT greater than 400 vpd)

ADT > 400 vpd

ESTIMATED CONSTRUCTION COSTS -- TWO-LANE RURAL HIGHWAYS (DOLLARS)

			SHOULDER WIDTH (ft.)										
			0	2		4		6		8		10	
PERCENT TRUCKS	TERRAIN	TRAVELED WAY (ft.)	NO SHLDR	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED	SHOULDER TYPE PAVED	SHOULDER TYPE UNPAVED
< 10 %	LEVEL	18	633,058	704,383	680,261	775,708	727,465	847,033	774,669	918,358	821,872	989,683	869,076
		20	677,766	749,091	724,969	820,416	772,173	891,741	819,377	963,066	866,580	1,034,391	913,784
		22	722,474	793,799	769,678	865,124	816,881	936,449	864,085	1,007,774	911,288	1,079,099	958,492
		24	767,182	838,507	814,386	909,832	861,589	981,157	908,793	1,052,482	955,996	1,123,807	1,003,200
	ROLLING	18	676,403	750,340	726,218	824,276	776,033	898,213	825,849	972,150	875,664	1,046,086	925,479
		20	722,417	796,354	772,232	870,290	822,047	944,227	871,863	1,018,164	921,678	1,092,100	971,493
		22	768,431	842,367	818,246	916,304	868,061	990,241	917,876	1,064,177	967,692	1,138,114	1,017,507
		24	814,445	888,381	864,260	962,318	914,075	1,036,255	963,890	1,110,191	1,013,706	1,184,128	1,063,521
	MOUNTAINOUS	18	1,028,771	1,123,917	1,099,795	1,219,062	1,170,820	1,314,208	1,241,844	1,409,354	1,312,868	1,504,500	1,383,892
		20	1,085,389	1,180,535	1,156,414	1,275,681	1,227,438	1,370,827	1,298,462	1,465,972	1,369,487	1,561,118	1,440,511
		22	1,142,008	1,237,154	1,213,032	1,332,299	1,284,056	1,427,445	1,355,081	1,522,591	1,426,105	1,617,737	1,497,129
		24	1,198,626	1,293,772	1,269,651	1,388,918	1,340,675	1,484,063	1,411,699	1,579,209	1,482,723	1,674,355	1,553,748
> 10 %	LEVEL	18	687,331	758,656	734,535	829,981	781,738	901,306	828,942	972,631	876,145	1,043,956	923,349
		20	738,070	809,395	785,273	880,720	832,477	952,045	879,680	1,023,370	926,884	1,094,695	974,087
		22	788,808	860,133	836,012	931,458	883,215	1,002,783	930,419	1,074,108	977,622	1,145,433	1,024,826
		24	839,546	910,871	886,750	982,196	933,954	1,053,522	981,157	1,124,847	1,028,361	1,196,172	1,075,564
	ROLLING	18	730,676	804,613	780,491	878,550	830,307	952,486	880,122	1,026,423	929,937	1,100,360	979,752
		20	782,721	856,657	832,536	930,594	882,351	1,004,531	932,166	1,078,467	981,981	1,152,404	1,031,797
		22	834,765	908,701	884,580	982,638	934,395	1,056,575	984,210	1,130,511	1,034,026	1,204,448	1,083,841
		24	886,809	960,746	936,624	1,034,682	986,439	1,108,619	1,036,255	1,182,556	1,086,070	1,256,492	1,135,885
	MOUNTAINOUS	18	1,083,044	1,178,190	1,154,069	1,273,336	1,225,093	1,368,481	1,296,117	1,463,627	1,367,141	1,558,773	1,438,166
		20	1,145,693	1,240,839	1,216,717	1,335,985	1,287,742	1,431,130	1,358,766	1,526,276	1,429,790	1,621,422	1,500,814
		22	1,208,342	1,303,488	1,279,366	1,398,633	1,350,390	1,493,779	1,421,415	1,588,925	1,492,439	1,684,071	1,563,463
		24	1,270,991	1,366,136	1,342,015	1,461,282	1,413,039	1,556,428	1,484,063	1,651,574	1,555,088	1,746,719	1,626,112

28-ft roadway unit costs per mile ($916,304 minus $870,290). Annualized, this results in a cost difference of $4,012 per mile per year (i.e., $46,014 × 0.08718).

The incremental benefits of the 30-ft roadway are based on the difference in accident rates (see Table 10): for a roadway with 10-ft lanes and 4-ft shoulders in rolling terrain, 2.41 accidents per MVM; and for a roadway with 11-ft lanes and 4-ft shoulders in rolling terrain, 1.31 accidents per MVM.

For the example case, with traffic volumes of 400 vpd and accidents valued at $60,000, the following is the calculated an-

nual benefit of the wider cross section per mile per year: Benefits = (difference in accident rates)(365)(400)(10^{-6})($60,000) = (2.41 - 1.31)(0.146)($60,000) = $9,636 per mile per year. In this example above, because the accident benefits exceed the annualized difference in construction costs, the wider cross section is considered cost-effective.

Although there are many possible cost-effectiveness comparisons, inspection of the accident rates and construction cost implications greatly simplifies the analysis. Figure 5 and Table 10 summarize the research findings regarding safety-effectiveness of variable widths. The following points are emphasized.

There is no direct, measurable benefit of 10-ft lanes with no shoulders or 9-ft lanes with no shoulders compared to any narrower roadway design. For roadways with 10-ft lanes, there is no incremental safety benefit of shoulders of 4 ft or less. Increasing shoulder widths to 5 ft does produce additional expected benefits, but shoulder width increases beyond 5 ft do not produce additional safety benefits.

For low-volume roads with shoulders less than 4 ft wide, there is a measurable safety benefit of 11-ft lanes compared to 10-ft lanes. No safety benefit is evident for roadways with 11-ft or 12-ft lanes beyond providing 4-ft shoulders.

Eleven-ft lanes with shoulders of 4 ft or more are marginally safer than 12-ft lanes with narrow or no shoulders. Also, for lane widths of 11 ft or 12 ft, having shoulders 3 ft in width is associated with a lower accident rate than shoulder widths of 2 ft or less.

Issue 14—Cost-Effective Roadway and Shoulder Width Combinations for Design Standards

The following points are relevant regarding cross-section design standards.

In many cases (lower design speed, lower classification highways in rolling to mountainous terrain), the evidence suggests that lane widths as low as 9 ft are reasonable (i.e., produce a cost-effective design).

Design values for lane width should reflect not only known safety relationships but also quantifiable operational requirements, such as width effects on speed and highway capacity, and large truck requirements. For highways with higher design speeds, with design year traffic volumes greater than 1,500 vpd, significant truck volumes, and higher functional classification, lane widths of up to 12 ft may be appropriate regardless of limited safety cost-effectiveness.

Shoulder width design values should be based on functional requirements associated with drainage, structural support and traffic operations, as well as on safety cost-effectiveness. Two feet is considered a minimum functional shoulder width value. Widths as great as 8 ft are appropriate for functional requirements associated with maintenance and storage of vehicles, particularly on facilities with higher functional classification.

Thus, cost-effectiveness analysis as it relates to derivation of design standards can be reduced to the following questions:

1. For the range of terrain and other conditions, at what ADT levels is it justified to design for 5-ft shoulders (versus the minimum 2-ft shoulders) on highways with 10-ft lanes?
2. For the range of terrain and other conditions, at what ADT levels is it justified to design for 4-ft shoulders (versus the minimum 2-ft shoulders) on highways with 11-ft lanes?
3. For the range of terrain and other conditions, at what ADT levels is it justified to design for 4-ft shoulders (versus minimum 2-ft shoulders) on highways with 12-ft lanes?
4. In some cases, either an 11-ft or 10-ft lane width may be appropriate for design purposes. For the range of terrain and other conditions, at what ADT levels is a cross section employing 10-ft lanes and 6-ft shoulders more cost-effective than one with 11-ft lanes and 2-ft shoulders?
5. In some cases, either an 11-ft or 10-ft lane width may be appropriate for design purposes. For the range of terrain and other conditions, at what ADT levels is a cross section of 11-ft lanes and 2-ft shoulders more cost-effective than one with 10-ft lanes and 2-ft shoulders?
6. In some cases, either an 11-ft or 10-ft lane width may be appropriate for design purposes. Accompanying shoulder width values appropriate for safety cost-effectiveness vary depending on lane width. For the range of terrain and other conditions, at what ADT levels is a cross section with 11-ft lanes and 4-ft shoulders more cost-effective than one with 10-ft lanes and 5-ft shoulders?
7. In some cases, either a 12-ft or an 11-ft lane width may be appropriate. For the range of terrain and other conditions, at what ADT levels is a cross section with 12-ft lanes and 3-ft shoulders more cost-effective than one with 11-ft lanes and 4-foot shoulders?

The following discussion addresses the foregoing questions.

Comparison of 10-Ft Lanes with 5-Ft Shoulders to 10-Ft Lanes with 2-Ft Shoulders

Some highways may have minimum lane widths of only 10 ft. For low volumes, a 2-ft shoulder is operationally sufficient. At what volume level and under what design conditions are wider shoulders appropriate for roads with 10-ft lanes?

The analysis summarized in Table 22 indicates that a "breakeven" traffic volume level for wider shoulders varies with the terrain (and, hence, typical construction costs per mile). Note that, based on the accident analysis, there is no incremental safety benefit of shoulders with widths of 4 ft or less with 10-ft lanes. For level to rolling terrain, about 400 to 450 vpd is an estimated, breakeven ADT for roads with paved shoulders, and 300 vpd is calculated for roads with unpaved shoulders. In mountainous terrain, breakeven ADT volumes are 600 vpd and about 450 vpd for paved shoulders and unpaved shoulders, respectively.

Comparison of 11-Ft Lanes with 4-Ft Shoulders to 11-Ft Lanes with 2-Ft Shoulders

For highways where an 11-ft lane width is most appropriate, even for the lowest traffic volume levels, there is a question of when a more than minimum 2-ft shoulder is justified. The bottom of Table 23 summarizes analyses of the ADT levels that justify the addition of 2 ft to each shoulder. From the accident studies, there is a significant safety benefit of a design with 11-ft widths

TABLE 22. Comparison of 10-ft lanes with 5-ft shoulders to 10-ft lanes with 2-ft shoulders

Typical Construction Costs per Mile ($000s) from Table 21							
Lane/Shoulder Width (feet)	Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
		Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
10/5	<10%	$856.1	$795.8	$907.3	$847.0	$1,323.3	$1,263.0
	>10%	$916.4	$856.1	$967.6	$907.3	$1,383.6	$1,323.3
10/2	<10%	$749.1	$725.0	$796.4	$772.2	$1,180.5	$1,156.4
	>10%	$809.4	$785.3	$856.7	$832.5	$1,240.8	$1,216.7

Difference in Annualized Construction Costs per Mile (20-Year Project Life, 6-Percent Discount Rate, and Capital Recovery Factor of 0.08718)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	$9,328	$6,172	$9,668	$6,521	$12,449	$9,293
>10%	$9,328	$6,172	$9,668	$6,521	$12,449	$9,293

Accidents and Accident Costs									
Lane Width/Shoulder Width (feet)	Related Accident Rate (per MVM) Terrain			Annual Related Accidents per Mile per 100 vpd Terrain			Annual Related Accident Costs per Mile per 100 vpd Terrain		
	L	R	M	L	R	M	L	R	M
10/5	1.30	1.43	1.88	0.047	0.052	0.069	$2,820	$3,120	$4,120
10/2	2.28	2.41	2.86	0.083	0.088	0.104	$4,980	$5,280	$6,240
Difference	—	—	—	—	—	—	$2,160	$2,160	$2,160

Breakeven ADT for 10-Foot Lane Width and 5-Foot Shoulder Width (vpd)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	430	286	448	302	576	430
>10%	430	286	448	302	576	430

and 4-ft shoulders versus 11-ft lane widths and 2-ft shoulders. The difference in costs between the two alternatives varies with terrain, because much of the cost difference is associated with earthwork.

Using the analysis results as a general guideline, the following is concluded: for highways in level and rolling terrain, widening to a 4-ft shoulder with 11-ft lanes is justified for highways with paved shoulders at ADT levels of 500 vpd or greater, and at ADT of 400 vpd or greater for highways with unpaved shoulders; for highways in mountainous terrain, widening to a 4-ft shoulder with 11-ft lanes is justified at ADT levels of 700 vpd or greater for paved shoulders and 500 vpd or greater for unpaved shoulders.

Comparison of 12-Ft Lanes with 4-Ft Shoulders to 12-Ft Lanes with 2-Ft Shoulders

Certain highways should be designed with a minimum 12-ft lane width because of the design speed and functional classification. For such highways, there is a question of when a more than minimum 2-ft shoulder is justified. Table 24 summarizes analyses of the ADT levels that justify the addition of 2 ft to each shoulder. The results of the accident studies show a significant safety benefit of a design with 12-ft lane widths and 4-ft shoulders versus 12-ft lane widths and 2-ft shoulders. The difference in costs between the two alternatives varies with terrain, because much of the cost is associated with earthwork.

Using the analysis results as a general guideline, the following is concluded: for highways in level and rolling terrain, widening to a 4-ft shoulder with 12-ft lanes is justified for highways with paved shoulders at ADT levels of 500 vpd or greater, and at ADT of 400 vpd or greater for highways with unpaved shoulders; for highways in mountainous terrain, widening to a 4-ft shoulder with 12-ft lanes is justified at ADT levels of 700 vpd or greater for paved shoulders and 500 vpd or greater for unpaved shoulders.

Comparison of 11-Ft Lanes with 2-Ft Shoulders to 10-Ft Lanes with 2-Ft Shoulders

For certain functional classes and design speeds, either 10-ft or 11-ft lanes may be appropriate. The analysis summarized in

TABLE 23. Comparison of 11-ft lanes with 4-ft shoulders to 11-ft lanes with 2-ft shoulders

Typical Construction Costs per Mile ($000s) from Table 21							
Lane/Shoulder Width (feet)	Percent Trucks	Level Terrain Shoulders Paved	Level Terrain Shoulders Unpaved	Rolling Terrain Shoulders Paved	Rolling Terrain Shoulders Unpaved	Mountainous Terrain Shoulders Paved	Mountainous Terrain Shoulders Unpaved
11/4	<10%	$865.1	$816.9	$916.3	$868.1	$1,332.3	$1,284.1
	>10%	$931.5	$883.2	$982.6	$934.4	$1,398.6	$1,350.4
11/2	<10%	$793.8	$769.7	$842.4	$818.2	$1,237.2	$1,213.0
	>10%	$860.1	$836.0	$908.7	$884.6	$1,303.5	$1,279.4

Difference in Annualized Construction Costs per Mile (20-Year Project Life, 6-Percent Discount Rate, and Capital Recovery Factor of 0.08718)						
Percent Trucks	Level Terrain Shoulders Paved	Level Terrain Shoulders Unpaved	Rolling Terrain Shoulders Paved	Rolling Terrain Shoulders Unpaved	Mountainous Terrain Shoulders Paved	Mountainous Terrain Shoulders Unpaved
<10%	$6,216	$4,115	$6,443	$4,350	$8,291	$6,198
>10%	$6,225	$4,115	$6,443	$4,342	$8,291	$6,198

Accidents and Accident Costs									
Lane Width/Shoulder Width (feet)	Related Accident Rate (per MVM) Terrain L	R	M	Annual Accidents per Mile per 100 vpd Terrain L	R	M	Annual Accident Costs per Mile per 100 vpd Terrain L	R	M
11/4	1.18	1.31	1.76	0.043	0.048	0.064	$2,584	$2,880	$3,840
11/2	1.74	1.87	2.32	0.064	0.068	0.085	$3,840	$4,080	$5,100
Difference	—	—	—	—	—	—	$1,256	$1,200	$1,260

Breakeven ADT for 11-Foot Lane Width and 4-Foot Shoulder Width (vpd)						
Percent Trucks	Level Terrain Shoulders Paved	Level Terrain Shoulders Unpaved	Rolling Terrain Shoulders Paved	Rolling Terrain Shoulders Unpaved	Mountainous Terrain Shoulders Paved	Mountainous Terrain Shoulders Unpaved
<10%	495	328	537	362	658	491
>10%	495	328	537	362	658	491

Table 25 compares an 11-ft lane and 2-ft shoulder design with a 10-ft lane and 2-ft shoulder design. The former design has a better expected safety performance, at a higher construction cost.

It is concluded that the wider lane width becomes more cost-effective at ADT levels of 350 to 400 vpd for level to rolling terrain, and at about 500 vpd for mountainous terrain.

Comparison of 10-Ft Lanes with 6-Ft Shoulders to 11-Ft Lanes with 2-Ft Shoulders

Table 26 summarizes a comparison of two distinctly different designs. A cross section with 10-ft lanes and wide, 6-ft shoulders has a lower expected accident rate than one with 11-ft lanes and narrow, 2-ft shoulders. The wider total cross section has a greater construction cost as well.

Using the analysis results as a general guideline, it is concluded that, where paved shoulders are used, the 10-ft lane with a 6-ft shoulder design is cost-effective only at relatively high traffic volumes—800 to 900 vpd for level and rolling terrain and 1,200 vpd for mountainous terrain. Where shoulders are unpaved and shoulder costs are lower, the breakeven ADT levels for the 10-ft lane with a 6-ft shoulder design are somewhat lower—400 vpd in level terrain, about 500 vpd in rolling terrain, and 750 vpd in mountainous terrain.

Comparison of 11-Ft Lanes with 4-Ft Shoulders to 10-Ft Lanes with 5-Ft Shoulders

For certain functional classes and design speeds, either 10- or 11-foot lanes may be appropriate. Table 27 summarizes the analysis of a comparison between an 11-ft lane width and a 4-ft shoulder width design with a 10-ft lane width and a 5-foot shoulder width design. The wider lane width design offers a slight accident rate advantage at higher typical unit costs of construction. Note that the cost differences are greater for cases in which the shoulder is unpaved and where the pavement is designed to accommodate high truck volumes.

Using the analysis results as a general guideline, it is concluded

TABLE 24. Comparison of 12-ft lanes with 4-ft shoulders to 12-ft lanes with 2-ft shoulders

Typical Construction Costs per Mile ($000s) from Table 21							
Lane/Shoulder Width (Feet)	Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
		Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
12/4	< 10%	$909.8	$861.6	$962.3	$914.1	$1,388.9	$1,340.7
	> 10%	$982.2	$934.0	$1,034.7	$986.4	$1,461.3	$1,413.0
12/2	< 10%	$838.5	$814.4	$888.4	$864.3	$1,293.8	$1,269.7
	> 10%	$910.9	$886.7	$960.7	$936.6	$1,366.1	$1,342.0

Difference in Annualized Construction Costs per Mile (20-Year Project Life, 6-Percent Discount Rate, and Capital Recovery Factor of 0.08718)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
< 10%	$6,216	$4,115	$6,442	$4,342	$8,291	$6,190
> 10%	$6,216	$4,124	$6,451	$4,342	$8,299	$6,190

Accidents and Accident Costs									
Lane Width/Shoulder Width (feet)	Related Accident Rate (per MVM) Terrain			Annual Accidents per Mile per 100 vpd Terrain			Annual Accident Costs per Mile per 100 vpd Terrain		
	L	R	M	L	R	M	L	R	M
12/4	1.18	1.31	1.76	0.043	0.048	0.064	$2,584	$2,880	$3,840
12/2	1.74	1.87	2.32	0.064	0.068	0.085	$3,840	$4,080	$5,100
Difference	—	—	—	—	—	—	$1,256	$1,200	$1,260

Breakeven ADT for 12-Foot Lane Width and 4-Foot Shoulder Width (vpd)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
< 10%	495	328	537	362	658	491
> 10%	495	328	537	362	658	491

that the 11-ft lane width with 4-ft shoulder width design is cost-effective for highways with paved shoulders at ADT greater than 400 to 500 vpd. The 11-ft lane width with 4-ft shoulder width design is cost-effective where unpaved shoulders are used for highways with low truck volumes (less than 10 percent) and ADT greater than 750 vpd. Where truck volumes are greater than 10 percent, this design is cost-effective when ADT exceeds 1,000 vpd.

Comparison of 12-Ft Lanes with 3-Ft Shoulders to 11-Ft Lanes with 4-Ft Shoulders

For certain functional classes and design speeds, either an 11-ft or 12-ft lane width may be appropriate. Table 28 summarizes a comparison between a 12-ft lane width and 3-ft shoulder width design with an 11-ft lane width and 4-ft shoulder width design.

The accident analyses do not show a significant difference in the safety performance of the two alternatives. The question of choice, thus, is reduced to an assessment of the difference in costs. As shown in Table 28, typical construction costs are greater for the design with 12-ft lanes in all cases. Note, however, that the actual cost differential is very small, particularly for roads with paved shoulders and for roads designed for lower truck volumes.

It is concluded that, in general, a cross section with 11-ft lane widths and 4-ft shoulders is preferred for all volume levels for highways with unpaved shoulders and with pavements designed for truck volumes greater than 10 percent of ADT. For highways with paved shoulders that are designed to accommodate lower truck volumes (less than 10 percent of ADT), the 11-ft lane width and 4-ft shoulder width design is only marginally preferred. Within the limitations of cost modeling and the assumptions, no meaningful difference exists.

TABLE 25. Comparison of 11-ft lanes with 2-ft shoulders to 10-ft lanes with 2-ft shoulders

Typical Construction Costs per Mile ($000s) from Table 21							
Lane/Shoulder Width (feet)	Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
		Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
11/2	<10%	$793.8	$769.7	$842.4	$818.2	$1,237.2	$1,213.0
	>10%	$860.1	$836.0	$908.7	$884.6	$1,303.5	$1,279.4
10/2	<10%	$749.1	$725.0	$796.4	$772.2	$1,180.5	$1,156.4
	>10%	$809.4	$785.3	$856.7	$832.5	$1,240.8	$1,216.7

Difference in Annualized Construction Costs per Mile (20-Year Project Life, 6-Percent Discount Rate, and Capital Recovery Factor of 0.08718)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	$3,897	$3,897	$4,010	$4,010	$4,943	$4,943
>10%	$4,420	$4,420	$4,542	$4,542	$5,466	$5,466

Accidents and Accident Costs									
Lane Width/Shoulder Width (feet)	Related Accident Rate (per MVM) Terrain			Annual Accidents per Mile per 100 vpd Terrain			Annual Accident Costs per Mile per 100 vpd Terrain		
	L	R	M	L	R	M	L	R	M
11/2	1.74	1.87	2.32	0.064	0.068	0.085	$3,840	$4,080	$5,100
10/2	2.28	2.41	2.86	0.083	0.088	0.104	$4,980	$5,280	$6,240
Difference	—	—	—	—	—	—	$1,140	$1,200	$1,140

Breakeven ADT for 11-Foot Lane Width and 2-Foot Shoulder Width (vpd)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	342	342	334	334	433	433
>10%	388	388	377	377	479	479

TABLE 26. Comparison of 10-ft lanes with 6-ft shoulders to 11-ft lanes with 2-ft shoulders

Typical Construction Costs per Mile ($000s) from Table 21							
Lane/Shoulder Width (feet)	Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
		Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
10/6	<10%	$891.7	$819.4	$944.2	$871.9	$1,370.8	$1,298.5
	>10%	$952.0	$879.7	$1,004.5	$932.2	$1,431.1	$1,358.8
11/2	<10%	$793.8	$769.7	$842.4	$818.2	$1,237.2	$1,213.0
	>10%	$860.1	$836.0	$908.7	$884.6	$1,303.5	$1,279.4

Difference in Annualized Construction Costs per Mile (20-Year Project Life, 6-Percent Discount Rate, and Capital Recovery Factor of 0.08718)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	$8,535	$4,333	$8,875	$4,682	$11,647	$7,454
>10%	$8,012	$3,809	$8,352	$4,150	$11,124	$6,922

Accidents and Accident Costs									
Lane Width/Shoulder Width (feet)	Related Accident Rate (per MVM) Terrain			Annual Accidents per Mile per 100 vpd Terrain			Annual Accident Costs per Mile per 100 vpd Terrain		
	L	R	M	L	R	M	L	R	M
10/6	1.30	1.43	1.88	0.047	0.052	0.069	$2,820	$3,120	$4,140
11/2	1.74	1.87	2.32	0.064	0.068	0.085	$3,840	$4,080	$5,100
Difference	—	—	—	—	—	—	$1,020	$960	$960

Breakeven ADT for 10-Foot Lane Width and 6-Foot Shoulder Width (vpd)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	837	425	924	488	1,213	776
>10%	785	373	870	432	1,159	721

TABLE 27. Comparison of 11-ft lanes with 4-ft shoulders to 10-ft lanes with 5-ft shoulders

Typical Construction Costs per Mile ($000s) from Table 21							
Lane/Shoulder Width (feet)	Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
		Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
11/4	<10%	$865.1	$816.9	$916.3	$868.1	$1,332.3	$1,284.1
	>10%	$931.5	$883.2	$982.6	$934.4	$1,398.6	$1,350.4
10/5	<10%	$856.1	$795.8	$907.3	$847.0	$1,323.3	$1,263.0
	>10%	$916.4	$856.1	$967.6	$907.3	$1,383.6	$1,323.3

Difference in Annualized Construction Costs per Mile (20-Year Project Life, 6-Percent Discount Rate, and Capital Recovery Factor of 0.08718)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	$785	$1,839	$785	$1,839	$785	$1,839
>10%	$1,316	$2,363	$1,308	$2,363	$1,308	$2,363

Accidents and Accident Costs									
Lane Width/Shoulder Width (feet)	Related Accident Rate (per MVM) Terrain			Annual Accidents per Mile per 100 vpd Terrain			Annual Accident Costs per Mile per 100 vpd Terrain		
	L	R	M	L	R	M	L	R	M
11/4	1.18	1.31	1.76	0.043	0.048	0.064	$2,580	$2,880	$3,880
10/5	1.30	1.43	1.88	0.047	0.052	0.069	$2,820	$3,120	$4,140
Difference	—	—	—	—	—	—	$240	$240	$260

Breakeven ADT for 11-Foot Lane Width and 4-Foot Shoulder Width (vpd)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
<10%	327	766	327	766	302	707
>10%	548	984	545	984	503	909

TABLE 28. Comparison of 12-ft lanes with 3-ft shoulders to 11-ft lanes with 5-ft shoulders

Typical Construction Costs per Mile ($000s) from Table 21							
Lane/Shoulder Width (feet)	Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
		Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
12/3	< 10%	$874.2	$838.0	$925.3	$889.2	$1,341.3	$1,305.2
	> 10%	$946.5	$910.4	$997.7	$961.5	$1,413.7	$1,377.5
11/4	< 10%	865.1	816.9	916.3	868.1	1,332.3	1,284.1
	> 10%	931.5	883.2	982.6	934.4	1,398.6	1,350.4

Difference in Annualized Construction Costs per Mile (20-Year Project Life, 6-Percent Discount Rate, and Capital Recovery Factor of 0.08718)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
< 10%	$793	$1,839	$785	$1,839	$785	$1,839
> 10%	$1,308	$2,371	$1,316	$2,363	$1,316	$2,363

Accidents and Accident Costs									
Lane Width/Shoulder Width (feet)	Related Accident Rate (per MVM) Terrain			Annual Accidents per Mile per 100 vpd Terrain			Annual Accident Costs per Mile per 100 vpd Terrain		
	L	R	M	L	R	M	L	R	M
12/3	1.18	1.31	1.76	0.043	0.048	0.064	$2,584	$2,880	$3,840
11/4	1.18	1.31	1.76	0.043	0.048	0.064	$2,584	$2,880	$3,840
Difference	—	—	—	—	—	—	$0	$0	$0

Breakeven ADT for 12-Foot Lane Width and 3-Foot Shoulder Width (vpd)						
Percent Trucks	Level Terrain Shoulders		Rolling Terrain Shoulders		Mountainous Terrain Shoulders	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
< 10%	N/A	N/A	N/A	N/A	N/A	N/A
> 10%	N/A	N/A	N/A	N/A	N/A	N/A

CHAPTER 3

RESULTS, INTERPRETATION, APPRAISAL, AND APPLICATION

The primary research objective is to refine current width-related design values for low-volume roads. The AASHTO *Policy* suggests the framework for these standards. Design standards are appropriately based on the following considerations: functional classification, design speed, highway operational requirements, safety-effectiveness, and construction and maintenance costs.

It is noted that design standards are not based strictly on "cost-effectiveness." There are certain minimum width values necessary to accommodate the functional requirements of the drivers and vehicles that use the highway, regardless of the volume of traffic. These functional requirements include construction and design features, shoulder use, and highway operations.

Another central point regarding roadway width design standards is the need to confirm or establish compatibility with other design standards and criteria. The researchers consider a set of design standards flawed if, by their very nature, they produce operational or design conflicts when used with other established standards.

Specific to low-volume roads, derivation of appropriate width design standards is based on the following approach. For roadways with extremely low volumes, appropriate widths are based on minimum functional dimensions as well as compatibility with the design speed of the facility. Incrementally, greater widths for the total roadway (lanes plus shoulders) become cost-effective as the design volume increases, depending on the terrain and other cost sensitivities noted earlier. Consistency with speeds and sensitivity to shoulder functions controls the allocation of total width to maintain design standard compatibility.

Although the accident studies provide little justification for total roadway widths greater than 30 ft, other factors become important as design traffic volumes increase to 1,500 vpd or more. Lane and shoulder width design values should promote reasonable truck operations and enable achieving reasonable levels of service for the given terrain, functional classification, and design traffic conditions.

Tables 29(a) through 29(f) show recommended minimum design values for lane width, shoulder width, and total roadway width. To summarize, derivation of these widths was based on the following general approach:

1. The AASHTO framework for design values was used. Widths are characterized as a function of design speed, terrain, functional classification, and traffic characteristics (volume and percentage of trucks).
2. Minimum lane width values are first established for a given design speed and functional classification. The basis of these minimum widths is consistency in operating speed, with a 9-ft lane width considered the absolute minimum acceptable design. Greater lane widths of up to 12 ft are considered appropriate for even the lowest volumes where terrain and design speed dictate (refer to Appendix F).
3. A minimum shoulder width value of 2 ft for the lowest ADT class was established. A maximum shoulder width value of 8 ft was used for higher volume arterials and 6 ft for other classes.
4. Safety cost-effectiveness was the basis for recommending total roadway width values for each ADT range. This total width, then, was allocated in each case, given the relationships discussed above between design speed and lane width.
5. Where applicable (see Appendix E), the total lane and shoulder width values were increased to provide a compatible design with respect to capacity and level of service.

COMPARISON OF RECOMMENDED WIDTHS TO CURRENT AASHTO *POLICY*

The recommended values for minimum lane and shoulder widths on low-volume roads differ, significantly in some cases, from current AASHTO *Policy* values.

Format

In keeping with the cost and level-of-service sensitivities associated with terrain, width values are described in terms of level, rolling, and mountainous terrain. The cost-effectiveness studies in this research indicate that, in some instances, narrower widths are appropriate in mountainous terrain versus slightly wider values in rolling or level terrain. Also, width values are shown relative to design year ADT volume rather than to the somewhat confusing practice in AASHTO of mixing existing traffic, design traffic, ADT, and DHV. Finally, values for total width are shown in addition to lane width and shoulder width.

Local Road Design Values

The recommended design widths for local roads represent significant revisions to current AASHTO *Policy* values. Current policy specifies a range in lane widths from 9 ft to 12 ft, in shoulder widths from 2 ft to 6 ft, and in total width from 22 ft to 36 ft. Moreover, the minimum widths (both by element as well as total) increase steadily as traffic volumes increase.

The research performed here supports a different approach to design standards. First, for local roads, design speeds are generally in the range of 30 mph to 50 mph, with 20 mph possible in mountainous terrain. Under such operating conditions, given the classification and general volume levels, 10-ft lanes are ap-

TABLE 29(a). Local roads, design year ADT 0–2000 vpd (≤ 10% trucks)

Design Speed (mph)	Cross Section Elements* (feet)	Design Year Traffic Volumes (ADT) in Vehicles per Day					
		0-250	250-400	400-750	750-1500	1500-2000	Comments
LEVEL TERAIN							
30	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	*Minimum 10-foot lanes are appropriate for 50 mph
	TW LW SW	-	-	-	-	-	
ROLLING TERAIN							
30	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	10-foot lanes are appropriate for 50 mph
MOUNTAINOUS TERAIN							
20	TW LW SW	(22) 9 2	(22) 9 2	(22)* 9 2	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 20 mph
30	TW LW SW	(22) 9 2	(22) 9 2	(22) 9* 2	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 40 mph
50	TW LW SW	-	-	-	-	-	

TW——Total roadway width (lanes plus shoulders)
LW——Lane width
SW——Shoulder width (paved or unpaved)

*10-foot lanes and 5-foot shoulders may be considered as reasonable minimums for ADT greater than 600 vpd.

propriate in most cases. Indeed, for lower speed, lower volume conditions the research supports 9-ft minimum lane widths. For 50-mph design speed local roads, 11-ft lane widths may be appropriate, particularly when ADT is greater than 400 vpd. Twelve-ft lanes not only are more costly, but may promote higher speeds (speeds incompatible with horizontal and vertical alignment) than desired for these facilities. For these reasons, 12-ft lane widths are not recommended as a basic standard.

TABLE 29(b). Local roads, design year ADT 0–2000 vpd (> 10% trucks)

Design Speed (mph)	Cross Section Elements* (feet)	Design Year Traffic Volumes (ADT) in Vehicles per Day					
		0-250	250-400	400-750	750-1500	1500-2000	Comments
LEVEL TERRAIN							
30	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(24) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	10-foot minimum lanes are appropriate for 50 mph
	TW LW SW	-	-	-	-	-	
ROLLING TERRAIN							
30	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	10-foot minimum lanes are appropriate for 50 mph
MOUNTAINOUS TERRAIN							
20	TW LW SW	(22) 9 2	(22) 9 2	(22)* 9 2	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
30	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 40 mph
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	10-foot minimum lanes are appropriate for 50 mph
50	TW LW SW	-	-	-	-	-	

TW——Total roadway width (lanes plus shoulders)
LW——Lane width
SW——Shoulder width (paved or unpaved)

*10-foot lanes and 5-foot shoulders may be considered as reasonable minimums for ADT greater than 600 vpd.

In terms of combinations of lane and shoulder width, safety cost-effectiveness identifies traffic volume levels of about 300 vpd as the point at which a 5-ft shoulder is cost-effective, combined with a 10-ft lane width. Beyond this point, however, there is no safety justification for a total width greater than 30 ft. Note that where 11-ft lanes are considered appropriate, 4-ft shoulders, producing a total width of 30 ft, result in significant safety benefits. The cost-effectiveness analysis showed that ADT levels

TABLE 29(c). Collector roads, design year ADT 0–2000 vpd (≤ 10% trucks)

Design Speed (mph)	Cross Section Elements* (feet)	Design Year Traffic Volumes (ADT) in Vehicles per Day					
		0-250	250-400	400-750	750-1500	1500-2000	Comments
LEVEL TERRAIN							
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes appropriate for 40 mph
50	TW LW SW	(24) 10 2	(26) 11 2	(30) 11 4	(30) 11 4	(34) 11 6	10- or 11-foot lanes are appropriate for 50 mph
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(30) 11 4	(34) 11 6	11-foot lanes are appropriate for 60 mph
ROLLING TERRAIN							
30	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	10- or 11-foot lanes are appropriate for 50 mph
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(30) 11 4	(34) 11 6	11-foot lanes are appropriate for 60 mph
MOUNTAINOUS TERRAIN							
20	TW LW SW	(22) 9 2	(22) 9 2	(22)* 9 2	(30) 10 5	(32) 10 6	9-foot lanes are appropriate for 20 mph
30	TW LW SW	(22) 9 2	(22) 9 2	(22)* 9 2	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(24) 10 2	(24) 10 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	10- or 11-foot lanes are appropriate for 50 mph

TW——Total roadway width (lanes plus shoulders)
LW——Lane width
SW——Shoulder width (paved or unpaved)

*10-foot lanes and 5-foot shoulders may be considered as reasonable minimums for ADT greater than 600 vpd.

that justify this allocation are around 250 vpd for level and rolling terrain. Finally, for the highest volume range within the study (1,500 to 2,000 vpd), a minimum 6-ft shoulder is considered appropriate for shoulder functions. This leads to a minimum total width of 32 ft to 34 ft for the higher volume ranges.

The net effect of the recommendations is that the total width of local roads should vary much less with traffic volume than AASHTO indicates. Above an ADT of 250 vpd, (400 vpd in mountainous terrain), 30-ft total widths are justified. Total widths significantly above this value are not justified in terms of safety,

TABLE 29(d). Collector roads, design year ADT 0–2000 vpd (> 10% trucks)

Design Speed (mph)	Cross Section Elements* (feet)	Design Year Traffic Volumes (ADT) in Vehicles per Day					
		0-250	250-400	400-750	750-1500	1500-2000	Comments
LEVEL TERRAIN							
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes appropriate for 40 mph
50	TW LW SW	(24) 10 2	(26) 11 2	(30) 11 4	(30) 11 4	(34) 11 6	10- or 11-foot lanes are appropriate for 50 mph
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(30) 11 4	(34) 11 6	11-foot lanes are appropriate for 60 mph
ROLLING TERRAIN							
30	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(22) 9 2	(22) 9 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	10- or 11-foot lanes are appropriate for 50 mph
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(30) 11 4	(34) 11 6	11-foot lanes are appropriate for 60 mph
MOUNTAINOUS TERRAIN							
20	TW LW SW	(24) 9 3	(24) 9 3	(30) 10 5	(30) 10 5	(32) 10 6	9-foot lanes are appropriate for 20 mph
30	TW LW SW	(24) 9 3	(24) 9 3	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes are appropriate for 30 mph
40	TW LW SW	(24) 10 2	(24) 10 2	(30) 10 5	(30) 10 5	(32) 10 6	9- or 10-foot lanes appropriate for 40 mph
50	TW LW SW	(24) 10 2	(24) 10 2	(30) 11 4	(30) 11 4	(34) 11 6	10- or 11-foot lanes are appropriate for 50 mph

TW——Total roadway width (lanes plus shoulders)
LW——Lane width
SW——Shoulder width (paved or unpaved)

capacity, or design speed compatibility and, therefore, are not recommended as the basis for design standards.

Collector Design Values

The most significant difference between recommended and AASHTO minimum width values is in lane width. Ten-ft lanes are judged sufficient for lower design-speed collectors (30 to 40 mph). Indeed, this width is more compatible with the alignment quality expected in rolling and mountainous terrain. Moreover, wider lane widths are not required to provide sufficient capacity.

TABLE 29(e). Arterial roads, design year ADT 0–2000 vpd (≤ 10% trucks)

Design Speed (mph)	Cross Section Elements* (feet)	Design Year Traffic Volumes (ADT) in Vehicles per Day					
		0-250	250-400	400-750	750-1500	1500-2000	Comments
LEVEL TERRAIN							
40	TW LW SW	-	-	-	-	-	
50	TW LW SW	-	-	-	-	-	
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(36) 12 6	(40) 12 8	11- or 12-foot lanes are appropriate for 60 mph
70	TW LW SW	(28) 12 2	(28) 12 2	(30) 12 4	(36) 12 6	(40) 12 8	12-foot lanes are appropriate for 70 mph
ROLLING TERRAIN							
40	TW LW SW	(24) 9 3[a]	(24) 9 3[a]	(30) 11 4	(34) 11 6	(38) 11 8	9-foot lanes are appropriate for 40 mph
50	TW LW SW	(26) 10 3[a]	(26) 10 3[a]	(30) 11 or 10 4 or 5[b]	(34) 11 6	(38) 11 8	10- or 11-foot lanes are appropriate for 50 mph
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(30) 11 4	(40) 12 8[c]	11- or 12-foot lanes are appropriate for 60 mph
MOUNTAINOUS TERRAIN							
20	TW LW SW	-	-	-	-	-	
30	TW LW SW	-	-	-	-	-	
40	TW LW SW	(26) 10 3[a]	(26) 10 3[a]	(26) 11 2	(34) 11 6	(34) 11 6	10- or 11-foot lanes are appropriate for 40 mph
50	TW LW SW	(26) 10 3[a]	(26) 10 3[a]	(26) 11 2	(34) 11 6	(34) 11 6	10- or 11-foot lanes are appropriate for 50 mph

TW——Total width (lanes plus shoulders)
LW——Lane width
SW——Shoulder width (paved or unpaved)

[a]3-foot shoulders recommended as minimums for arterials with 9- or 10-foot lanes.
[b]10/5 design is minimum for unpaved shoulders; 11/4 design is minimum for paved shoulders.
[c]Minimum lane and shoulder widths to provide sufficient capacity.

The accident studies confirm that 10-ft lanes, when coupled with at least 5-ft shoulders, are cost-effective. For speeds of 50 mph and 60 mph, a greater lane width of 11 ft may be used, particularly, on roads with traffic volumes above 750 vpd. In such cases, note that the minimum shoulder width need only be 4 ft to provide the most cost-effective design. Finally, in no case is a recommended minimum 12-ft lane width required, given that collectors are generally designed with, at most, a 60-mph design

TABLE 29(f). Arterial roads, design year ADT 0–2000 vpd (≥ 10% trucks)

Design Speed (mph)	Cross Section Elements* (feet)	Design Year Traffic Volumes (ADT) in Vehicles per Day					
		0-250	250-400	400-750	750-1500	1500-2000	Comments
LEVEL TERRAIN							
40	TW LW SW	-	-	-	-	-	
50	TW LW SW	-	-	-	-	-	
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(30) 11 4	(38) 11 8	11- or 12-foot lanes are appropriate for 60 mph
70	TW LW SW	(28) 12 2	(28) 12 2	(32) 12 4	(32) 12 4	(40) 12 8	12-foot lanes are appropriate for 70 mph
ROLLING TERRAIN							
40	TW LW SW	(26) 10 3[a]	(26) 11 2	(30) 11 4	(30) 11 4	(38) 11[b] 8	10-foot minimum lanes are appropriate for high truck percent
50	TW LW SW	(26) 10 3[a]	(26) 11 2	(30) 11 4	(30) 11 4	(38) 11[b] 8	10- or 11-foot lanes are appropriate for 50 mph
60	TW LW SW	(26) 11 2	(26) 11 2	(30) 11 4	(30) 11 4	(40) 12[b] 8	11- or 12 foot lanes are appropriate for 60 mph
MOUNTAINOUS TERRAIN							
20	TW LW SW	-	-	-	-	-	
30	TW LW SW	-	-	-	-	-	
40	TW LW SW	(26) 10 3[a]	(26) 10 3[a]	(26) 11 2	(34) 11 6[b]	(36) 12[b] 6	
50	TW LW SW	(26) 10 3[a]	(26) 11 2	(26) 11 2	(34) 11 6	(36) 12[b] 6	

TW——Total roadway width (lanes plus shoulders)
LW——Lane width
SW——Shoulder width (paved or unpaved)

[a]3-foot minimum shoulders recommended in rolling and mountainous terrain with 10-foot lanes.
[b]Minimum lane and shoulder widths to provide required capacity.

speed. For the highest volume design class (1,500 to 2,000 vpd), 11-ft lanes and 6-ft shoulders provide sufficient highway capacity and reasonable shoulder functions. There is no identifiable safety benefit of a 12-ft versus 11-ft lane width, in either case, when coupled with wide shoulders. Finally, 11-ft lane widths are reasonably compatible with even 60-mph speeds.

Note, again, that the sensitivity of total roadway width to ADT is much less than that shown by current AASHTO design values.

The most cost-effective total width of 30 ft is justified at low traffic volumes—250 vpd in level and rolling terrain and 400 vpd in mountainous terrain.

Arterial Design Values

The recommended lane width values are less than those called for by AASHTO for lower volume arterials (less than 400 vpd). For very low-volume and lower speed arterials (40 to 50 mph design speed), there is no evidence to suggest that 11-ft or 12-ft lanes are necessary as minimums. Also, for such traffic volumes, 2-ft shoulders rather than 4-ft shoulders generally appear sufficient. Minimum design values for shoulder width (and total width) are not increased substantially until design traffic exceeds 750 vpd. For the highest volume design class, full 8-ft shoulders are recommended on arterials in rolling and level terrain. Also, minimum 12-ft lanes are recommended, in some cases, to provide compatibility with highway capacity and level-of-service requirements. Again, note that the total width requirements vary much less by volume than current AASHTO *Policy*.

APPLICATION TO 3R DESIGN PROBLEMS

The accident relationships developed in this research provide guidance toward appropriate, cost-effective treatments for existing low-volume road cross sections. The following general findings provide a basis for such guidelines:

1. Safety-effectiveness is primarily sensitive to total roadway width, and less sensitive to the allocation of width between lanes and shoulders. (This is true for normal combinations of lane width and shoulder width.)
2. Within the range of typical total roadway widths, the safety-effectiveness of incremental widths is distinctly nonlinear. For total roadway widths of 24 ft or less, related accident rates are in the range of 1.7 to 2.3 accidents per MVM. Related accidents decrease significantly as total widths increase to 28 to 30 ft. Above 30 ft, little or no safety-effectiveness is expected with incremental widening.
3. Specifically, the research did not uncover high accident rates for roadways with 8-ft or 9-ft lane widths. The accident effects of 8-ft lane widths were mixed and unclear from the available low-volume data because of the small sample of mileage. Based on the available evidence, the use of lane widths below 9 ft is not considered to be desirable.
4. The effect of terrain on accident rates does not appear to be width-sensitive. ("Terrain" is considered a surrogate variable describing quality of horizontal and vertical alignment, and also roadside quality). The effect of terrain is the same, for example, on 26-ft roadways as on 38-ft roadways.

Guidelines for 3R Design Problems

The research findings and general approach to design standards outlined here provide the following guidelines for use in 3R projects.

1. Designers should note the incremental safety-effectiveness of widening from 24-ft or 26-ft total roadway widths to 30 ft. For existing narrow roadways, minimal widening may be significantly effective at very low volumes.
2. Conversely, where the existing total width is 30 ft or greater, width-related 3R safety improvements may be minimal. In such cases, the focus should probably be shifted to roadside improvements, spot geometric improvements, and traffic control.
3. Routine 3R widening of very narrow (less than 10-ft lanes) roadways should not necessarily be performed. Rather, decisions to widen should be based in large part on analysis of existing accident experience. Related accident rates contained in this report (also see Appendixes A and B) can be referenced to determine whether or not a location is unusual or a "high-accident" location.
4. For 3R projects on highways with design volumes of 1,500 vpd or greater, decisions regarding widening may involve highway operational requirements. An appropriate approach would be to conduct speed and volume studies to determine actual operations and level of service. Increasing lane widths for capacity or truck traffic should be done on a site-specific basis, although the design values given in Tables 29(a) through 29(f) can be referenced.
5. Any 3R design project should be undertaken with a sensitivity to the classification and design speed issues discussed herein. Care should be taken not to widen a narrow road until it can be determined that any resulting speed increases are appropriate given the existing horizontal and vertical alignment. (Note: The nature of 3R projects is that they involve minimal alignment revisions or reconstruction.)
6. Widening shoulders rather than lanes is less costly and will be more cost-effective. For 3R projects where existing total width is 26 ft or less, the optimal approach may be to focus on shoulder widening. The discussion, earlier, regarding lane width and speed compatibility can be useful in deciding the need for lane widening on such narrow roads.
7. Designers should investigate spot widening alternatives because these options may be more cost-effective than continuous widening. Widening through curves, implementation of truck climbing lanes, or spot shoulder widening may all be effective, site-specific alternatives to continuous widening.

Procedures for Evaluation of Low-Volume Road Design Options

Appendix A, "Cost-Effectiveness Guide for Design Improvements to Roadway Cross Sections for Low-Volume Rural Roads," supplements the roadway width guidelines developed in this study. The Guide provides a procedure for computing the accident benefits related to various design improvements to roadway cross section (i.e., widening lanes, widening shoulders, paving shoulders, or improving roadsides) on sections of rural two-lane roads that are low volume (i.e., have ADTs of less than 2,000). Using this procedure, agencies can estimate their expected project costs for one or more design alternatives on a given roadway section along with expected accident benefits to determine the most cost-effective project alternative. A project alternative may consist of upgrading only one design feature (e.g., widening 9-ft lanes to 11-ft lanes) or upgrading combinations of features (e.g., widening lanes from 9-ft to 11-ft, adding a 4-ft paved shoulder, plus increasing the roadside lane zone from 11

ft to 15 ft). This guide is not intended to replace the use of the minimum width guidelines, but can provide useful input when deciding between two or more "acceptable" design options. Specifically, using the guide can assist a highway agency in getting the most accident savings per dollar spent on design improvements.

EVALUATION OF CASE STUDIES

Case studies for recent construction and reconstruction projects were solicited from the state agencies that responded to the survey of construction costs. NCHRP project panel members also provided case studies from their agency files.

The following four case studies were evaluated to compare design decisions reached in the actual project with the proposed design values derived from this research.

Case Study No. 1: *US 62 and 281—Widening and Reconstruction; Caddo County, Oklahoma*

The Oklahoma Department of Transportation recently reconstructed approximately 2.7 miles of US 62 and 281 in Caddo County. The project included a combination of widening and some realignment both horizontally and vertically. Key project data are summarized as follows:

	Preconstruction	Designed Improvement
Functional Classification	Arterial	—
Design Speed	—	55 mph
Terrain	Rolling	Rolling
Design Year Traffic:		
ADT	1,300 vpd (1990)	2,000 vpd
Percent Trucks	—	22
Typical Cross Section:		
Lane Width	11 ft	12 ft
Shoulder Width	—	8 ft

The cost of reconstruction was estimated at $2.7 million, or $1.0 million per mile. No accident or other operational data were provided.

Referring to Table 29(f), under the proposed design values, the lane and shoulder widths to meet full standards would be identical to those actually constructed. A 60-mph design speed is assumed to apply from Table 29(f). In this case, therefore, the revised standards would not reflect a change in design.

Case Study No. 2: *State Highway 46—Reconstruction; Gooding and Camas Counties, Idaho*

State Highway 46 was recently reconstructed through Camas and Gooding Counties in Idaho. The 4.4-mile project involved reconstruction along existing alignments with adjustments to the profile. Key project data, summarized in the three major sections of work, include:

		Improvement		
	Preconstruction	Section 1 (0.6 mi)	Section 2 (2.1 mi)	Section 3 (1.7 mi)
Functional Classification	Collector*	Collector	Collector	Collector
Design Speed	—	35 mph	60 mph	60 mph
Terrain	Rolling	Rolling	Rolling	Rolling
Design Year Traffic:				
ADT	770–2,400 vpd	2,880 vpd	1,620 vpd	930 vpd
Percent Trucks	—	3.6	6.4	11.1
Typical Cross Section:				
Combined Lane and Shoulder Width (one direction)	14 ft	14 ft	14 ft	14 ft

*Federal-Aid Secondary Road

Note that a 14-ft paved roadway (28 ft both directions) was the existing as well as proposed, reconstructed cross section. The reconstruction cost of $1.9 million translates to approximately $430,000 per mile.

Data provided by the Idaho Department of Transportation showed that the existing accident rate for State Highway 46 was 2.5 accidents per MVM. It was noted that this rate was only slightly higher than the state average. Thus, resolution of an existing safety problem did not appear to be a primary objective of the improvement project.

From inspection of Tables 29(c) and 29(d), the design values proposed for the reconstruction are less than would be called for by the revised standards. For section 1 of the improvement, a total width of 32 ft (10-ft lanes and 6-ft shoulders) is specified. For section 2, 11-ft lanes and 6-ft shoulders (34 ft total roadway width) would meet the revised standard. Finally, for section 3, 11-ft lanes and 4-ft shoulders (a 30-ft total roadway width) appear appropriate.

There are a number of interesting facets to Case Study No. 2. First, the great variation in traffic volume and design speed over the 4.4-mile project creates an unusual design problem. The theoretical design standards would call for three different designs, varying both lane and shoulder width. Such variation over a short distance may create the appearance of a discontinuous facility and be unnecessarily costly to design and construct. While no indication was given regarding how the lanes would be striped, the proposed design offers the opportunity to use 10-ft lanes and 4-ft shoulders (fully paved), or 11-ft lanes and 3-ft shoulders. As shown below, the theoretical accident rate for these designs does not differ significantly from the accident rate for the full standard. In addition, it is clear that the incremental costs of widening from the existing 28-ft roadway to a 30- to 34-ft roadway would be significant. In this case, therefore, where an existing total roadway width of 28 ft occurs, and where there is no existing serious safety problem, maintenance of the existing width appears to be a reasonable design approach.

	Full Standard	As Designed (28-ft Roadway)
Section 1:		
Lane/Shoulder Width (ft)	10/6	10/4 or 11/3
Predicted Related Accident Rate	1.43	2.41 or 1.31
Section 2:		
Lane/Shoulder Width (ft)	11/6	11/3
Predicted Related Accident Rate	1.31	1.31
Section 3:		
Lane/Shoulder Width (ft)	11/4	11/3
Predicted Related Accident Rate	1.31	1.31

Case Study No. 3: ***Oak Harbor Southeast Road—Resurfacing; Ottawa County, Ohio***

The Ohio Department of Transportation recently resurfaced 3.1 miles of Oak Harbor Southeast Road in Ottowa County, Ohio. The $600,000 project included about $280,000 for structure repair. The project was essentially a 3R project, with no significant adjustments to horizontal or vertical geometry. Key project data are summarized as follows:

Functional Classification	Collector
Design Speed	55 mph
Terrain	Rolling
Design Year Traffic:	
ADT	1,350 vpd
Percent Trucks	10
Typical Cross Section:	
Lane Width	12 ft
Shoulder Width	4 ft

The contract plans indicate that the existing and resurfaced cross sections are the same (12-ft lanes and 4-ft shoulders). Also, the plans note that a design exception for shoulder width was obtained for the project.

Based on the proposed design standards from the research here, not only would a design exception not be required, but the proposed cross section would actually exceed the minimum standard of 11-ft lanes and 4-ft shoulders.

In the case of existing roads with 12-ft lanes, maintenance of this full width (as opposed to a narrower width per the proposed standards) is a rational 3R decision. It should be made, however, with full understanding of the operational and safety performance of total widths, and of various lane and shoulder width combinations. As noted in Table 10, either 11-ft or 12-ft widths, when paired with at least 3-ft shoulders (total roadway width of 28 ft or 30 ft), would optimize safety.

Case Study No. 4: ***Grande Ronde River Road 51—Reconstruction; La Grande, Oregon***

The U.S. Forest Service reconstructed 6.1 miles of Grande Ronde River Road 51 in La Grande, Oregon, in 1988. The road, open to public travel, serves primarily logging traffic and recreational traffic. The $1.7-million project (approximately $280,000 per mile) included minor horizontal alignment revisions. The major work involved revision to the cross section, as noted below:

	Preconstruction	Plan
Functional Classification	Minor arterial	Minor arterial
Design Speed	30 mph	40 mph
Terrain	Rolling	Rolling
Design Year Traffic:		
ADT	NA	NA
Percent Trucks	39	—
Typical Cross Section:		
Lane Width	10 ft	12 ft
Shoulder Width	2 ft	1 ft

A spot accident problem was noted on one curve that was related to logging trucks encroaching on the centerline.

While no traffic data were available, it is assumed that the road carries less than 400 vpd. Based on the standards developed by this study, a design incorporating 11-ft lanes and 2-ft shoulders (see Table 29f) could have been constructed, versus the 12-ft lane and 1-ft shoulder that was constructed. The total width is the same in both cases. However, the narrower lane width and wider shoulder would offer the following advantages over the 12-ft lane width design: construction cost would be lower, the 2-ft shoulder would meet minimal functional requirements, and the 11-ft lane width would be more compatible with the low design speed of 40 mph.

The expected safety performance of the various alternatives is noted below:

	Lane/Shoulder Width (ft)	Related Accident Rate (per MVM) per Table 10
Preconstruction	10/2	2.41
Plan As Constructed	12/1	1.87
Proposed Standards	11/2	1.87

Note that the previously outlined advantages come with no worse expected accident experience than the design that was constructed.

Summary of Case Studies

The four case studies are not necessarily representative of national experience in low-volume road construction. Nonetheless, they do illustrate the expected impacts of revised width standards as proposed by this study.

First, as in Case Study No. 1, there are many miles of roadway for which no changes in standards are proposed. Current AASHTO *Policy* is confirmed as reasonable in some cases. Second, there are design benefits of the proposed standards that do

not necessarily translate to construction cost savings, but are noteworthy nonetheless. The lower overall standards produce greater design flexibility. In Case Study No. 2, application of a minimum standard everywhere for the three sections would be possible. Alternatively, using one design that is consistent throughout (as was actually done) is also possible. This is an important facet of standards that is often overlooked. The presence of a minimum standard should not preclude the use of greater dimensions, particularly where there is good reason to do so. Another example of design flexibility is offered by Case Study No. 3. While the design itself would not have changed, had the proposed standards been in place, the design agency would not have had to evaluate, request, and process a "design exception."

Third, and perhaps most important, there are clearly examples of low volume roads that could be reconstructed at lower cost *without any degradation in expected safety performance.* As shown by Case Study No. 4, construction and reconstruction of many miles of low-volume road using standards implied by the current AASHTO *Policy* may not represent a cost-effective use of highway funds.

CHAPTER 4

CONCLUSIONS

This study demonstrates that there are opportunities to refine current lane and shoulder width standards for low-volume roads. Revised design values based on the safety studies, operational analyses, and cost-effectiveness evaluations would produce meaningful savings in construction and reconstruction costs associated with the low-volume rural system.

The major research conclusions stem from a series of studies and analyses of all facets of low-volume roads.

ACCIDENTS ON LOW-VOLUME ROADS

Low-volume roads were found to experience a slightly higher percentage of injury accidents than the full sample of rural roads. Single-vehicle accidents (fixed object, rollover, run-off-road) are greater proportionately and multivehicle accidents (rear-end, angle, turning) lesser proportionately than all two-lane rural roads.

The studies found that low-volume road accidents are affected primarily by roadway width, roadside hazard, terrain, and driveways per mile. Accident rates are significantly associated with varying lane and shoulder widths for single-vehicle and opposite direction accidents.

ACCIDENT EFFECTS OF LANE AND SHOULDER WIDTH

The study determined that the presence of a shoulder is associated with significant accident reductions for lane widths of at least 10 ft. For lane widths of 11 ft and 12 ft, shoulder widths of at least 3 ft have significant effects. With respect to all combinations of lane width and shoulder width (for lane widths of 10 ft or more), there is no apparent accident reduction above a total roadway width (i.e., lanes plus shoulders) of 30 ft.

The study also addressed very narrow roads (i.e., with lane widths of 8 ft or 9 ft). For a combination of reasons, some relating to sample size and others less clear, there is no apparent accident benefit of widening such lanes to 10 ft. Indeed, the study produced evidence that 9-ft lanes with wide shoulders may be preferable to 10-ft lanes with narrow shoulders.

ACCIDENT EFFECTS OF PAVED VS. UNPAVED SURFACES

The study determined that accident experience does not appear significantly different for unpaved versus paved surfaces at traffic volume levels of 250 vpd or less. Above this volume, accident rates are significantly greater for unpaved roads than for paved roads, all else being equal.

ACCIDENT EFFECTS OF LARGE TRUCKS

The study did not uncover a relationship between the composition of traffic volume (i.e., percent trucks in the traffic stream) and accident rate for low-volume roads.

ACCIDENT BENEFITS OF WIDENING LOW-VOLUME ROADS

The study produced a linear model that was used to estimate expected accident effects of various combinations of lane width and shoulder width. For 10-ft lanes, accident rates were lower by 0.98 per MVM when accompanied by shoulders of greater than 4 ft versus shoulders of 4 ft or less. For 11-ft and 12-ft lanes, shoulder widths of 3 ft or greater produced accident rates 0.56 per MVM lower than the accident rates produced with shoulder widths less than 3 ft. The accident model produced identical accident benefits for 11-ft and 12-ft lanes.

Economic benefits of accident reductions were estimated using research by others that establish societal costs of motor vehicle injuries and fatalities. The research approach used FHWA's recommended methodology for such costs. A recommended value, considered conservative, of $60,000 per low-volume road accident was used to calculate benefits of accident reductions.

Design standards for highways are based on more than safety performance. The research also investigated traffic operational requirements related to width elements, and width-related effects of construction costs. A central theme of the study was that width-related design standards should be compatible with primary design policy controls. These include design speed and functional classification.

Capacity and Level-of-Service Effects on Width of Low-Volume Roads

The study demonstrated that, based on known operational effects of lane and shoulder widths, for certain terrain conditions and traffic composition, capacity requirements should influence design standards. For a design ADT of 1,500 vpd or more, combinations of lane and shoulder width in excess of those required merely for safety are necessary to produce levels of service compatible with AASHTO design policy guidelines.

Speed-Related Widths

The study referenced other research on the operating speed effects of various lane widths. It was concluded that lane widths should produce operating speeds compatible with the selected design speed. Wider lane widths (say, 11-ft or 12-ft) on roadways designed with lower design speeds (say, 40-mph or 50-mph) may be undesirable. Such widths may promote operating speeds above those for which the alignment was intended to accommodate.

Shoulder Functions Related to Width

The study referenced other research on the function of shoulders and widths required to accommodate those functions. It was concluded that for certain combinations of functional classification, traffic volume and composition, shoulder widths in excess of those required solely for safety are necessary. For the upper range of traffic volumes (greater than 1,500 vpd), this study recommends minimum shoulder widths of 6 ft to 8 ft, depending on the functional class of the facility.

Truck Operations Related to Width

The study also referenced other research on the operational effects of longer, wider vehicles. It was concluded that, where such vehicles can be expected to operate, providing incrementally greater lane and shoulder widths is desirable to accommodate the off-tracking and encroachment problems associated with these vehicles.

Costs of Construction of Low-Volume Roads

A cost model based on a comprehensive survey of state design engineers and practices was produced. The model was used to investigate the sensitivities of variable lane and shoulder width designs, as well as other relevant factors such as terrain. Cost per mile of construction was found to be greatly influenced by terrain, total roadway width, and lane width.

Cost-Effective Width Combinations

The accident model and construction cost model led to an evaluation of the cost-effectiveness of various combinations of lane and shoulder width. "Breakeven" ADT levels were computed to determine when widening appeared justified.

A major conclusion of this exercise was that width combinations less than those called for by current AASHTO *Policy* appear appropriate. In particular, where total roadway widths (i.e., lanes plus shoulders) currently exceed 30 ft, there are many cases where lesser widths could be employed at a lower cost with no apparent degradation in safety. Also, the cost-effectiveness analysis demonstrated that less variation in widths for the range in traffic volumes is appropriate compared to current AASHTO *Policy*.

Recommended Standards

The primary objective of the research was development of recommended design values for lane and shoulder width for low-volume roads. These values were developed from all of the foregoing analyses, and were given in Tables 29(a) through 29(f).

This research recommended revisions to the format of design standards as well as values for the range of relevant condition. Overall, the research supports conclusions of earlier work from *TRB Special Report 214*. Lesser width combinations for lanes and shoulders on low-volume roads should be considered in subsequent editions of the AASHTO *Policy*.

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APPENDIX A

COST-EFFECTIVENESS GUIDE FOR DESIGN IMPROVEMENTS TO ROADWAY CROSS SECTIONS ON LOW-VOLUME RURAL ROADS

The purpose of this guide is to assist state and local agencies in determining the accident benefits and costs related to various design improvements to roadway cross sections (i.e., widening lanes, widening shoulders, or improving roadsides). The procedure applies only to sections of rural, two-lane roads with low traffic volumes, that is, with average daily traffic (ADTs) of 2,000 or less.

This cost-effectiveness procedure is based on the results of the accident analyses conducted as part of the NCHRP Project 15-12 study, "Roadway Widths for Low Traffic Volume Roads." It also makes use of an FHWA 1987 study by Zegeer, et al., "Safety Cost-Effectiveness of Incremental Changes in Cross-Section Design—Informational Guide" (*7*). The procedures in that Guide pertained to rural, two-lane roads of all ADT levels. That procedure has been modified, herein, based on the accident experience on low-volume roads *only* (ADT of 2,000 or less).

GEOMETRIC DESIGN TERMINOLOGY

The following terminology is used in the procedures for defining geometric and safety relationships.

Cross-Section Elements

Figure A-1 describes the elements of rural highway cross sections. Such elements include lane and shoulder width, roadside, and sideslope, while the ADT and terrain are also important in safety analyses. The only nonstandard terminology in this procedure regards roadway width, roadside recovery distance, and related accidents. The first two terms are defined as follows; and the third term, related accidents, is identified under "Procedure Assumptions."

Roadway width includes the combined width of the lanes and shoulders on a highway section. Total roadway width is one of the most important features in the safety performance of a two-lane highway. *Roadside recovery distance* is defined as a relatively flat, unobstructed and smooth area adjacent to the edge of travel lane (i.e., edgeline) where there is reasonable opportunity for safe recovery of an out-of-control vehicle; the roadside recovery distance is the lateral distance from the outside edge of the travel lane to the nearest of the following:

- A hinge point where the slope first becomes steeper than 4:1,
- A longitudinal element such as a guardrail or bridge rail,
- An unyielding and hazardous object,
- The ditch line of a nontraversable side ditch, and
- Other features, such as a rough or irregular surface, loose rocks, or a watercourse, that pose a threat to errant vehicles.

This is similar to the concept of a clear zone, except that the roadside recovery distance includes only recoverable slopes. According to the AASHTO "Roadside Design Guide," the clear zone includes nonrecoverable slopes.

Procedure Assumptions

The procedures used in this guide are based on information compiled and analyzed only for highway sections (i.e., preferably 0.5 mile or longer) under the following conditions: two-lane rural roads with an ADT between 50 and 2,000; lane widths of 8 to 12 ft; and shoulders (0 to 12 ft wide) that are paved, unpaved, or partly paved and partly unpaved.

The procedures in this guide assume that no net change in maintenance cost will occur because of the project alternatives. If an analyst expects maintenance costs to change because of an alternative, he or she should adjust the project annual cost (line 34 of Form A, provided at the end of this appendix).

The term, *related accidents*, on the basis of a research study for which this supplement was developed, includes the accident types that were found to be related to roadway cross section (i.e., lane and shoulder widening, and roadside improvements):

- Single-vehicle accidents (fixed-object, rollover, and other run-off-road crashes), and
- Opposite-direction accidents (head-on and opposite-direction sideswipe crashes).

ANALYSIS PROCEDURE FOR DETERMINING PROJECT COST-EFFECTIVENESS

The Form A worksheet helps an analyst calculate the accident benefits from cross-section improvements (lane widening, shoulder widening, and increasing roadside recovery distance). Analysts begin the worksheet by entering the "header" identification information at the top of the form. The form provides room for analyzing as many as three predefined project alternatives. Analysts interested in considering more than three alternatives should use more than one form. The form is completed using the following steps.

Step One of the form provides spaces to enter basic data on the current conditions of the roadway section and on the alternatives. Analysts need to provide data for lane width, shoulder width, roadside recovery distance, sideslope, and current ADT that are averages for both sides of the road along the entire section. If a value of one of these variables changes dramatically along a section, the section should be broken up and analyzed as several shorter sections. It is recommended that the procedure be applied to sections of 0.5 mile or longer.

The number of total accidents per year on the section is given on line 14, and the number of "related" (run-off-road plus opposite-direction) accidents per year is given on line 15. Note that if the number of "related" accidents is not known, it can be approximated as 63 percent of the total number of accidents. For example, assume that 20 total accidents occurred on a 2.5-mile section over a 3-year period. This would correspond to (20 accidents) ÷ (2.5 miles) =

8.0 total accidents per mile per year, or (8) × (0.63) = 5.0 related accidents per year.

In line 16, the rate R_r, of related accidents [related accidents per million vehicle miles MVM)] is computed as:

$$R_r = \frac{\text{(No. of related accidents per year) (1,000,000)}}{\text{(365)(ADT) (Section length in miles)}}$$

Lines 17, 18, and 19 involve inputting accident costs for property damage only (PDO) accidents and per injury or death (i.e., per person injured or killed, not per injury accident or fatal accident). These inputs are necessary for computing accident benefits (savings) that are expected because of the improvement. The users may input their values here, but default values of $3,000 per PDO accident, $15,000 per injury, and $1,500,000 per fatality are suggested, based on recent costs recommended by FHWA. Such costs may be updated each year.

Step Two involves updating the accident rates based on future conditions. On the basis of the expected project life of a given alternative (10 or 20 years) and the projected annual traffic growth rate (i.e., 0, 1 percent, 2 percent, or 3 percent per year), the traffic growth factor is obtained from Table A-1. It is multiplied by the current ADT to obtain future ADT over the project life (line 21).

For line 22, note that if no accidents have occurred on the roadway section within the last several (e.g., 3 to 5) years, an economic analysis is not appropriate because no accident benefits would necessarily be expected as a result of a widening improvement. In this case, any proposed widening would need to be justified based on other considerations (capacity, operational factors for accommodation of large trucks).

In line 23, the number of future related accidents per year is computed. This is the expected number of related accidents on the section per year if no treatments are made. This value is used in determining the expected accident benefits from one or more project alternatives. In line 24, the annualization factor is recorded from Table A-2 for later use in computing annual project costs.

Step Three involves determining the expected percent reduction in related accidents (i.e., accident reduction factor, AR) resulting from roadway widening, roadside improvements, or other improvements. This is determined in line 25 by first identifying the rate of related accidents in the current (untreated) condition and comparing it with the appropriate rate after roadway widening, and computing the percent change (if any). These AR factors are determined using Tables A-3, A-4, and A-5.

To illustrate the use of these tables to compute AR factors, assume an *existing* section of low-volume, two-lane road is in a rolling area with a 9-ft lane width and no shoulder. The current rate is 2.75 related accidents per MVM. The proposed improvement will widen the roadway to 11-ft lanes with 4-ft shoulders.

From Table A-3, the improved condition should result in an average rate of 1.31. Thus, the AR factor, AR (i.e., percent reduction) in related accidents between the before (B) and after (A) conditions, would be:

$$AR = \frac{B - A}{B} = \frac{(2.75) - (1.31)}{2.75} = \frac{1.44}{2.75} = 0.52$$

a 52 percent reduction in related accidents. A value of 0.52 would be recorded on line 25.

Note that if the current (untreated) lane width is 10 ft or greater, it would also be possible to select rate values from Table A-3 for both the before and after conditions to compute the AR factor. For example, assume a level roadway section with a 10-ft lane and no shoulder to be considered for widening to 12-ft lanes with no shoulder. From Table A-3, a before rate of 2.28 would be used with an after rate of 1.74. This would result in an accident reduction (AR) of:

$$AR = \frac{B - A}{B} = \frac{(2.28) - (1.75)}{2.28} = \frac{0.54}{2.28} = 0.237$$

or a 24 percent reduction in related accidents. Such rate values for both the before and after conditions can then be used to compute the accident reduction factor for roadway widening when: (1) the lane width in the current (untreated) condition is between 10 and 12 ft, and (2) the analyst decides that using this approach will be more reliable than using the actual accident rate at the site in the before period (e.g., because of a small sample of accidents or other accident data problems).

In line 26, the accident reduction due to roadside improvements can also be included in the cost-effectiveness analysis using accident reduction factors from Tables A-3 and A-4. Assume a low-volume roadway section with a current roadside recovery distance (RRD) of only 5 ft. A roadway widening improvement is being considered that would also increase the RRD from 5 ft to 20 ft as a result of tree removal and slope flattening. The proposed increase in RRD would be 20 ft - 5 ft = 15 ft. Using Table A-4, a 35 percent reduction in related accidents would be expected. Thus, a value of 0.35 would be entered on line 26.

If sideslope flattening is proposed (as the only roadside improvement) on a slope relatively clear of fixed objects, Table A-5 can be used to estimate reduction in related accidents. For example, assume a 2:1 slope which may be flattened to 6:1. This would result in a 21 percent reduction in related accidents. The reader should note that the AR factor from either Table A-4 (on increasing RRD) or Table A-5 (flattening sideslope) can be used for a given improvement alternative. Also, an AR factor for roadside improvements (from either Table A-4 or A-5) can be used in an analysis even if no roadway widening is being considered.

In Step 27, two or more accident reduction factors (A1, A2, A3, ...) may be combined into one overall accident reduction (AR) based on the following equation:

$$AR = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4) \ldots$$

For example, assume that a roadway widening and roadside improvements on a roadway section for Alternative A would give accident reductions of 52 percent and 21 percent, respectively. The combined accident reduction (AR) is *not* the sum of those values, but should be computed as:

$$AR = 1 - (1 - 0.52)(1 - 0.21)$$
$$AR = 1 - (0.48)(0.79)$$
$$AR = 1 - (0.38) = 0.62 =$$

a 62 percent reduction in related accidents because of the combined improvements for Alternative A. The combined AR is recorded on line 27 and is used in Step 4 to compute accident benefits resulting from one or more roadway improvements. AR factors for up to three different alternatives may be recorded on each Form A. More than two AR factors could be included only if additional roadway improvements are being proposed (e.g., alignment changes) for which the analyst can estimate the effect on related accidents.

Step 4 involves computing annual accident benefits. The annual number of related accidents reduced is computed in line 29. Lines 29, 30, and 31 are used to determine the average cost per accident reduced, based on the severity distribution of crashes and the number of people injured or killed in such crashes, as found in the analysis of low-volume roads database. Also, other selected values of average costs for PDO only accidents, injuries, and fatalities may be inserted by the analyst in lines 17, 18, or 19, respectively. Default values of $3,000 per PDO accident, $15,000 per injury (per *person* injured, not per injury accident), and $1.5 million per fatality (i.e., per *person* killed) were used, as recommended in a recent FHWA study (*15*).

The annual safety benefit is determined in line 33, and the annualized project cost is computed in line 34. The analyst may then compute the benefit-cost ratio (line 35) and annual net benefits (line 36) of each alternative and select the most desirable project alternative. An example problem is worked out on the following Form A to illustrate the procedure.

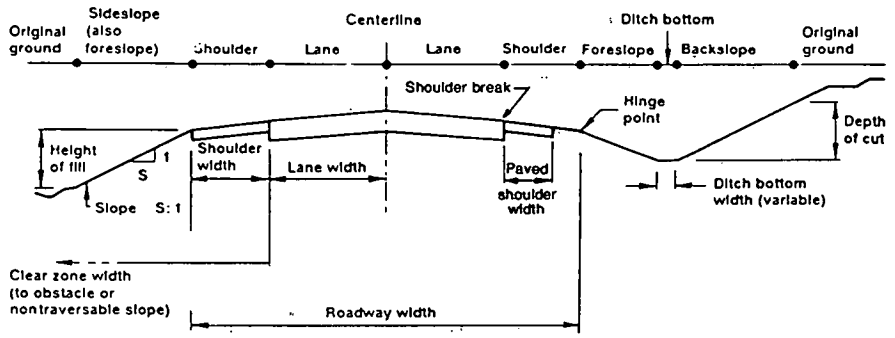


Figure A-1. Elements of rural highway cross sections.

FORM A

Cross-Section Alternative Worksheet

Analyst: _____ Unit _____ Date: _____

Study Location: Co. _____ Route _____ Begin MP _____ End MP _____

Alternative A: _____

Alternative B: _____

Alternative C: _____

	Current	Alternatives		
		A	B	C
Step One - Inputs	XXXX	XXXX	XXXX	XXXX
1. Average lane width (LW) in feet				
2. Average paved shoulder width (PSW) in ft				
3. Average unpaved shoulder width (USW), ft				
4. Total shoulder width (PSW + USW) ft				
5. Average roadside recovery distance (RRD), ft				
6. Average sideslope ratio (horiz.: vert.)				
7. Terrain (flat, rolling, or mountainous)		XXXX	XXXX	XXXX
8. Section length, miles		XXXX	XXXX	XXXX
9. Current average daily traffic (ADT)		XXXX	XXXX	XXXX
10. Current average annual traffic growth rate, percent		XXXX	XXXX	XXXX
11. Expected project life, years	XXXX			
12. Project implementation cost	XXXX			
13. Discount (interest) rate, percent	XXXX			
14. Avg. number of total accidents per year over the entire section. This line is optional--can proceed without it.		XXXX	XXXX	XXXX
15. Avg. number of related accidents per year (i.e., single-vehicle plus opposite direction accidents). If unknown, enter (.63) x (line 14).		XXXX	XXXX	XXXX
16. Rate of related accidents (current) per million vehicle miles (R_r) (see text).		XXXX	XXXX	XXXX

FORM A (Continued)

	Current	Alternatives		
		A	B	C
17. Cost per PDO accident. Default - $3,000		XXXX	XXXX	XXXX
18. Cost per injury. Default = $15,000		XXXX	XXXX	XXXX
19. Cost per fatality. Default = $1,500,000		XXXX	XXXX	XXXX
Step Two - Update Inputs	XXXX	XXXX	XXXX	XXXX
20. Enter growth factor from Table 1 using the average annual traffic growth rate (line 10) and project useful life (line 11)	XXXX			
21. Multiply line 20 by line 9. This is the updated ADT.	XXXX			
22. If line 16 (related accidents per year) is 0, an economic analysis is not appropriate, and no further economic analysis is necessary. If line 15 is a positive value, enter it here.	XXXX			
23. Multiply lines 20 by line 22. This is the future number of related accidents per year in the untreated condition.	XXXX			
24. Enter annualization factor from table 2.	XXXX			
Step Three - Determine Accident Reduction	XXXX	XXXX	XXXX	XXXX
25. Record the percent accident reduction which would result from lane and/or shoulder widening (see discussion in text).	XXXX			
26. Record the percent reduction due to roadside improvements from table 2 or 3.	XXXX			
27. Combine two or more accident reduction factors for the same alternative, where Total AR = 1 - $(1-AR_1)(1-AR_2)(1-AR_3)$....	XXXX			
Step Four - Compute Annual Benefits	XXXX	XXXX	XXXX	XXXX
28. Annual number of accidents reduced. Multiply line 27 by line 23.	XXXX			
29. Multiply line 17 by .603.		XXXX	XXXX	XXXX
30. Multiply line 18 by .588.		XXXX	XXXX	XXXX

FORM A (Continued)

	Current	Alternatives		
		A	B	C
31. Multiply line 19 by .022.		XXXX	XXXX	XXXX
32. Add lines 29, 30, and 31.		XXXX	XXXX	XXXX
33. Multiply line 28 by line 32. This is the annual safety benefit.	XXXX			
34. Multiply line 12 by line 24. This is the annual cost. Compare lines 33 and 34 to assist choosing an alternative.	XXXX			
35. Compute benefit/cost ratio of each alternative. Divide line 33 by line 34.	XXXX			
36. Compute net benefits of each alternative. Subtract line 34 from line 33.	XXXX			
37. Choose the alternative which is most desirable in terms of benefit/cost ratio and/or net benefits.	XXXX			

FORM A

Cross-Section Alternative Worksheet

Analyst: CVZ Unit DOT Date: 4/1/93

Study Location: Co. Main Route SR 10 Begin MP 0.0 End MP 2.7

Alternative A: Widen lanes from 9 to 11 ft

Alternative B: Widen lanes (9 to 12 ft) and shoulders (0 to 4 ft of ~~Alternative C~~ gravel), and increase roadside rec. dist. from 5 to 15 ft.

	Current	Alternatives		
		A	B	C
Step One - Inputs	XXXX	XXXX	XXXX	XXXX
1. Average lane width (LW) in feet	9	11	12	
2. Average paved shoulder width (PSW) in ft	0	0	0	
3. Average unpaved shoulder width (USW), ft	0	0	4	
4. Total shoulder width (PSW + USW) ft	0	0	4	
5. Average roadside recovery distance (RRD), ft	5	5	15	
6. Average sideslope ratio (horiz.: vert.)	4:1	4:1	4:1	
7. Terrain (flat, rolling, or mountainous)	Rolling	XXXX	XXXX	XXXX
8. Section length, miles	2.7	XXXX	XXXX	XXXX
9. Current average daily traffic (ADT)	1,200	XXXX	XXXX	XXXX
10. Current average annual traffic growth rate, percent	2%	XXXX	XXXX	XXXX
11. Expected project life, years	XXXX	10	10	
12. Project implementation cost	XXXX	$500,000	$650,000	
13. Discount (interest) rate, percent	XXXX	5%	5%	
14. Avg. number of total accidents per year over the entire section. This line is optional--can proceed without it.	12	XXXX	XXXX	XXXX
15. Avg. number of related accidents per year (i.e., single-vehicle plus opposite direction accidents). If unknown, enter (.63) x (line 14).	7 (actual)	XXXX	XXXX	XXXX
16. Rate of related accidents (current) per million vehicle miles (R_1) (see text).	5.9	XXXX	XXXX	XXXX

$$\text{Rate} = \frac{(7)(1{,}000{,}000)}{(365)(1200)(2.7)} = 5.9$$

FORM A (Continued)

	Current	Alternatives A	Alternatives B	Alternatives C
17. Cost per PDO accident. Default - $3,000	$3,000	XXXX	XXXX	XXXX
18. Cost per injury. Default = $15,000	$15,000	XXXX	XXXX	XXXX
19. Cost per fatality. Default = $1,500,000	$1,500,000	XXXX	XXXX	XXXX
Step Two - Update Inputs	XXXX	XXXX	XXXX	XXXX
20. Enter growth factor from Table 1 using the average annual traffic growth rate (line 10) and project useful life (line 11)	XXXX	1.12	1.12	
21. Multiply line 20 by line 9. This is the updated ADT.	XXXX	1,344	1,344	
22. If line 16 (related accidents per year) is 0, an economic analysis is not appropriate, and no further economic analysis is necessary. If line 15 is a positive value, enter it here.	XXXX	7	7	
23. Multiply lines 20 by line 22. This is the future number of related accidents per year in the untreated condition.	XXXX	7.8	7.8	
24. Enter annualization factor from table 2.	XXXX	.130	.130	
Step Three - Determine Accident Reduction	XXXX	XXXX	XXXX	XXXX
25. Record the percent accident reduction which would result from lane and/or shoulder widening (see discussion in text).	XXXX	.68	.78	
26. Record the percent reduction due to roadside improvements from table 2 or 3.	XXXX	0	.25	
27. Combine two or more accident reduction factors for the same alternative, where Total AR = 1 - $(1-AR_1)(1-AR_2)(1-AR_3)$....	XXXX	.68	.835	
Step Four - Compute Annual Benefits	XXXX	XXXX	XXXX	XXXX
28. Annual number of accidents reduced. Multiply line 27 by line 23.	XXXX	5.3	6.5	
29. Multiply line 17 by .603.	$1,809	XXXX	XXXX	XXXX
30. Multiply line 18 by .588.	$8,820	XXXX	XXXX	XXXX

Option A: $AR = \frac{B-A}{B} = \frac{5.9-1.87}{5.9} = .68$

Option B: $AR = \frac{B-A}{B} = \frac{5.9-1.31}{5.9} = .78$

Option B: Combined AR = $1-(1-.78)(1-.25)$ $= 1-(.22)(.75)$ $= .835$

FORM A (Continued)

	Current	Alternatives		
		A	B	C
31. Multiply line 19 by .022.	$33,000	XXXX	XXXX	XXXX
32. Add lines 29, 30, and 31. (rounded)	$43,600	XXXX	XXXX	XXXX
33. Multiply line 28 by line 32. This is the annual safety benefit.	XXXX	$231,080	$283,400	
34. Multiply line 12 by line 24. This is the annual cost. Compare lines 33 and 34 to assist choosing an alternative.	XXXX	$65,000	$84,500	
35. Compute benefit/cost ratio of each alternative. Divide line 33 by line 34.	XXXX	3.6	3.4	
36. Compute net benefits of each alternative. Subtract line 34 from line 33.	XXXX	$166,080	$198,900	
37. Choose the alternative which is most desirable in terms of benefit/cost ratio and/or net benefits.	XXXX	Choose Alt. B,		

although either option is desirable.

Table A-1. ADT and accident growth factors.

Useful Life (Years) / Ave. Annual Traffic Growth Rate (Percent)	Growth Factor	
	10	10
0	1.00	1.00
1	1.06	1.11
2	1.12	1.24
3	1.18	1.38

Table A-2. Annualization factor.

Discount Rate \ Useful Life	10	20
2	0.111	0.061
4	0.123	0.074
5	0.130	0.080
6	0.136	0.087
8	0.149	0.102

Table A-3. Accident rates used for determining accident reductions due to roadway widening on low-volume roads.

Lane Width (feet)	Shoulder Width (feet)	Accident Rates (Accidents per MVM)		
		Terrain		
		Level	Rolling	Mountainous
10	0-2	2.28	2.41	2.86
	3-4	2.28	2.41	2.86
	>4	1.30	1.43	1.88
11	0-2	1.74	1.87	2.32
	3-4	1.18	1.31	1.76
	>4	1.18	1.31	1.76
12	0-2	1.74	1.87	2.32
	3-4	1.18	1.31	1.76
	>4	1.18	1.31	1.76

Table A-4. Accident reduction factors due to increasing roadside clear recovery distance.

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

Table A-5. Summary of expected percentage reduction in related accident types due to sideslope flattening.

Sideslope in Before Condition	Sideslope in After Condition				
	3:1	4:1	5:1	6:1	7:1 or Flatter
2:1	2	7	11	15	20
3:1	-	6	10	14	19
4:1	-	-	4	9	14
5:1	-	-	-	4	10
6:1	-	-	-	-	6

APPENDIX B

CRITICAL REVIEW OF LITERATURE

A critical review of the literature dealing with the safety and geometrics of low-volume roads as they pertain to roadway width was conducted. As found in the literature, the types of design and traffic elements that affect accidents include ADT, lane width, shoulder width, shoulder type, and other geometric features that combine with roadway width to affect accidents. Other important variables include roadside condition, horizontal and vertical alignment, sight distance, number of intersections and driveways, access control, and pavement edge drop-off. The influences of terrain, percent trucks and roadway design speed on safety and operations for low-volume roads were also considered to be of interest prior to developing roadway width guidelines.

The critical reviews focused on two general types of studies: (1) studies that provide recommended roadway width guidelines for rural, two-lane roads; and (2) studies that develop relationships between accidents and roadway width (and/or lane width, shoulder width, and shoulder type).

Approximately 70 studies related to safety effects of various roadway features were critically reviewed. Detailed critical reviews were prepared for 14 studies that pertain most directly to roadway width effects and guidelines (see Table B-1). Of those 14 studies, those involving *lane width* effects on accidents include Dart and Mann (1970) in a study of 246 highway sections involving 6,000 accidents in Louisiana from 1962-1966; Foody and Long (1974) in a study of 1,800 roadway sections in Ohio using 1969-1970 accident data; Roy Jorgensen & Associates (1978) in an NCHRP study of 12,400 miles of roadway in Washington and Idaho (with preliminary analysis using Maryland data); and Zegeer, Mayes, and Deen (1979) in an analysis of 16,760 accidents (1976 data) on 15,944 1-mile sections in Kentucky.

Studies critically reviewed by project team members on *shoulder width* and *type* include a 1983 study by Barbaresso and Bair in Oakland County, Michigan; a 1974 study by Heimbach, Hunter, and Chao in North Carolina; a 1976 study by Shannon and Stanley (Idaho and Washington); and studies in 1981 and 1982 by Turner, Fambro, and Rogness in Texas (1981-1982). Studies by Rinde (1977), Glennon (1979), and Griffin and Mak (1988) focused on *overall roadway* (i.e., lane plus shoulder) *width*. Three of the studies (TRB 1987, Glennon 1979, and Griffin and Mak 1988) resulted in proposed guidelines for roadway width, as discussed previously. The 1987 study by Zegeer, et al., using data from seven states and the October 1987 TRB 3R study (*Special Report 214*) both involve an analysis of lane width, shoulder width, and shoulder type. The following is a brief discussion of some of these studies.

CROSS-SECTION STUDY

One of the major studies of importance is the FHWA/TRB report, "Safety Effects of Cross-Section Design for Two-Lane Roads," by Zegeer, Hummer, Reinfurt, Herf, and Hunter (1987). The study quantified the benefits and costs resulting from various cross-sectional improvements for two-lane rural roads. Accident types found to be related to cross-sectional elements included single-vehicle, head-on, and sideswipe (same and opposite direction), and were termed "related accidents." An accident predictive model, developed for related accidents, shows the interrelationships between various traffic and roadway variables with respect to crashes. The model includes ADT, terrain, lane width, paved shoulder width, unpaved shoulder width, and roadside condition. The roadside was expressed in terms of a seven-point roadside hazard scale or a measure of roadway clear recovery distance. The model also was expressed as a nomograph (see Figure B-1) and accident reduction factors then were developed for lane widening and shoulder widening (paved and unpaved shoulders), roadside improvements, and side-slope flattening. A summary of accident reduction factors for various combinations of lane and shoulder improvements is given in Table B-2.

The relationship between related (AO) accidents (i.e., the combined accident types—run-off-road, sideswipe and head-on) and lane and shoulder width are illustrated in Figure B-2 based on the accident model. For example, assume an ADT of 1,000 vpd on a rolling terrain, and a roadside rating of 5. Widening lanes from 9 to 11 ft would be expected to reduce related accidents from 0.77 to 0.42, a 45-percent decrease. The Zegeer, et al., study also developed a project cost model to assist in estimating various types of project costs (Zegeer, et al., October 1987). An informational guide also was written to present step-by-step information for estimating costs and benefits due to various improvements on specific sections of rural, two-lane roads (Zegeer, et al., December 1987).

TRB *SPECIAL REPORT 214* (TRB, 1987)

In 1987, the Transportation Research Board published *Special Report 214* titled, "Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation." The study was conducted under contract with FHWA in response to a provision in the Surface Transportation Assistance Act of 1982 to study "the safety cost-effectiveness of highway geometric design standards and recommend minimum standards for resurfacing, restoration, and rehabilitation (3R) projects on existing federal-aid highways, except freeways." As a part of the overall TRB study, critical reviews of prior research were sponsored on safety effects of numerous highway features, including lane width, shoulder width, and shoulder type; alignment; sight distance; bridge width; pavement surface condition; and pavement and shoulder drop-offs.

A summary of the results of these reviews and the most-likely accident relationships for these topics was published by TRB in the 1987 *State-of-the-Art Report 6*—"Relationships Between Safety and Key Highway Features—A Synthesis of Prior Research." The critical review on lane width, shoulder width, and shoulder type was conducted by Zegeer and Deacon (1986). Based on information from four studies (Foody and Long, 1974; Zegeer, Mayes and Deen, 1979; Turner, et al., 1981; and TRB *State-of the-Art Report 6,* 1987), a model was developed by the authors for run-off-road and opposite-direction accident rate as a function of lane and shoulder width, as shown in Figure B-3. Accident relationships with other roadway features (i.e., roadsides, bridge width) also are contained in TRB's *Special Report 214* (1987).

NCHRP 214 (GLENNON, 1979)

The objective of this 1979 study by Glennon was to evaluate existing highway safety guidelines, requirements, and criteria for roads with fewer than 400 vpd. This differed from most other roadway width studies that include rural roads of a wider range of ADT.

Guidelines for roadway width (in addition to other features) were developed, based on a review of the literature and an analysis of safety requirements.

On the basis of an analysis for tracking and head-on clearances, shoulders were found to be needed on low-volume rural roads with design speeds above 45 mph. In terms of conflict rates alone, no separate justification was found for shoulders to accommodate emergency and leisure stops. Vehicular tracking and lateral clearances to opposing vehicles were reviewed in an analysis to determine requirements for total roadway width (i.e., width of traveled way plus shoulders). The minimum total roadway width requirements ranged from 18 ft on a 50-vpd roadway designed for 20 mph to 30 ft on a 400-vpd roadway designed for 50 mph. Specific width guidelines were developed for these low-volume roads, as discussed earlier in this report.

GRIFFIN AND MAK (1988)

Another study that addressed low-volume rural roads was a 1988 study by Griffin and Mak, which attempted to quantify the relationship between accident rate and roadway surface width on two-lane rural roads in Texas with ADT of 1,500 vpd or less. Log-linear accident prediction models were developed for 36,215 miles of roadway within several ADT categories.

Multivehicle accident rates (accidents per mile per year) were not found to relate to surface width for any of the ADT groups tested. Single-vehicle accident rates were noted to increase as roadway width decreased for ADT groups between 401 and 1,500 vpd. Accident reduction factors were developed for various widening projects within these ADT ranges. On the basis of an economic analysis, widening was not found to be cost-beneficial for ADT below 1,000 vpd.

A comparison of accident reduction factors for lane widening from the 1988 Griffin and Mak study, with the October 1987 Zegeer, et al., study, reveals very similar results, as indicated in Table B-3. When averaging the accident reductions for the three ADT groups used by Griffin and Mak, the accident reductions were 11 to 12 percent for 2 ft of lane widening, 21 to 22 percent for 4 ft of widening, 30 to 31 percent for 6 ft of widening, and 38 percent for 8 ft of widening. These values are within 1 to 2 percent of the values found by Zegeer, et al., using data from seven states (Zegeer, 1987).

The similarity of accident reductions may seem surprising, since the seven-state database model was able to control for roadside, terrain, and other roadway factors not analyzed in the Griffin and Mak study. However, it should be mentioned that while roadside hazard, alignment, and other such factors are known to affect accidents, they have also been shown to be related to ADT. In other words, roadsides are typically more hazardous on narrow roads (compared to wide roads) and on low-volume roads (compared to high-volume roads). Thus, because Griffin and Mak controlled for ADT by developing models within various ADT groups, they may have also indirectly controlled for roadside and other roadway features within each ADT group. Note also that the Griffin and Mak study found accident reduction factors to be about twice as high for the highest ADT groups (ADT of 1,001 to 1,500 vpd) than they were for the lowest ADT groups (ADT of 401 to 700 vpd).

OTHER STUDIES OF LANE WIDTH, SHOULDER WIDTH, AND TYPE

There have been numerous other research studies conducted relative to *lane width* and safety. Examples of such studies include Stohner (1956) of 9,299 accidents on 8,746 miles of two-lane highways in New York using 1952 accident data; Gupta and Jain (1973) of crash data for 1,470 rural, two-lane sections in Connecticut; Sparks (1968) of 1964 accident data from Oklahoma; Raff (1953) of 16,421 accidents in 1953 on 32,091 highway sections from 15 states; and a synthesis report (1982) by the Texas Transportation Institute for FHWA.

Studies on accident effects of *shoulder width* and *type* on safety include older studies by Barbaresso and Bair (1983); Belmont (1954) in California; Blensley and Head (1960) in Oregon; Belmont (1956) in New York State; E. T. Perkins (1956); and Head and Kaestner (1956) in Oregon.

While the results of the previous studies varied widely on the relationship between accidents and *roadway width*, several of the studies did develop accident relationships and expected effects of roadway widening on accidents. For example, Figure B-4 illustrates the relationship between lane width and accident rate developed in five separate studies, as summarized in the 1982 Texas Transportation Institute FHWA synthesis report. Note that considerable differences were found in some of the studies for a variety of reasons (i.e., data for different states had a variety of roadway alignment or roadside conditions; weather conditions were not controlled for; etc.).

Accident reductions associated with roadway widening projects are given in Table B-4 based on studies by Rinde in California (1977) and Rogness, et al. (1982) in Texas for various ADT groups. These illustrate only a few of the many studies previously conducted on roadway width and its relation to safety. Note that these results include roads with traffic volumes as high as 7,000 vpd.

Table B-1
Summary of Selected Studies Critically Reviewed

Author [Reference]	Date	States Included	Cross-Sectional Elements Analyzed				Type of Analysis				
									Comparative Analysis		
			Lane Width	Shld. Width	Rdwy. Width	Shld. Type	Funct. Analy.	Before/ After	No Predict Equation	Predict Equation	Roadway Width Guidelines Proposed
Dart and Mann [16]	1970	LA	X	X						X	
Heimbach, Hunter and Chao [19]	1974	NC				X			X		
Foody, Long [17]	1974	OH	X	X		X				X	
Shannon, Stanley [20]	1976	ID, WA	X**	X**						X	
Rinde [23]	1977	CA			X			X			
Jorgensen & Assoc. [8]	1978	WA** ID	X	X		X				X	
Zegeer, Mayes, Deen [9]	1979	KY	X	X					X		
Turner, Fambro Rogness [21]	1981	TX				X			X		
Rogness, Fambro, Turner [22]	1982	TX			X			X			
Barbaresso and Bair [18]	1983	Oakland Co. (MI)		X					X		
Glennon [4]	1979	No state data			X		X				X
TRB 3R Study [3]	1987	Based on data (KY,OH)	X	X						X	X
Zegeer, et al. (Cross-Sect. Study) [5, 7]	1987	AL, MI, MT, NC, WVA, UT, WA	X	X		X				X	
Griffin, Mak [6]	1988	TX			X					X	X

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

Table B-2
Accident Reduction Factors for Related Accident Types for Various Combinations of Lane and Shoulder Widening

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

Notes:

Blank cells correspond to projects that would decrease shoulder width and/or change paved shoulders to unpaved shoulders.

P = paved, U = unpaved.

These values are for two-lane rural roads only.

Source: Zegeer, et al. (October 1987).

Table B-3
Comparison of Accident Reductions From Lane Widening

Amount of Lane Widening (ft)	Roadway Width (ft)		Percent Accident Reduction[a]				
			Griffin and Mak 1988 Study			Avg. of 3 ADT Groups	Zegeer, et al. Study[b]
	Before	After	ADT = 401-700 (vpd)	ADT = 701-1,000 (vpd)	ADT = 1001-1,500 (vpd)		
2	18	20	7	12	14	11	12
	20	22	7	12	15	11	12
	22	24	7	13	16	12	12
	24	26	7	13	17	12	12
4	18	22	13	23	27	21	23
	20	24	13	23	28	21	23
	22	26	13	24	30	22	23
6	18	24	19	32	38	30	32
	20	26	19	33	40	31	32
8	18	26	25	41	49	38	40

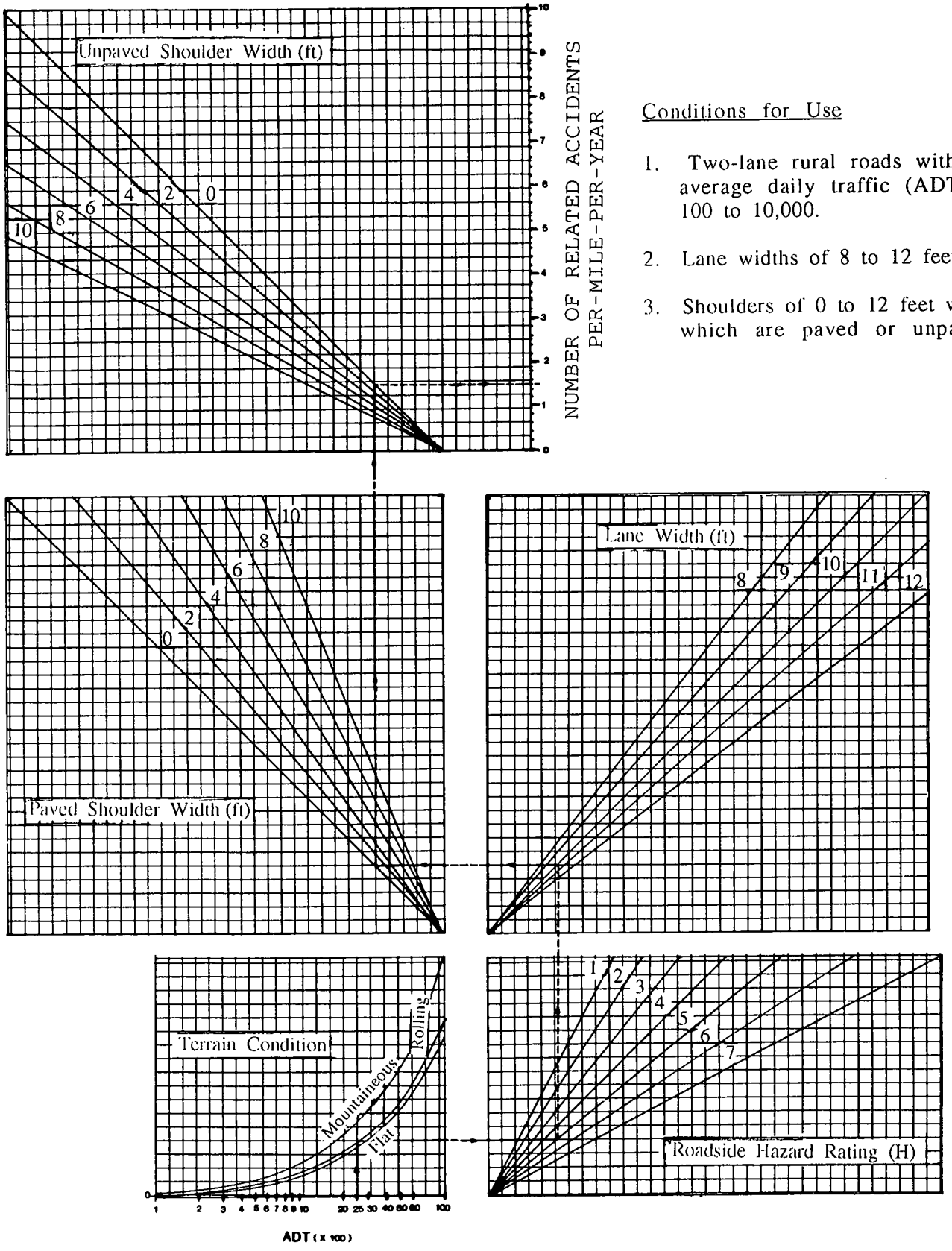
[a]Accident reduction factors are rounded to the nearest whole number.
[b]Zegeer, et al., October 1987.

Table B-4
Summary of Accident Reduction Found in the Literature for Actual Roadway Widening Projects

State	Type of Project	Expected Percent Reduction in Accidents			
		ADT Range (vpd)	Total Accidents	Single-Vehicle Accidents	Head-On Accidents
California[a]	Widening 20- to 24-ft roadway to 28 ft	0-3,000	16	22	45
	Widening 18- to 24-ft roadway to 32 ft	< 5,000	35*	49*	48*
	Widening 18- to 24-ft Roadway to 40 ft	> 5,000	29*	22*	51*
Texas[b]	Adding full-width paved shoulders to two-lane roads	1,000-3,000	27*	55*	Unknown
		3,000-5,000	13*	21*	Unknown
		5,000-7,000	18*	0	Unknown

[a]Values from the Rinde (1977) study in California.
[b]Values from the Rogness, et al. (1982) study in Texas.
*These percent differences were significant at the 95 percent level of confidence for California sites and 90 percent confidence level at the Texas sites.

Source: Turner, et al., 1981; Rogness, et al., 1982; and Rinde, 1977.



Conditions for Use

1. Two-lane rural roads with an average daily traffic (ADT) of 100 to 10,000.

2. Lane widths of 8 to 12 feet.

3. Shoulders of 0 to 12 feet wide which are paved or unpaved.

Figure B-1. Accident-predictive nomograph.

Source: Zegeer, et al., October 1987.

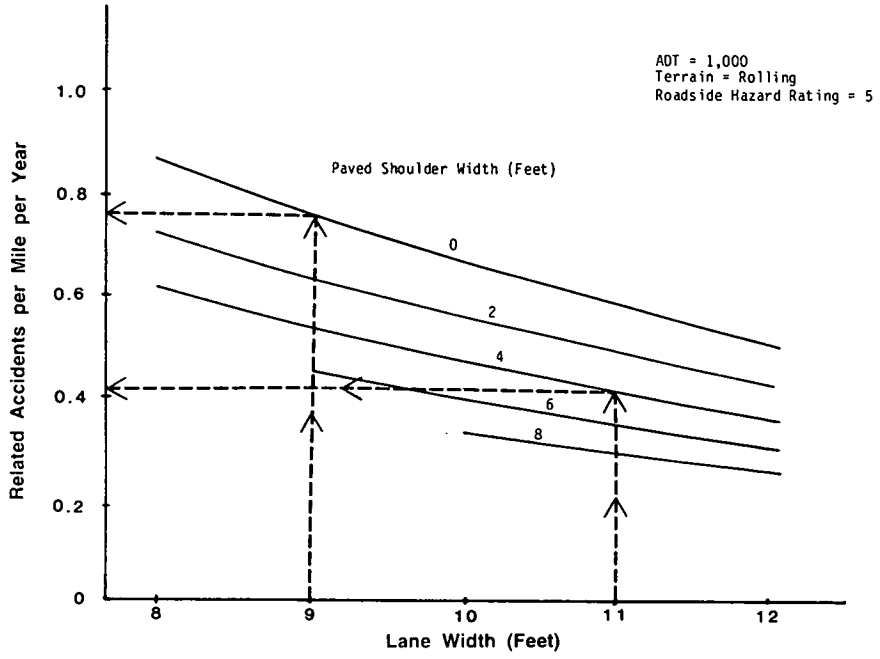


Figure B-2. Plot of related accidents for lane and shoulder widths based on the predictive model.

Source: Zegeer, et al., October 1987.

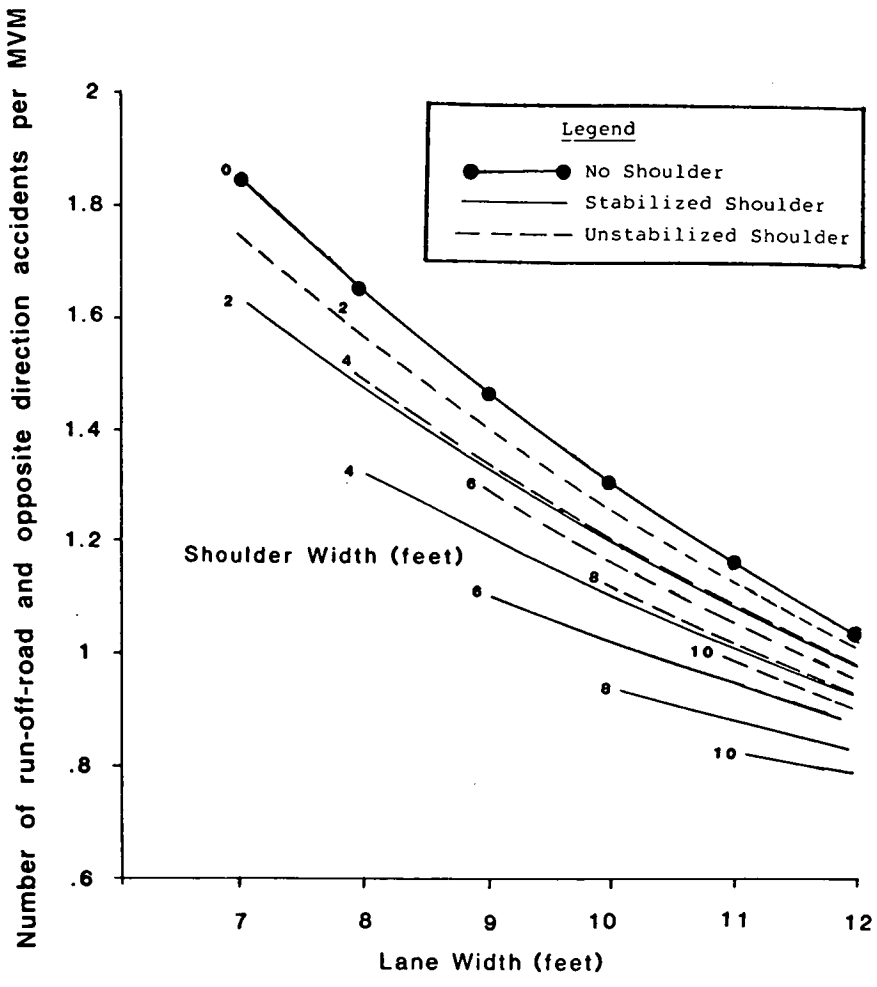


Figure B-3. Rate of related accidents based on most-likely accident relationship.

Source: Zegeer, C.V. and J. Deacon. "Effect of Lane Width, Shoulder Width, and Shoulder Type on Highway Safety: A Synthesis of Prior Literature." Transportation Research Board: Washington, D.C. March 1986.

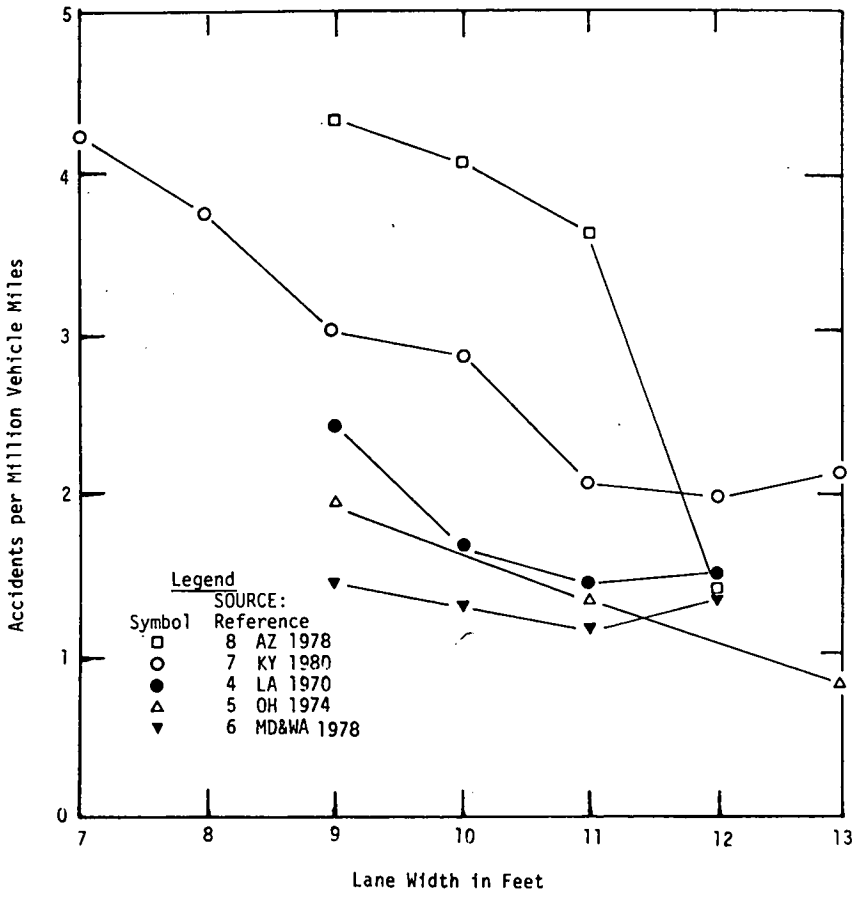


Figure B-4. Accident Rate Based on Lane Width for Two-Lane Rural Roads

SOURCE: Synthesis of Safety Research Related to Traffic Control and Roadway Elements, Volume 1, Chapter 1, "Roadway Cross Section and Alinement," Federal Highway Administration Report No. FHWA-TS-82-232, December 1982.

APPENDIX C

ANALYSIS OF LOW-VOLUME ROADS DATA

PRELIMINARIES

Some basic issues that arose prior to carrying out the main data analysis tasks involved the choice of models and analysis techniques to be used, the choice of the dependent variables to analyze, and the choice of independent variables to include in the analysis. The nature of the research question and the available data seemed to dictate that some form of co-variance analysis would be appropriate because a study goal is to compare the accident experience on roads with specific lane and shoulder widths while taking into account certain other factors, some of which may be measured as continuous variables. Based on previous work by Zegeer and Stewart, et al. (1989), a weighted, least-squares analysis of some types of accident rate also seemed appropriate for this study. To select the dependent variable, preliminary analyses were carried out to determine what types of accident rates were correlated with lane width and shoulder width. For these analyses, co-variance models were fit to the following accident rates: single-vehicle accidents (fixed-object, rollover, and run-of-road); opposite-direction accidents (head-on and opposite-direction sideswipe); angle accidents; same-direction accidents (sideswipe and rear-end); and other accidents (including pedestrian and animal accidents).

All accident rates were given as accidents per million vehicle miles. The independent variables in these analyses included lane width, shoulder width, terrain, and roadside hazard rating.

The results of the preliminary analyses showed only single-vehicle accident rates and opposite-direction accident rates to be associated significantly with varying lane and shoulder widths. Following these analyses, single-vehicle and opposite-direction accidents were combined (this combination is referred to as "related accidents"). Thus, related accidents per million vehicle miles was the primary dependent variable in the subsequent analyses. To investigate severity questions, certain types of injury accident rates also were analyzed (as discussed in a later section of this appendix).

Independent variables were selected on the basis of being associated significantly with related accident rates and having valid values on a large portion of the study sections. Thus, variables related to grade and curvature were not considered because they were available for only about half of the study sections. Other independent variables used in the analyses were state, functional class, clear recovery distance, terrain, and number of driveways per mile. Lane width, shoulder width, and total roadway width of lanes (plus shoulders) were treated as class variables; that is, each specific value (i.e., width in feet) was considered as a treatment level. State and functional class also were class variables. Terrain was given the following values: 1 = flat, 2 = rolling, 3 = mountainous; it was sometimes used as a class variable and sometimes as a continuous variable (the effects were quite similar). Hazard rating and clear recovery zone were continuous and essentially interchangeable, with only one being used in a given model. The state, functional class, and the road-width variables tended to be interrelated strongly, and after two similar models were estimated, one containing functional class as a variable and the other with that variable omitted so that the results could be compared.

Variables that were tested and found not significant include number of intersections per mile, speed limit, and percent trucks. It should be noted that the posted speed limit varied very little in the data (i.e., usually 55 mph), because all of the sections were on rural roads. Sections with no posted speed limit were assumed to have 55-mph speed limits. A separate analysis of paved roads was carried out using all available data. Data on unpaved roads were obtained only from Michigan, North Carolina, and Utah. Another analysis was carried out for both paved and unpaved roads from these three states.

GENERAL ANALYSES OF ACCIDENT RATES ON PAVED ROADS

Two types of models were developed for paved roads—one using both lane width and shoulder width separately and one based on total roadway width. Six lane-width categories were used: 8 ft or less, 9 ft, 10 ft, 11 ft, 12 ft, 13 ft or greater. Shoulder width categories were 0, 1-2, 3-4, and 5-6 ft. All combinations of these categories were present in the data with the exception of lane widths of 8 ft or less together with shoulder widths of greater than 6 ft. A basic model for the lane- and shoulder-width analysis relative to related accident rate contains the following variables: lane/shoulder width—consists of 29 discrete values representing the combinations of lane and shoulder width; state—consists of three discrete values representing the three groups of states: Alabama, Montana, and Washington; North Carolina and Michigan; Utah and West Virginia. It was found in preliminary analyses that the states within these groups had similar effects relative to related accident rates; number of driveways per mile—a continuous variable; hazard rating—a roadway rating scale ranging from 1 to 7 (good to bad) treated as a continuous variable (note that clear recovery distance, a continuous variable, often was used in place of hazard rating and had essentially the same effects; and terrain—a value of 1, 2, or 3 representing flat, rolling, or mountainous terrain, respectively (this variable was used in the initial model as a continuous variable and later included as a class variable, with essentially the same effect in either form).

Results from a weighted, least-squares analysis of these variables using SAS PROC GLM are given below. The product ADT x section length was used as the weight function as in an earlier study by Zegeer, et al. (1990). Thus, the accident effects on longer and more heavily traveled sections were given more weight in the development of the model coefficients.

The resulting model contained 33 estimated parameters: 28 for lane and shoulder width, 2 for state, and 1 each for driveways per mile, hazard rating, and terrain. Each of the first four factors was significant at $p = 0.0001$. Terrain was not very significant at $p = 0.1226$. The model had an $R^2 = 0.234$. The estimated model coefficients of driveways per mile, hazard rating, and terrain were 0.030, 0.268, and 0.118, respectively. Thus, an increase in each of these factors corresponded to an increase in related accident rate.

Of particular interest are the least-squares means of related accident rate by lane and shoulder width class. These are adjusted mean accident rates, adjusted according to the other factors in the model, or mean accident rates by lane and shoulder width, "all other things being equal" (certain average values depend on the variables in the model and the manner in which they are classified). Thus, while the relative values of the least-squares means resulting from a given analysis are meaningful, the values themselves have little meaning and cannot be compared to least-squares mean values resulting from a different analysis using different variables and classifications.

The least-squares means of accident rate by lane and shoulder width categories from the basic model described previously are given in Table C-1. In addition to the least-squares means, Table C-1 also shows the sample size within each lane and shoulder width category and p-values from two sets of significance tests. The first set of tests (Test I) compares each shoulder-width category with the preceding smaller category within the same lane width. Thus, the first value (0.19) in the Test I column is the p-value for a test comparing accident rates on roads with lane widths of 8 ft or less and no shoulders, with the rates on roads with lane widths of 8 ft or less and 1- to 2-ft shoulders.

Very few of these "pairwise" comparisons are statistically significant. For example, none of the comparisons are significant for 9-ft lane widths; for 10-ft lanes, the only significant difference (of those tested) was between 3- to 4-ft shoulders and 5- to 6-ft shoulders, and so on. For lane widths of 8 ft or less, a significant difference is indicated between 3- or 4-ft shoulders and 5- or 6-ft shoulders. However, because only two sections in the data had 5- or 6-ft shoulders and lane widths of 8 ft or less, and because the least-squares mean rate of related accidents is negative, the foregoing result does not appear meaningful.

The second set of tests involved a simultaneous comparison of several shoulder width categories within a fixed lane width. For example, for 9-ft lanes, a test of the equality of all five shoulder width categories had a p-value of 0.90 (which does not indicate significant variation in related accident rates across the five shoulder width categories for roads with 9-ft lanes). In fact, of the Test II results shown in Table C-1, only the results comparing the four shoulder width categories for 8-ft lanes was very significant. This result, again, seems to stem from the fourth shoulder width category and is not a meaningful result. For 12-ft shoulder widths, there were significant differences, but the rate fluctuated in a nonuniform way. For example, the accident rate for 5- or 6-ft shoulders was higher than the rate for 3- or 4-ft shoulders (1.85 versus 1.40).

For the next step in the analysis, a similar model was run with the shoulder width categories tested under Test II combined. This resulted in 10 lane-width by shoulder-width categories (rather than the original 29). Least-squares means from this model are presented in Table C-2 along with least-squares means from a second model in which clear recovery distance was substituted for hazard rating, and terrain was entered as a class variable with three levels (rather than as a continuous variable). The two sets of least-squares means are quite similar and, more importantly, the pattern down the column is the same. Namely, roads with 8- and 9-ft lane widths have about the same accident rates, the rate increases for roads with 10-ft lanes and narrow shoulders, and the rates then decrease for 11- and 12-ft lanes with narrow shoulders. Roads with 10- or 12-ft lanes and wider shoulders have rates that are lower than those for 12-ft lanes with narrow shoulders. For the relatively few roads in the study data with lane widths of 13 ft or greater, those with narrow shoulders have accident rates that fall between the 11- and 12-ft lane and narrow shoulder rate and the 10- to 12-ft lane and wide shoulder rate. The roads with 13-ft lanes and wide shoulders have the lowest rates of all. The p-values from significance tests of these comparisons are shown in the last column of Table C-2.

The second type of model developed was based on categories of lane width and shoulder width (i.e., half of the total width of lanes plus shoulders). Initially, 13 total width categories were considered: 9 ft or less, 10, 11, 12, ..., 20, and 21 ft or more. Along with the independent variables described earlier, a variable indicating whether or not the shoulder was paved was included in the initial analyses of total roadway width. This variable was not significant ($p = 0.662$), and was not included in later analyses.

Results from two different models for related accident rates on the 13 roadway width categories are presented in Table C-3. Model I, in addition to roadway width, included state (three levels) and terrain as class variables, and clear recovery distance and number of driveways per mile as continuous variables. In Model II, state and two levels of functional class (local versus all other) were taken as class variables, while terrain, hazard rating, and driveways per mile were included as continuous variables. Table C-3 shows least-squares means of related accident rate by the road width categories for each of the two models, and test results for comparing adjacent width categories. Use of functional class Model II reduces the sample size from 1,107 to 982 because functional class is unknown in the Michigan data. With all the differences, the pattern of least-squares means is very consistent between the two models. Specifically, 9-ft widths have lower rates than 10-ft widths. The rates are about the same for 10- to 14-ft widths and, then, they decrease again for widths of 20 ft and over. A comparison of Models I and II is given in Figure C-1.

When the width categories were combined in exactly the manner described, and Model I was reestimated using the reduced number of width categories (four), the results were as given in Table C-4. The results of these analyses seem quite consistent with those of the lane width and shoulder width analysis, with 10-ft lanes and narrow shoulders generating many of the 10- and 11-ft total width sections. The rates of related accidents from Table C-4 are shown in Figure C-2.

FURTHER REFINEMENT OF ACCIDENT RELATIONSHIPS ON PAVED ROADS

Using the primary low-volume roads database (Zegeer, et al., October 1987), the information shown in Table C-2 was used to further combine lane and shoulder width categories when the rates of related accidents did not differ significantly. This process led to the seven lane and shoulder width categories given in Table C-5, which gives least-squares rates of related accidents (i.e., single-vehicle plus opposite-direction accidents) estimated from a model with co-variates indicating state, terrain type, clear recovery distance, and number of driveways per mile. It should be noted that the data in Table C-2 were derived from the application of a similar (collapsing) procedure applied to Table C-1, which resulted in the unequal shoulder width categories in Table C-2 and, also, in Table C-5. An illustration of the rates from Table C-5 are shown in Figure C-3. Note that for lane widths of 10 ft and above, related accident rates decrease as shoulder widths decrease. No difference in accident rate was found for lane widths of 11 versus 12 ft. Lane widths of 8 and 9 ft had a lower rate of related accidents (1.66) than 10-ft lanes with narrow shoulders (2.41). This could be the result of lower vehicle speeds on roads with 8- and 9-ft lanes.

The accident rates in Table C-6 represent a slight modification to the data in Table C-5, where consistent shoulder width categories of zero to 4 ft (narrow) and 5 ft and over (wide) have been selected. As expected, the only noticeable difference between Tables C-6 and C-5

involves the 11- and 12-ft lane, narrow shoulder category. Figure C-4 illustrates the rates from Table C-6.

The pattern of related accident rates given in Tables C-5 and C-6 (see Figures C-3 and C-4) seems to fit well with expectations for roads with 10-ft and wider lane widths. Note that very little information was available for roads with 8-ft lanes; thus, more than 90 percent of the data for roads with 8- and 9-ft-wide lanes, in fact, results from a survey of 9-ft-wide lanes. Moreover, the estimated rate of related accidents for 8- and 9-ft lanes in Tables C-5 and C-6 of 1.66 is quite consistent with the rates for other lane widths on roads having wide shoulders. The puzzling result, then, is that the estimated rates for roads with 9-ft lanes and narrow shoulders (see Table C-1), seems to be lower than would be expected relative to rates for 9-ft lanes and wide shoulders, and rates for 10-ft lanes and narrow shoulders.

In an effort to investigate the unexplained accident rate reduction for 8- and 9-ft lanes (compared to 10-ft lanes), the primary database was split into two subgroups: data from the cross-section database (Zegeer, et al., December 1987) and data from the supplemental databases (e.g., data from roads in Utah and in Oakland County, Michigan; and in North Carolina from minor roads). As shown in Figure C-5, rates were higher for 10-ft lanes and narrow shoulders in each database subset. This indicated that there was not one portion of the data that was causing this trend. In general, all of these databases revealed this same trend in reduced accident rate for 8- and 9-ft lanes.

To take one further look at this question, models used to generate Tables C-1, C-2, C-5, and C-6 were fit to the cross-section database (developed for FHWA by Zegeer, et al., December 1987). This database originally included approximately 5,000 miles of rural, two-lane roads in seven U.S. states with a full range of ADT (i.e., 100 vpd to approximately 20,000 vpd). From this database, a subsample was selected for all rural road sections with ADT less than or equal to 5,000 vpd. Initially, 11 lane and shoulder width categories were considered (the same as those in Table C-2), but with the 9-ft lane width roads split into two categories—one with shoulder widths of zero to 4 ft and the other with shoulder widths of 5 ft or greater. Estimated rates of related accidents from this analysis are given in Table C-7. Again, note that the rates for the two 9-ft lane categories are virtually identical and are less than the rates for the 10-ft lane, narrow-shoulder roads.

On the basis of hypothesis tests of the equality of various sets of the rates in Table C-7, categories were further collapsed into the six categories given in Table C-8. A similar set of analyses was carried out using only shoulder widths of zero to 4 ft and 5 ft or greater. The resulting estimated rates of related accidents (following collapsing of categories in Table C-8) are presented in Table C-9.

The low-volume roads database and the cross-section database overlap—the cross- section data on rural roads with ADT less than or equal to 2,000 vpd contained in both. Nonetheless, the results given in Tables C-7, C-8, and C-9 seem to provide further validation of the results given in Tables C-5 and C-6.

Figure C-6 compares rates of related accidents by lane and shoulder width categories for the low-volume roads database (ADT less than or equal to 2,000 vpd) to rates for the cross-section database (ADT less than or equal to 5,000 vpd). This comparison of rates from Tables C-6 and C-9 uses similar categories of shoulder widths. While the rates differ for some categories of lane and shoulder width, the general rate trends are relatively similar, suggesting that similar lane and shoulder width effects on accidents is supported by both databases.

ANALYSIS OF UNPAVED ROADS

A total of 164 roadway sections of unpaved roads (from Michigan, North Carolina, and Utah) was available for analysis. These sections were placed into three width categories (corresponding to lane width plus shoulder width for paved roads) with roughly equal sample sizes: 9 ft or less, 10 and 11 ft, and 12 ft and greater. Because of the small number of unpaved roads and the interest to compare paved and unpaved conditions, paved and unpaved roads from the three states were analyzed together.

A class variable, with six levels corresponding to the three width categories of paved and unpaved roads, was analyzed in models containing many of the other variables used in the analyses described above. Because functional class was not available for Michigan data, and was highly confounded with state and roadway width variables in the other two states, no attempt was made to include functional class in any of the analyses. Comparisons of the estimated effects were made of width within pavement types, and of paved versus unpaved roads within width categories. Table C-10 contains results from fitting three different models (labeled A, B, and C) to the data. Model A contained only the road class variable, terrain, and clear recovery distance. In Model B, driveways per mile was added, and in Model C, state was added as a class variable. The R^2 values for these three models were 0.147, 0.162, and 0.170, respectively. Figure C-7 (which illustrates related accident rate by lane width for paved and unpaved roads using Model A) clearly shows that unpaved roads have higher accident rates than paved roads for given lane widths.

Table C-10 lists three sets of least-squares means and the significance levels from three sets of pairwise comparison tests, where the symbols P_1, P_2, P_3, U_1, U_2, and U_3 are used to denote the three width categories for paved and unpaved roads, respectively. The same pattern of least-squares mean accident rates is seen for all three models. This pattern also is consistent with the previous results—accident rates are lower for narrower roadways. The significance tests consistently show a significant difference between accident rates on unpaved roads with lane plus shoulder width less than or equal to 9 ft wide, and those for unpaved roads 10 and 11 ft wide. Accident rates for paved roads differ significantly from accident rates for unpaved roads for width categories of 10 to 11 ft and for 12 ft and greater.

Another type of comparison of paved versus unpaved roads was done by partitioning the data according to three ranges of ADT rather than by roadway width. The three ADT ranges used were ADT $\leq$ 250 vpd, 250 vpd $<$ ADT $\leq$ 400 vpd, and ADT $>$ 400 vpd. Again, a road type variable with six classes is given: paved, ADT $\leq$ 250 vpd; paved, 250 vpd $<$ ADT $\leq$ 400 vpd; ... unpaved, ADT $>$ 400 vpd. Table C-11 gives results from a model for related accident rate as a function of road type, state, terrain, and clear recovery distance. These analyses show that rates of related accidents on paved roads decrease significantly with increases in ADT category. On unpaved roads, rates on roads with ADT less than 400 vpd were shown to be significantly lower than rates on roads with 250 vpd $\leq$ ADT $<$ 400 vpd, though the sample sizes were quite small for these two categories.

The rates did not differ significantly between paved and unpaved roads with ADT less than 250 vpd. Paved roads had significantly lower rates than unpaved roads in the ADT range from 250 to 400 vpd. For roads with ADT greater than 400 vpd, again the difference was not significant.

Because of the very small number of unpaved roads with ADT greater than 400 vpd, the upper two ADT categories were combined and then compared. The last line of Table C-11 indicates that this difference is statistically significant. Accident rates from Table C-11, for paved versus unpaved roads for various ADT groups, are shown in Figure C-8.

ANALYSES OF INJURY RATES

The question of how roadway features relate to crash severity can be approached in two different ways: (1) calculate various types of injury rates in the form of injury accidents (at some level of severity) per million vehicle miles, and fit models to these rates in the same manner as was done with related accident rates; and (2) examine how the distribution of injuries, given an accident rate, varies with roadway features. Because our basic data file consists of counts of accidents of various types (e.g., injury accidents, fatal accidents), only the former approach was pursued in this study.

Three types of injury rates were used: (all) injury accidents per million vehicle miles; accidents resulting in K, A, or B injuries per million vehicle miles; and accidents resulting in K or A injuries per million vehicle miles. These rates are referred to simply as injury rate, KAB rate, and KA rate, respectively. It should be noted that for these analyses, accidents are not restricted to related accidents.

To investigate relationships between injury rate and lane and shoulder width, models were fit to each type of injury rate using the original 29 lane and shoulder width categories, along with state, terrain, clear recovery distance, and driveways per mile. Patterns of least-squares mean injury rates clearly resembled those of related accident rates, and a similar set of test statistics indicated it would be appropriate to group the lane and shoulder width categories into 10 groups as done previously for related accident rates. Least-squares mean injury rates from the resulting combined categories are given in Table C-12. The pattern down the injury rate column is similar to that of the related accident rates in Table C-2, with the exception of the relatively high injury rates for roads with 13-ft lanes. As injury severity increases (KAB rate and KA rate) the overall pattern becomes less pronounced. A part of the pattern that is retained is that the injury rates for roads with 10-ft lanes and narrow shoulders are consistently higher than the rates for roads with 8- and 9-ft lanes. This could logically be related to lower vehicle speeds on roads with lane widths of 8 and 9 ft, compared to 10 ft. A test of the difference between rates for roads with 9-ft lanes versus 10-ft lanes with narrow shoulders is statistically significant for all three injury rates ($p \leq 0.0002$). The relatively higher injury rates for roads with 13-ft lanes may result from more angle accidents (which were not included in related accident rates).

Table C-13 shows least-squares means of the three injury rates from the three-state, paved versus unpaved analysis. As was pointed out with respect to Table C-12, the injury rates in Table C-13 are quite similar to the rates for related accidents in Table C-10. Also, as with the accident rates of Table C-10, injury rates were significantly higher on 10- to 11-ft unpaved roads than on unpaved roads with widths less than or equal to 9 ft. In addition, paved roads differed significantly from unpaved roads with respect to injury rate for the categories of 10- and 11-ft lanes and greater than or equal to 12-ft lanes. A similar pattern also can be seen for the KAB rate column. Again, the same comparison tests were statistically significant. The pattern is much less discernable for the KA rate column and, with these rates, none of the comparisons was statistically significant ($p < 0.05$). Figure C-9 shows a plot of injury rates by surface type and lane width.

The similar pattern in the variation of injury rates across lane and shoulder width categories and for related accident rates suggests that the distribution of accident severity remains relatively constant with respect to lane and shoulder width. In particular, there are relatively high injury rates on the narrowest roads where there are relatively low accident rates.

VALIDATION AND EXTENSION OF LANE AND SHOULDER WIDTH ANALYSES

Data from three state data systems (Illinois, Minnesota, and North Carolina) were used to validate and extend the results presented in the primary analysis of the safety implications of varying lane widths and shoulder widths on both paved and unpaved, low-volume roadway sections. The North Carolina data represented additional sections not used in the primary analysis. Again, all accident rates were in terms of related accidents only (i.e., single-vehicle plus opposite-direction crashes), unless otherwise stated.

In the analyses of the seven-state primary database, lane and shoulder width effects on related accidents per million vehicle miles were estimated while adjusting for differences in functional class, terrain, clear recovery distance (or hazard rating), and number of driveways per mile. Functional class was the only variable available in all of the three secondary analysis files; terrain also was available in the North Carolina data.

Table C-14 shows the available paved roadway sections for the primary data set and for the three validation data sets, classified into the 30 lane width by shoulder width categories used in the primary analysis (and shown earlier in Table C-1). Differences in the distributions of lane and shoulder width from state to state are apparent from Table C-14. The following discussion of each state will highlight these differences.

Analysis of Illinois Data

The Illinois data contained no information on unpaved roads. With respect to paved roads, Table C-14 indicates that Illinois has very few roads with lane widths of 8 ft or less, and few roads with shoulders of less than 3 ft in width, making comparisons with the primary analysis results very difficult in certain categories. However, even given these difficulties, a first comparison of Illinois rates with those from the primary study involved the classification of roadways into the same 10 groups as used in Table C-1. Least-squares mean rates, presented in Table C-15 and Figure C-10, represent related accidents per million vehicle miles from a model that contained only one other factor, functional class (local versus other).

For comparison purposes, the same model (i.e., a model only involving functional class) also was run on the primary data set (see the last column of Table C-15 for the results). Clearly, the two sets of least-square estimates differ in magnitude or scale. A state variable was a significant factor in the primary analysis, therefore, a difference in scale between the two data sets is not unexpected. However, the state difference between Illinois and the other states was much greater than the state differences within most states of the primary database. For whatever reasons, the Illinois rates are consistently lower than the primary analysis rates.

Also, note that the Illinois rate for 8-ft lanes is based on very few observations, and the 9-ft rate is derived primarily from roads with shoulder widths of 5 ft or more. Given these limitations, and even with the lower rates, there is an increased rate for the 10-ft-wide lanes with narrow shoulders. Patterns for other lane width groups also indicate increased rates with respect to decreased shoulder width.

Because most of the Illinois data are for roads with lanes of 9 ft or more and relatively wide shoulders, rates of related accidents were estimated for five categories of these roads and compared with rates from similar roads from the primary database. Results from these analyses are given in Table C-16 and shown on Figure C-11. It should be noted here that the last entry under the primary data column in Table C-16 is based on relatively few observations. Both sets of estimates show steadily decreasing related accident rates with increasing lane width.

Using the Illinois estimates, a decrease of about 10 percent of related accidents is found for each additional foot of lane width (for roadways with relatively wide shoulders). Using the primary database, the decrease is roughly the same for lane widths of 9 to 12 ft.

Analysis of Minnesota Paved Roads

From Table C-14, the Minnesota data (similar to data from Illinois) contain virtually no information for roadways with lane widths of 8 ft or less, and relatively little information for those with 9-ft lanes. Very large samples, however, are available for wider roads and, especially, for wider roads with wide shoulders. Starting with the basic categories of Table C-14, related accident rates were estimated and categories with similar rates were combined to yield 14 categories for further analysis. The first two categories again consisted of all roads with lane widths of 8 ft or less, and all roads with 9-ft lanes, respectively. For roads with lane widths of 10 ft or more, three shoulder width categories were considered: narrow, medium, and wide. These groups are specified explicitly in Table C-17, which lists the least-squares mean accident rates from an analysis that included three levels of functional class (arterial, collector, and local) as a second factor.

For a fixed lane width, reductions in rates of related accidents are generally found as shoulder width increases, as given in Table C-17 and shown on Figure C-12. For example, for a 10-ft lane width, shoulder widths of zero to 2, 3 to 6, and greater than 7 ft yield accident rates of 1.03, 0.86, and 0.42, respectively. Accident rates also generally decrease for increases in lane width for fixed shoulder width categories in only some cases. This is further borne out by the hypothesis tests at the bottom of Table C-17, which show no significant differences due to lane width (10 ft to more than 13 ft wide) on roads with the widest shoulders ($p = 0.6959$). For the other shoulder width categories, there are statistically significant differences by lane width, but accident rates do not consistently decrease with increasing lane width (holding shoulder width constant).

Rates of total injury accidents were computed as total number of all injury crashes on a section (i.e., not just related accidents divided by million vehicle miles) in addition to the rate of more serious injury accidents (i.e., fatal, A-type, plus C-type, termed KAB rate). The injury rate and KAB rate are also given in Table C-17 by lane and shoulder width combinations. Such rates are by far the highest for lane widths of $\leq$ 8 ft (i.e., 1.92 injury rate and 1.21 KAB rate). For 9-ft lanes and 10-ft lanes with narrow (6 ft wide or less) shoulders, injury rates drop to between 0.84 and 0.88, while KAB rates drop to between 0.58 and 0.64. Injury and KAB rates drop further and fluctuate somewhat for wider lanes and shoulders.

Least-squares mean rates of related accidents by functional class also were computed for Minnesota paved roadways. These values were arterials—0.64, collectors—0.75, and local—0.87.

As expected, the arterials had the lowest rates, probably because of generally better geometric design. Local roads had the highest rates, as may be expected.

Analysis of Minnesota Unpaved Roads

The Minnesota sample contained data on 4,900 unpaved road sections with lane widths ranging from 6 to 16 ft. For 96.7 percent of these sections, the file also indicates a shoulder of at least 1 ft in width. Analyses were carried out on both lane and shoulder width categories and on total width categories. Table C-18 gives results from a model with 19 lane width by shoulder width categories and functional class at two levels (local versus collector) as independent class variables. Table C-18 gives the least-squares mean rate of related accidents and sample size for each of the 19 categories.

The width factor was not statistically significant in the estimated model ($p = 0.3717$), and the mean accident rates do not display consistent tendencies with respect to lane width or shoulder width. Functional class was significant ($p = 0.0057$) with mean rates of related accidents of 0.64 and 0.78 for collector and local roads, respectively.

The second analysis of Minnesota unpaved roads involved adding the width of the lanes and shoulders to form a single width variable. Twelve width categories, ranging from 18 ft or less to 40 ft or more, were formed and analyzed in a model with functional class as a second factor. In this model, the width categories were marginally significant ($p = 0.0715$), while functional class was significant ($p = 0.0052$). The total width categories, their estimated mean rates of related accidents, and sample sizes are given in Table C-19 and shown on Figure C-13. As with the lane width by shoulder width categories, there does not seem to be a discernable pattern of change in rate of related accidents with increasing roadway width. This finding differs from the findings from two studies of the primary database, where wide unpaved roads had lower accident rates than narrow unpaved roads. It is not clear why the two databases do not agree.

Combined Analysis of Minnesota Paved and Unpaved Roads Data

A third analysis was carried out on the Minnesota file, this time on the combined data for paved and unpaved roads. This analysis involved estimating a model with 16 lane width by shoulder width categories as one factor, functional class (three levels), and a variable indicating paved or unpaved as two additional factors. Both the width categories and functional class were statistically significant ($p = 0.0001$ for each). Pavement status was not significant ($p = 0.3980$).

The width categories and their estimated accident rates are given in Table C-20. As might be expected from the previous analyses, the results in Table C-20 (paved plus unpaved) appear to agree with the results for paved roads shown in Table C-17, except for the 8-ft lane width category, where the rate for paved roads was much higher. This is perhaps because of the higher speeds on narrow paved roads (8-ft lane width) compared to unpaved roads.

Analysis of North Carolina Data on Paved Roads

Unlike the data for Illinois and Minnesota, data on the additional North Carolina sections not used in the primary analysis contained relatively high frequencies of roads in the less than or equal to 9-ft lane width range, but virtually none with lane widths greater than 12 ft. The first analysis of these data was done on the first 25 lane width by shoulder width categories given in Table C-14. The analysis was formulated as a model with a lane width factor, a shoulder width factor, a lane width by shoulder width interaction, and two additional factors—functional class at three levels and terrain at three levels.

The lane width by shoulder width interaction was not statistically significant ($p = 0.8115$); therefore, the model was rerun with the interactions removed. Least-squares mean rates of related accidents by each of the other factors are given in Table C-21 and shown on Figure C-14, which controlled for variables of importance. It would appear from Table C-21 that some of the rates listed are essentially equal, (i.e., lane width $\leq$ 8 and 9 or 11 and 12, shoulder width of 0 to 4 ft).

Statistical hypotheses tests confirmed these conjectures. As a result, lane widths were reclassified into two categories ($\leq$ 9 ft, $\geq$10 ft), and shoulder widths into three categories (0-4, 5-6, $\geq$7 ft). The model was rerun with this reclassification. Again, an interaction term was included because, even though this factor was not significant, including it results in the calculation of least-squares mean rates of related accidents for each lane width by shoulder width combination. These recalculated rates are given in Table C-22 and shown on Figure C-15.

Table C-22 indicates that rates of related accidents generally decrease as shoulder width increases for a given lane width category. For example, for lane widths of 10 ft or more, the related accident rate drops from 1.85 (for shoulder widths of 0 to 4 ft) to 1.65 (for shoulder widths of 5 to 6 ft) to 1.43 (for shoulder widths of 7 ft or greater). Also, for a given shoulder width category, lane widths of greater than 10 ft had slightly lower rates than lane widths of less than 9 ft. These results, considered with those in Table C-21, show some similarities and some differences with the primary analysis. First of all, wider shoulders (particularly for shoulders 5 ft and wider) in the North Carolina and the primary data analyses showed a lower accident rate for 8- and 9-ft lanes, a higher rate for 10-ft lanes, and a much reduced rate for 11- and 12-ft lanes. The North Carolina analyses, however, revealed the highest rates of related accidents for lanes of $\leq$ 9 ft (1.95), with lower rates for 10-, 11-, and 12-ft lanes (a rate of approximately 1.7 for each of these three widths). See Table C-21.

Analysis of Unpaved North Carolina Roads Data

The North Carolina data file contained information on 236 unpaved road sections. All but nine of these sections were classified as having zero shoulder width, which suggests an inventory coding decision has been made in North Carolina not to attempt to separate lane width from shoulder width on unpaved roads. This may result from the nature of most unpaved North Carolina roads—the gravel cover and grading extend from ditch line to ditch line. The data were grouped into six lane width categories: 5 to 6, 7 to 8, 9, 10, 11 to 12, and 13 to 16.

In an analysis with lane width as one factor and terrain and functional class (local versus collector) as other factors, neither lane width nor terrain were statistically significant ($p = 0.1895$ and $p = 0.5398$, respectively). With terrain deleted from the model, lane width was still not significant ($p = 0.1301$). Least-squares mean rates of related accidents by lane width and functional class are given in Table C-23.

In addition to lane width not being statistically significant, little evidence suggests that any logical regrouping by expanded lane width categories would lead to meaningful results. The rates in Table C-23 reveal an inconsistent relationship between width and related accident rate for unpaved roads. Possible reasons for this trend include the relatively small sample sizes for most width categories, possible problems with accident reporting on unpaved roads, or reduced speeds on some unpaved road sections that may result in reduced accident rates. Regardless of the explanation, it does not appear that changes in lane width on unpaved roads affect accident rate. This conclusion differs from that of the primary analysis, which indicates that wider, unpaved roads have lower accident rates than more narrow, unpaved roads.

A comparison of the estimated rates of related accidents of Table C-23 with those of Tables C-21 and C-22 suggests that North Carolina rates are considerably higher on unpaved roads than on paved roads. The overall, unadjusted mean rate of related accidents was found to be 1.63 for paved roads versus 3.45 for unpaved roads, which supports this conclusion. However, the fact that most of the paved roads, even with narrow lanes, tended to have some shoulders, while the unpaved roads tended to have narrow lanes and no shoulder, complicated the analysis of paved and unpaved roads together to produce a meaningful measure of road width. In an analysis with four lane width categories (i.e., $\leq$ 8 ft, 9, 10, $\geq$ 11 ft), together with factors for terrain, functional class, and pavement status, all factors were significant ($p = 0.0001$ for each factor). The least-squares mean rates of related accidents for paved road versus unpaved road, after adjusting for the other factors, were 1.82 for paved and 3.26 for unpaved roads.

SUMMARY AND CONCLUSIONS

For paved roads, aside from differences in magnitude from state to state, the validation analyses seemed, overall, to confirm the findings of the primary analyses. Rates of related accidents (i.e., single-vehicle plus opposite-direction accidents) decrease with both increasing lane widths and increasing shoulder widths. In Illinois, most road sections had relatively wide shoulders, and accident rates decreased consistently with increasing lane width. The Minnesota data (which contained much information on wider roads with a full range of shoulder widths), showed rates of related accidents to decrease consistently with increasing shoulder width, but much less consistently with increasing lane width. In fact, for roads with the widest shoulders, rates did not differ significantly with differing lane widths. North Carolina's data were shifted more towards roads with narrower lanes and a fairly full range of shoulder widths. On these roads, consistent decreases in related accident rates were found with both increases in lane width and increases in shoulder width, although the range of the decreases due to shoulder width was somewhat greater.

Overall, the data seem to show that, with respect to related accident rates on paved roads, shoulder width is at least as important a factor as lane width. In particular, increasing lane width at the expense of decreasing shoulder width would not appear to be a cost-effective approach. This finding is consistent with the results of recent research on higher volume, two-lane roads.

A large amount of data on unpaved roads was available from Minnesota and a lesser amount from North Carolina. Neither of these samples showed related accident rates to vary significantly with roadway width. In Minnesota, the rate of related accidents did not differ significantly on paved and unpaved roads, while in North Carolina, rates of related accidents on unpaved roads were estimated to be nearly double those on paved roads.

Table C-1
Least-Squares Mean Rate of Related Accidents and Significance Test for 29 Lane and Shoulder Width Categories

Lane Width (feet)	Shoulder Width (feet)	Number of Sections	L.S. Mean Accident Rates	Test I p-Value	Test II p-Value
≤8	0	7	1.38	—	
≤8	1-2	9	2.45	0.19	0.03
≤8	3-4	6	2.12	0.69	
≤8	5-6	2	-0.21	0.01	
9	0	24	1.56	—	
9	1-2	38	1.83	0.52	
9	3-4	97	1.66	0.58	0.90
9	5-6	90	1.60	0.79	
9	6+	25	1.43	0.61	
10	0	28	2.31	—	
10	1-2	52	2.23	0.85	0.84
10	3-4	85	2.40	0.56	
10	5-6	54	1.45	0.00	0.19
10	6+	29	1.08	0.19	
11	0	14	1.79	—	
11	1-2	48	1.81	0.97	0.97
11	3-4	51	1.21	0.04	
11	5-6	50	1.13	0.74	0.85
11	6+	43	1.27	0.57	
12	0	42	1.81	—	0.91
12	1-2	89	1.78	0.91	
12	3-4	71	1.40	0.11	
12	5-6	36	1.85	0.10	0.06
12	6+	65	1.22	0.02	
≥13	0	30	1.20	—	
≥13	1-2	8	1.32	0.84	0.96
≥13	3-4	8	1.36	0.96	
≥13	5-6	8	0.80	0.45	0.58
≥13	6+	4	0.40	0.58	

Table C-2
Least-Squares Mean Rates of Related Accidents for Collapsed Lane and Shoulder Width Categories

Lane Width (feet)	Shoulder Width (feet)	Model 2 L.S. Mean Accident Rates	Model 3 L.S Mean Accident Rates	Significance Tests p-Values
8	all	1.62	1.55	
				0.7170
9	all	1.63	1.67	
				0.0001
10	0-4	2.34	2.41	
				0.0001
11	0-2	1.80	1.88	
12	0-2	1.78	1.86	
				0.0077
10	≥ 5	1.30	1.43	
11	≥ 3	1.21	1.32	
12	≥ 3	1.41	1.30	
13+	0-4	1.24	1.57	
				0.0506
13+	≥ 5	0.65	0.76	

Table C-3
Results from Models of Lane Plus Shoulder Width

Width of Lane Plus Shoulder (feet)	Number of Sections	Model I L.S. Rates of Related Accidents	Model I Pairwise Tests p-Value	Model II L.S. Rates of Related Accidents	Model II Pairwise Tests p-Value
< 9	34	1.44		2.17	
			0.01		0.09
10	46	2.41		2.83	
			0.25		0.57
11	69	2.03		2.64	
			0.49		0.35
12	145	1.87		2.43	
			0.82		0.74
13	180	1.83		2.37	
			0.84		0.35
14	194	1.87		2.52	
			0.11		0.11
15	119	1.59		2.23	
			0.04		0.11
16	92	1.19		1.91	
			0.38		0.35
17	60	1.37		2.14	
			0.64		0.42
18	41	1.49		2.36	
			0.90		0.82
19	39	1.45		2.28	
			0.17		0.30
20	39	1.05		1.92	
			0.75		0.79
≥ 21	55	1.13		1.85	

Table C-4
Least-Squares Mean Rates for Four Categories of Lane Plus Shoulder Width

Width of Lane Plus Shoulder (feet)	L.S. Mean Rates of Related Accidents	Test p-Value
<9	1.43	——
10-14	1.90	0.09
15-19	1.41	0.0001
20 & Over	1.10	0.03

Table C-5
Mean Rates of Related Accidents on Collapsed Lane and Shoulder Width Categories from Primary Database

Lane Width (feet)	Shoulder Width (feet)	L.S. Mean Rate of Related Accidents
8, 9	all	1.66
10	0-4	2.41
10	≥5	1.43
11, 12	0-2	1.87
11, 12	≥3	1.31
13	0-4	1.57
13	≥5	0.76

Table C-6
Rates of Related Accidents for Modified Lane and Shoulder Width Categories

Lane Width (feet)	Shoulder Width (feet)	L.S. Mean Rate of Related Accidents
8, 9	all	1.66
10	0-4	2.41
10	≥5	1.43
11, 12	0-4	1.65
11, 12	≥5	1.30
13	0-4	1.54
13	≥5	0.74

Table C-7
Estimated Rates of Related Accident for 11 Lane and Shoulder Width Categories from Cross Section Database

Lane Width (feet)	Shoulder Width (feet)	L.S. Mean Accident Rate
8	all	1.52
9	0-4	1.37
9	≥ 5	1.34
10	0-4	1.82
10	≥ 5	1.22
11	0-2	1.64
11	≥3	1.05
12	0-2	1.50
12	≥ 3	0.93
13	0-4	1.57
13	≥ 5	0.46

Table C-8
Estimated Accident Rates of Related Accidents for Lane and Shoulder Width Categories[a]

Lane Width (feet)	Shoulder Width (feet)	L.S. Mean Accident Rate
8 & 9	all	1.36
10	0-4	1.81
11, 12, 13	0-2 (11- & 12-foot Lane) 0-4 (13-foot Lane)	1.57
10	≥ 5	1.22
11,12	≥3	0.98
13	≥ 5	0.47

[a]Collapsed from Table C-7

Table C-9
Estimated Rates of Related Accidents for Lane and Equal Shoulder Width Categories from Cross Section Database

Lane Width (feet)	Shoulder Width (feet)	L.S. Mean Accident Rate
8 & 9	all	1.36
10	0-4	1.82
11, 12, 13	0-4	1.38
10	≥ 5	1.21
11, 12	≥ 5	0.93
13	≥ 5	0.47

Table C-10
Model Results Comparing Paved and Unpaved Roads

Road Type	Lane Width (feet)	Model A L.S. Mean Rates of Related Accidents	Model B L.S. Mean Rates of Related Accidents	Model C L.S. Mean Rates of Related Accidents
P_1 - Paved	≤ 9	1.20	1.13	1.32
P_2 - Paved	10-11	2.06	1.94	2.04
P_3 - Paved	≥ 12	1.99	1.99	2.09
U_1 - Unpaved	≤ 9	1.72	1.85	1.94
U_2 - Unpaved	10-11	3.95	3.95	3.85
U_3 - Unpaved	≥ 12	3.88	3.92	3.83

Pairwise Comparisons	Model A P-Values	Model B P-Values	Model C P-Values
$P_1 = P_2$	0.074	0.089	0.131
$P_2 = P_3$	0.802	0.866	0.872
$U_1 = U_2$	0.006	0.010	0.019
$U_2 = U_3$	0.921	0.958	0.984
$P_1 = U_1$	0.517	0.353	0.427
$P_2 = U_2$	0.001	0.001	0.001
$P_3 = U_3$	0.001	0.001	0.001

Table C-11
Paved Versus Unpaved Roads Within ADT Range

Pavement Type	ADT	L.S. Mean Rates of Related Accidents	Sample Size
P_1 - Paved	≤ 250	3.71	86
P_2 - Paved	250-400	2.61	91
P_3 - Paved	> 400	1.96	430
U_1 - Unpaved	≤ 250	3.94	128
U_2 - Unpaved	250-400	4.16	23
U_3 - Unpaved	> 400	2.29	13

Comparisons	P-Value
$P_1 = P_2$	0.046
$P_2 = P_3$	0.032
$U_1 = U_2$	10.751
$U_2 = U_3$	0.013
$P_1 = U_1$	0.730
$P_2 = U_2$	0.015
$P_3 = U_3$	0.519
$P_2 + P_3 = U_2 + U_3$	0.024

Table C-12
Estimated Injury Rates as a Function of Lane and Shoulder Width

Lane Width (feet)	Shoulder Width (feet)	Injury Rate	KAB Rate	KA Rate
8 or less	all	1.08	0.34	0.13
9	all	1.04	0.38	0.20
10	0-4	1.56	0.74	0.35
10	5+	0.89	0.33	0.20
11	0-2	0.96	0.72	0.38
11	3+	0.82	0.36	0.19
12	0-2	0.99	0.90	0.48
12	3+	0.76	0.51	0.26
≥ 13	0-4	1.03	0.92	0.41
≥ 13	5+	0.63	0.62	0.30

Table C-13
Estimated Injury Rates on Paved and Unpaved Roads

Road Type	Lane Width (feet)	Least-Squares Mean		
		Injury Rate	KAB Rate	KA Rate
Paved	≤ 9	0.67	0.48	0.23
Paved	10-11	1.23	0.86	0.43
Paved	≥ 12	1.09	0.77	0.37
Unpaved	≤ 9	0.86	0.51	0.24
Unpaved	10-11	2.11	1.43	0.52
Unpaved	≥ 12	1.97	1.33	0.47

Table C-14
Data Set Sample Sizes for Paved Roadway Sections

Lane Width (feet)	Shoulder Width (feet)	Primary Data	Illinois Data	Minnesota Data	North Carolina Data
≤ 8	0	7 (25.1)	0 (0)	0 (0)	24 (45.5)
≤ 8	1-2	9 (33.4)	0 (0)	6 (7.7)	46 (140.5)
≤ 8	3-4	6 (16.5)	1 (6.9)	2 (5.6)	234 (580.8)
≤ 8	5-6	2 (8.2)	1 (1.2)	0 (0)	109 (308.6)
≤ 8	7+	0 (0)	10 (22.1)	0 (0)	9 (16.8)
9	0	24 (87.0)	5 (12.7)	0 (0)	109 (238.1)
9	1-2	38 (134.1)	1 (3.5)	14 (27.9)	89 (263.6)
9	3-4	97 (325.6)	13 (26.7)	23 (44.8)	770 (2,082.8)
9	5-6	90 (264.8)	125 (250.8)	4 (7.3)	1,080 (3,210.9)
9	7+	25 (78.9)	137 (283.2)	8 (13.1)	158 (459.4)
10	0	28 (83.5)	3 (3.9)	5 (14.7)	50 (117.0)
10	1-2	52 (175.8)	2 (7.9)	70 (157.0)	46 (135.5)
10	3-4	85 (247.1)	10 (18.6)	209 (471.6)	420 (1,217.7)
10	5-6	54 (151.6)	74 (146.5)	26 (78.0)	798 (2,385.6)
10	7+	29 (94.4)	74 (154.4)	101 (303.6)	216 (773.4)
11	0	14 (48.8)	3 (5.0)	31 (68.7)	3 (5.2)
11	1-2	48 (171.3)	2 (4.3)	723 (2,009.6)	7 (28.6)
11	3-4	51 (142.2)	63 (137.1)	1,278 (3,618.2)	87 (244.8)
11	5-6	50 (149.9)	74 (135.1)	214 (601.5)	160 (487.5)
11	7+	43 (145.6)	292 (615.5)	106 (299.8)	81 (309.2)
12	0	42 (146.8)	9 (14.2)	27 (64.5)	4 (7.3)
12	1-2	89 (302.6)	1 (2.1)	822 (2,311.2)	2 (4.3)
12	3-4	71 (244.8)	144 (282.0)	2,832 (7,872.8)	36 (80.4)
12	5-6	36 (114.5)	177 (378.5)	1,086 (2,919.0)	61 (160.4)
12	7+	65 (206.0)	456 (974.6)	849 (2,137.5)	104 (349.7)
≥ 13	0	30 (96.9)	2 (5.0)	28 (53.9)	0 (0)
≥ 13	1-2	8 (27.8)	7 (20.7)	120 (321.2)	0 (0)
≥ 13	3-4	8 (25.3)	29 (73.4)	170 (495.5)	2 (3.2)
≥ 13	5-6	8 (24.0)	16 (37.4)	120 (319.6)	0 (0)
≥ 13	7+	4 (9.6)	64 (167.2)	37 (81.4)	3 (21.1)
TOTALS		1,113 (3,581.1)	1,795 (3,790.9)	8,911 (24,258.9)	4,708 (13,678.3)

Numbers in parentheses indicate mileage within sample.

Table C-15
Illinois Least-Squares Mean Rates of Related Accidents

Lane Width Group*	Lane Width (feet)	Shoulder Width (feet)	Illinois L.S. Mean Rate of Related Accidents	Primary Data L.S. Mean Rate of Related Accidents
1	≤ 8	all	3.57	2.60
2	9	all	1.13	2.56
3	10	0-4	2.03	3.11
4	10	5 & over	1.02	2.16
5	11	0-2	1.12	2.28
6	11	3 & over	0.88	2.11
7	12	0-2	0.84	2.47
8	12	3 & over	0.85	2.04
9	≥ 13	0-4	0.90	1.79
10	≥ 13	5 & over	0.73	1.00

*See Table C-1

Table C-16
Comparison of Rates of Related Accidents from the Illinois and Primary Databases on Roads with Wide Shoulders

Lane Width (feet)	Shoulder Width (feet)	Illinois——Rate of Related Accidents	Primary Data——Rate of Related Accidents
9	5 & over	0.87	1.73
10	5 & over	0.80	1.38
11	3 & over	0.66	1.31
12	3 & over	0.63	1.23
≥13	3 & over	0.56	0.41

Table C-17
Related Accident Rates and Total Injury Rates for Paved Minnesota Roads

Width Group	Lane Width (feet)	Shoulder Width (feet)	L.S. Mean Accident Rate	Injury Rate	KAB Rate
1	≤ 8	all	2.32	1.92	1.21
2	9	all	0.85	0.86	0.58
3	10	0-2	1.03	0.88	0.64
4	10	3-6	0.86	0.84	0.59
5	10	≥ 7	0.42	0.43	0.29
6	11	0-2	0.67	0.65	0.44
7	11	3-6	0.63	0.63	0.45
8	11	≥ 7	0.37	0.43	0.30
9	12	0-2	0.72	0.68	0.47
10	12	3-6	0.55	0.57	0.40
11	12	≥ 7	0.37	0.41	0.29
12	≥ 13	0-2	0.81	0.85	0.57
13	≥ 13	3-6	0.55	0.53	0.37
14	≥ 13	≥ 7	0.39	0.41	0.29

Hypothesis Tests
No Difference by Shoulder Width for Lane Width of:

10 feet	$F_{2\infty} = 31.23$	$p = 0.0001$
11 feet	$F_{2\infty} = 17.35$	$p = 0.0001$
12 feet	$F_{2\infty} = 81.02$	$p = 0.0001$
13+ feet	$F_{2\infty} = 17.75$	$p = 0.0001$

Hypothesis Tests
No Difference by Lane Width for Shoulder Width:

Narrow	$F_{3\infty} = 5.43$	$p = 0.0010$
Medium	$F_{3\infty} = 15.79$	$p = 0.0001$
Wide	$F_{3\infty} = 0.48$	$p = 0.6959$

Table C-18
Rates of Related Accidents by Lane and Shoulder Width on Unpaved Minnesota Roads

Width Group	Lane Width (feet)	Shoulder Width (feet)	Least-Squares Rates of Related Accidents	Sample Size
1	6-7	all	0.76	67
2	8	0-2	0.59	71
3	8	≥ 3	0.89	170
4	9	0-2	1.01	152
5	9	≥ 3	0.76	389
6	10	0-2	0.76	317
7	10	≥ 3	0.73	724
8	11	0-2	0.62	464
9	11	≥ 3	0.75	641
10	12	0-2	0.66	505
11	12	≥ 3	0.85	455
12	13	0-2	0.69	256
13	13	≥ 3	0.78	184
14	14	0-2	0.66	137
15	14	≥ 3	0.71	122
16	15	0-2	0.70	68
17	15	≥ 3	0.52	52
18	16	0-2	0.80	74
19	16	≥ 3	0.21	52

Table C-19
Total Width Effects for Unpaved Minnesota Roads

Width Group	Road Width (feet)	L.S. Mean Rate of Related Accidents	Sample Size
1	≤ 18	0.74	36
2	20	0.57	102
3	22	0.98	321
4	24	0.81	732
5	26	0.63	1,167
6	28	0.72	1,121
7	30	0.82	616
8	32	0.78	364
9	34	0.69	202
10	36	0.58	119
11	38	0.64	60
12	≥ 40	0.46	60

Table C-20
Lane and Shoulder Width Effects on Paved and Unpaved Minnesota Roads

Width Group	Lane Width (feet)	Shoulder Width (feet)	Sample Size	L.S. Mean Rate of Related Accidents	L.S. Mean Rate of Related Accidents from Minnesota Paved Roads Only[a]
1	≤ 8	0-2	99	0.69	2.32
2	≤ 8	≥ 3	217	0.87	2.32
3	9	0-2	166	0.94	0.85
4	9	≥ 3	424	0.74	0.85
5	10	0-2	392	0.86	1.03
6	10	3-6	959	0.78	0.86
7	10	≥ 3	101	0.41	0.42
8	11	0-2	1,218	0.65	0.67
9	11	3-6	2,133	0.63	0.63
10	11	≥ 7	106	0.36	0.37
11	12	0-2	1,354	0.70	0.72
12	12	3-6	4,362	0.54	0.55
13	12	≥ 7	860	0.36	0.37
14	≥ 13	0-2	683	0.73	0.81
15	≥ 13	3-6	513	0.56	0.55
16	≥ 13	≥ 7	224	0.40	0.39

[a]From Table C-17.

Table C-21
Least-Squares Mean Rates of Related Accidents on North Carolina Paved Roads by Lane and Shoulder Width Categories, Functional Class, and Terrain

Lane Width (feet)	Accident Rate	Shoulder Width (feet)	Accident Rate
≤8	1.95	0	1.89
9	1.94	1-2	1.89
10	1.73	3-4	1.96
11	1.68	5-6	1.72
12	1.69	≥7	1.53
Functional Class	**Accident Rate**	**Terrain**	**Accident Rate**
Major Collector	1.45	Flat	1.62
Minor Collector	1.83	Rolling	1.81
Total	2.11	Mountainous	1.96

Table C-22
North Carolina Paved Roads Mean Rates of Related Accidents for Combined Lane and Shoulder Width Categories

Lane Width (feet)	Shoulder Width			
	0-4 feet	5-6 feet	≥ 7 feet	All
≤ 9	2.10	1.83	1.70	1.88
≥ 10	1.85	1.65	1.43	1.64
All	1.98	1.74	1.56	-

Table C-23
Least-Squares Mean Accident Rates on Unpaved North Carolina Roads

Lane Width (feet)	Accident Rate (per MVM)	Number of Sections
5-6	4.40	63
7-8	2.73	44
9	2.43	40
10	3.47	25
11-12	5.84	34
13-16	1.20	30

Functional Class	Accident Rate (per MVM)
Collector	2.49
Local	4.40

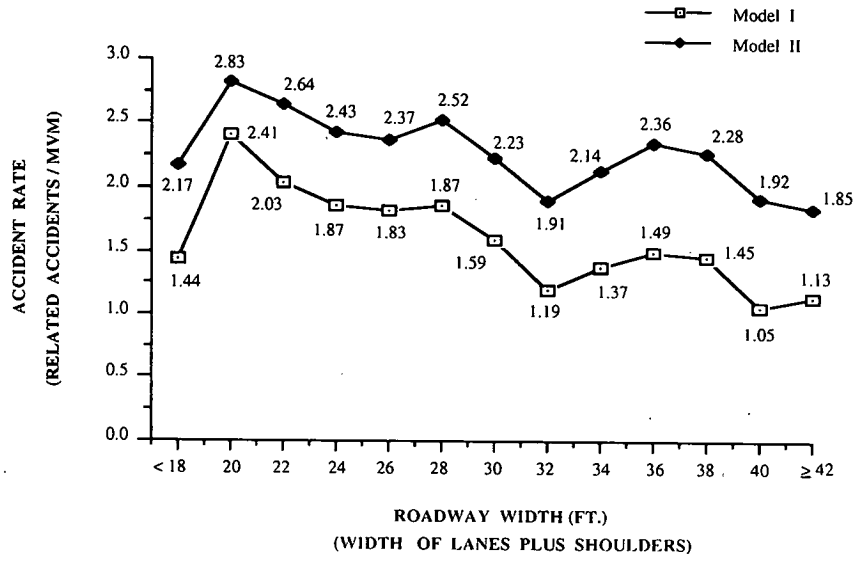


Figure C-1. Accident rates by roadway width from two different models.

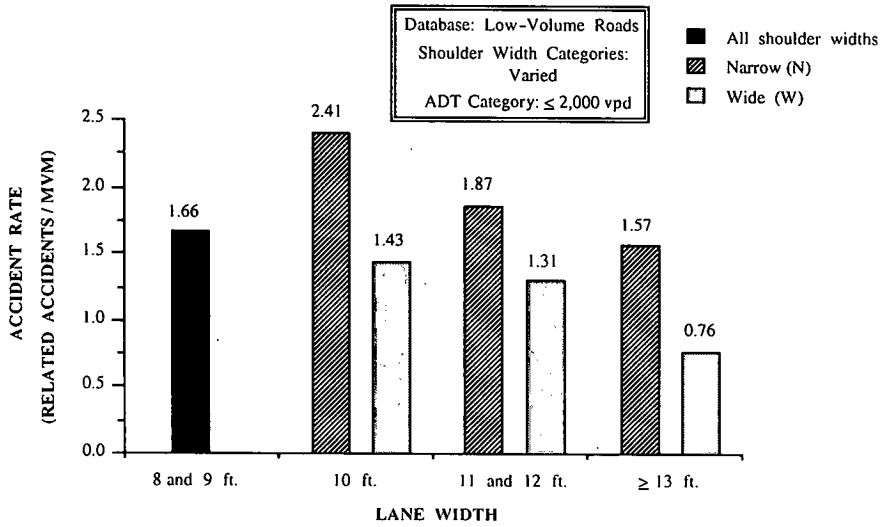


Figure C-3. Rates of related accidents by lane and shoulder width from the Low Volume Roads database using original shoulder width categories.

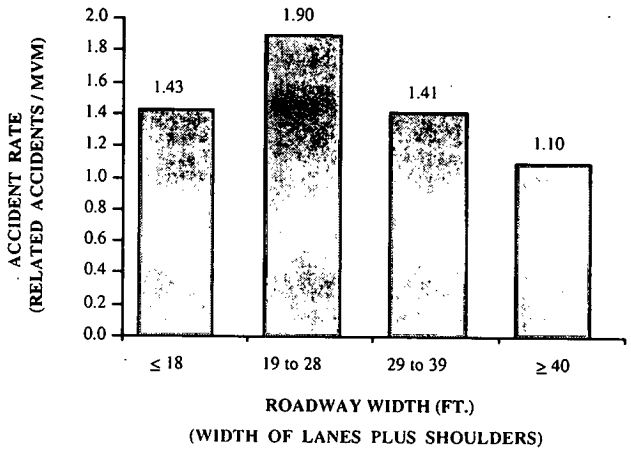


Figure C-2. Least-squares mean accident rates by roadway widths.

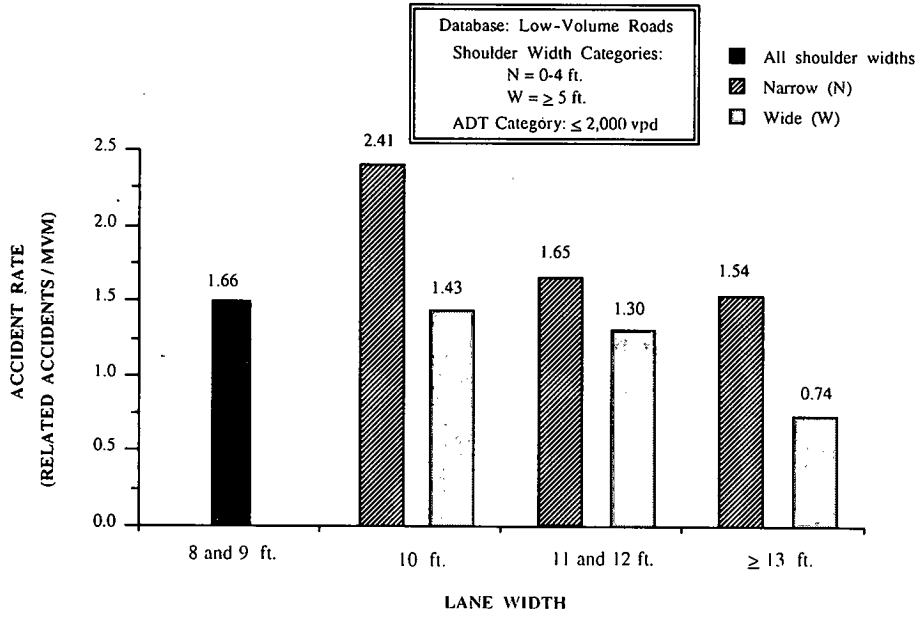


Figure C-4. Accident rates by lane and shoulder width from the Low Volume Roads database.

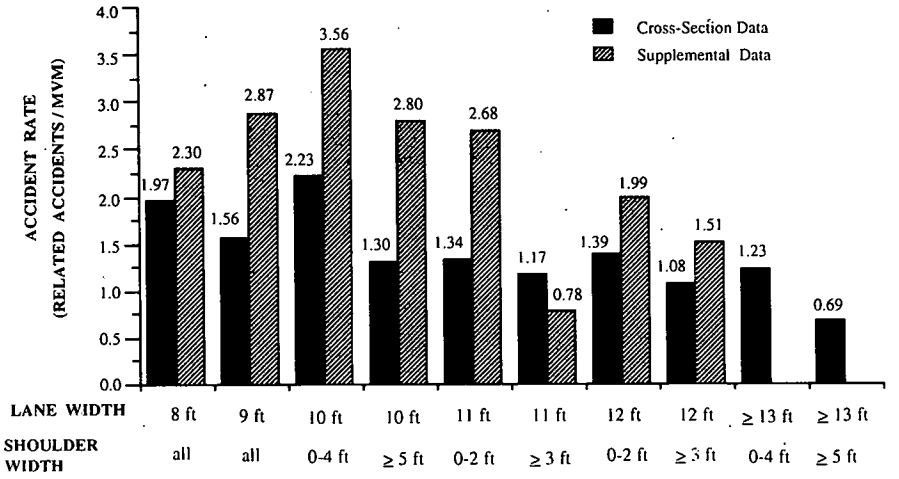


Figure C-5. Rates of related accidents by lane and shoulder width for the subgroups of the primary database.

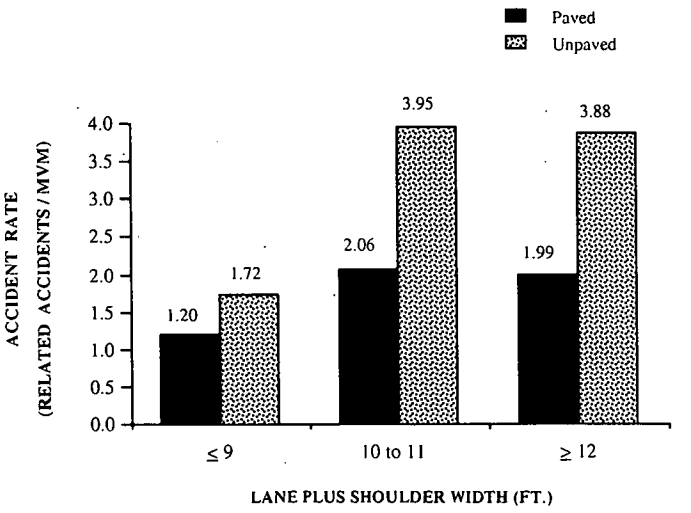


Figure C-7. Rate of related accidents for paved versus unpaved roads by lane plus shoulder width (Model A).

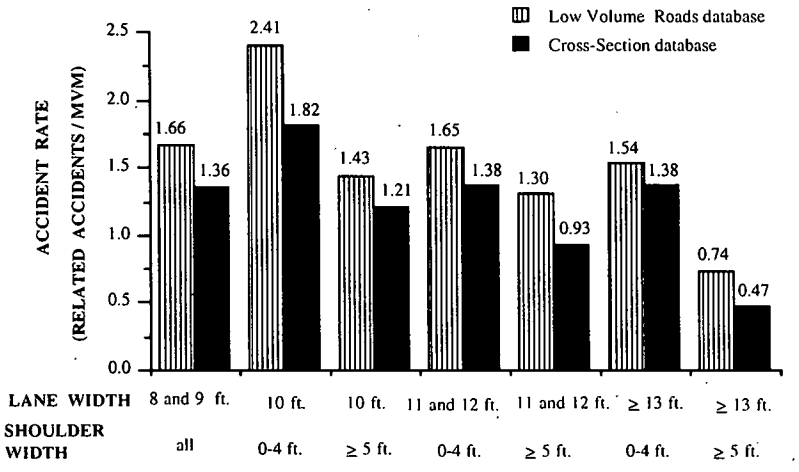


Figure C-6. Comparison of accident rates by lane and shoulder width between Low Volume Roads and Cross-Section databases.

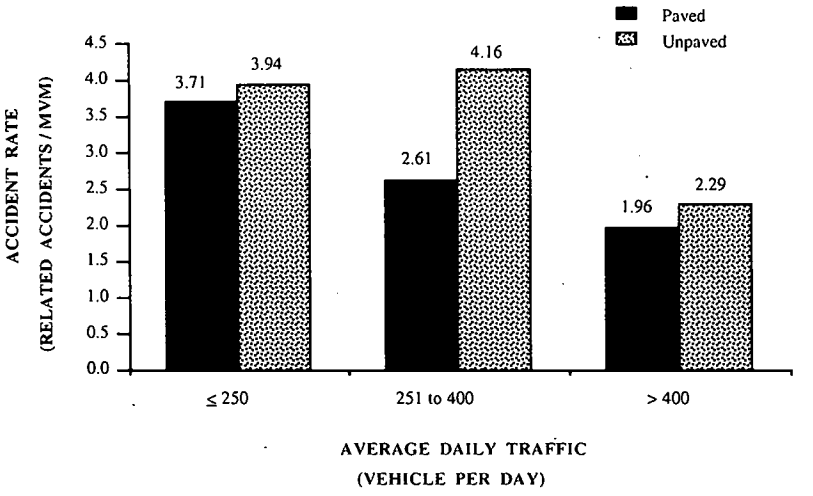


Figure C-8. Comparison of related accident rate for paved versus unpaved roads within ADT range.

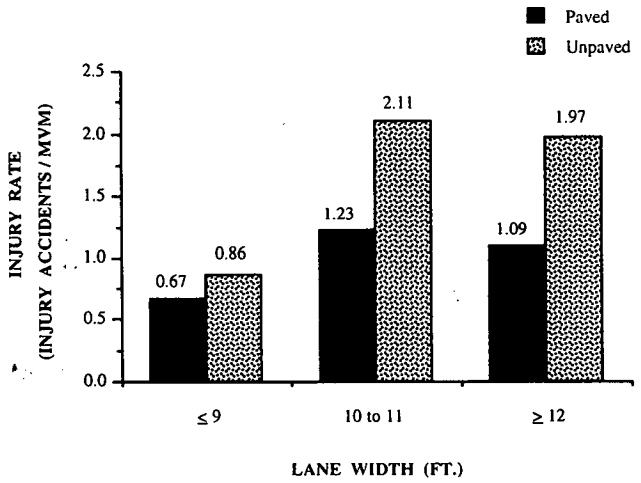


Figure C-9. Injury rates on paved versus unpaved roads by lane width.

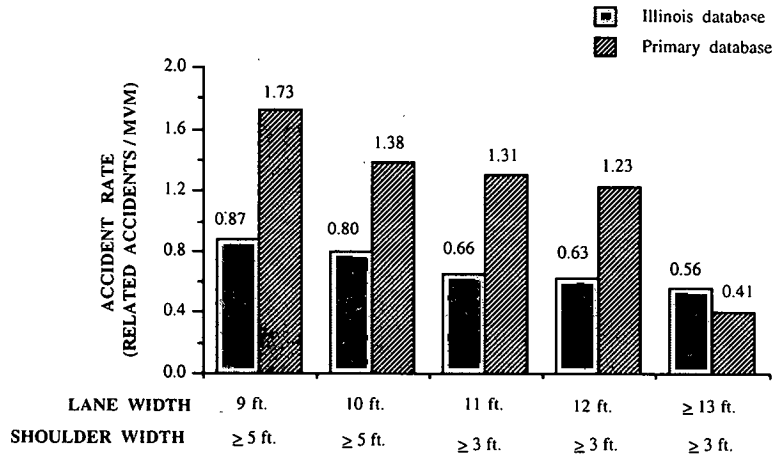


Figure C-11. Comparison of least-square mean accident rates for Illinois and primary databases for roads with wide shoulders.

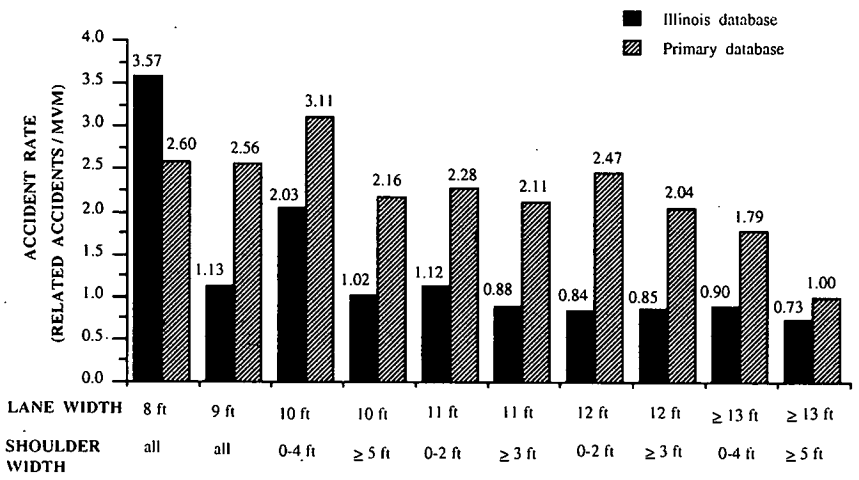


Figure C-10. Comparison of related accident rates for Illinois and primary databases.

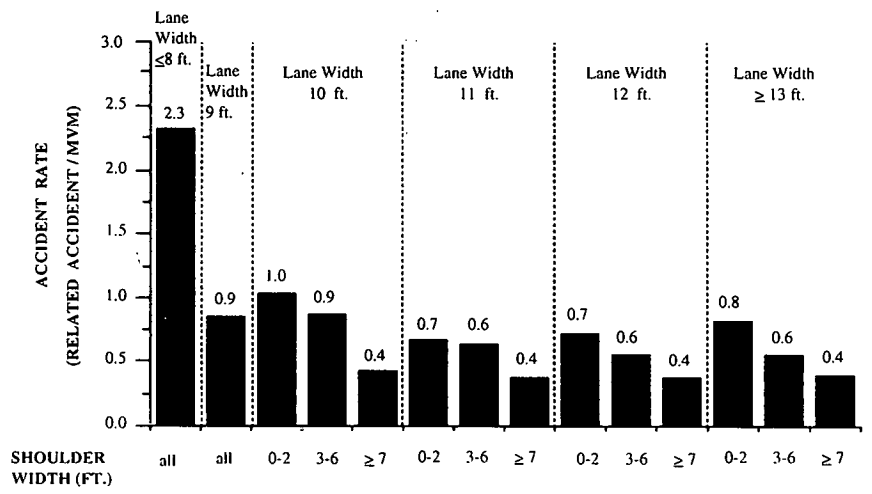


Figure C-12. Accident rates by lane and shoulder width for paved roads in Minnesota.

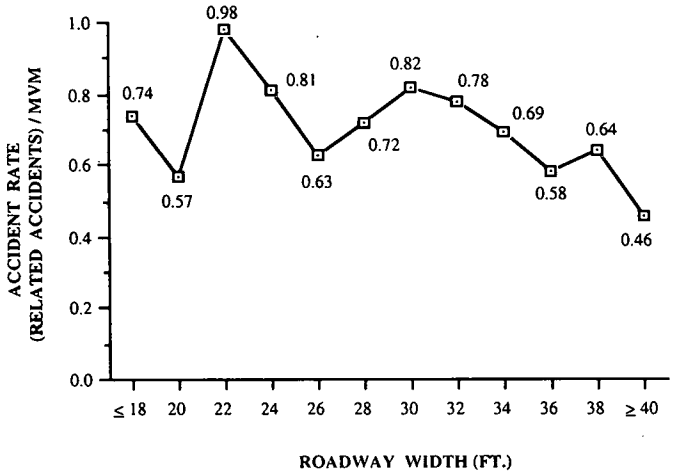


Figure C-13. Relationship between accident rate and total roadway width for unpaved roads in Minnesota.

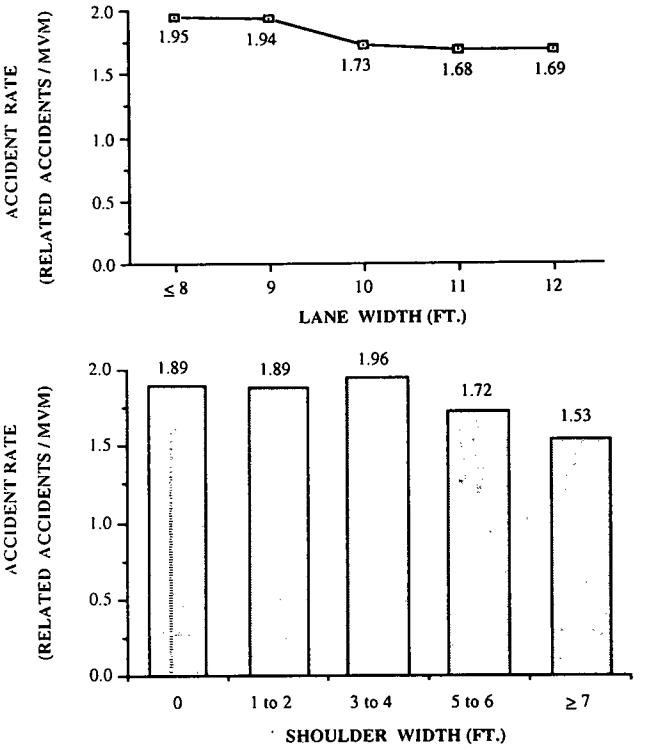


Figure C-14. Accident rates by lane width and shoulder width in North Carolina.

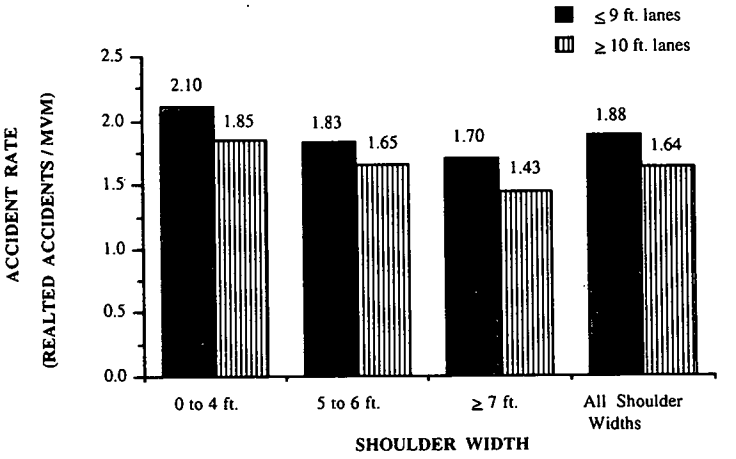


Figure C-15. Comparison of accident rates by lane and shoulder width in North Carolina.

APPENDIX D

SURVEY OF CONSTRUCTION COSTS—TWO-LANE RURAL HIGHWAYS

A survey was sent to state transportation departments to gather information on highway construction costs. The responses were tabulated, and they are presented in Tables D-1 to D-7.

TYPICAL PAVEMENT COSTS

1. What is a typical or average unit cost of *new pavement* for highways constructed or reconstructed in your state under typical soil and climate conditions?

Heavy Vehicles	Average Daily Traffic		
	0-400 vpd	401-750 vpd	751-2000 vpd
< 10%	$_____/sq. ft.	$_____/sq. ft.	$_____/sq. ft.
> 10%	$_____/sq. ft.	$_____/sq. ft.	$_____/sq. ft.

2. What is a typical or average unit cost of *resurfacing* existing highways in your state under typical soil and climate conditions?

Heavy Vehicles	Average Daily Traffic		
	0-400 vpd	401-750 vpd	751-2000 vpd
< 10%	$_____/sq. ft.	$_____/sq. ft.	$_____/sq. ft.
> 10%	$_____/sq. ft.	$_____/sq. ft.	$_____/sq. ft.

3. What is a typical or average unit pavement cost of *widening* existing highways in your state under typical soil and climate conditions? (For example, widening a 20-ft highway to a 22- or 24-ft highway).

Heavy Vehicles	Average Daily Traffic		
	0-400 vpd	401-750 vpd	751-2000 vpd
< 10%	$_____/sq. ft.	$_____/sq. ft.	$_____/sq. ft.
> 10%	$_____/sq. ft.	$_____/sq. ft.	$_____/sq. ft.

4. What is the intended service life of new pavement construction and resurfaced pavement?

_____ Years for new pavement
_____ Years for resurfaced pavement

SHOULDER COSTS

5. What is a typical or average unit cost of new shoulders for highways constructed or reconstructed in your state under typical soil and climate conditions?

$_____ Per square foot paved
$_____ Per square foot gravel/unpaved
$_____ Per square foot turf/unstabilized

EARTHWORK COSTS

6. What is a typical unit cost of earthwork for construction of new highways for the following conditions (include excavation, transport, placement, and compaction)? If the size of project typically influences unit costs, please indicate this below.

Size of Project or Quantity

Larger (_____ miles)	Average (_____ miles)	Smaller (_____ miles)
$_____ per cu. yd	$_____ per cu. yd	$_____ per cu. yd
$_____ per cu. yd	$_____ per cu. yd	$_____ per cu. yd

7. What range of earthwork unit costs has your agency encountered? Please note the factors that contribute to higher or lower unit costs (e.g., transport distance, type of material), and indicate the low and high range of unit costs for such cases?

High unit cost $_____ Low unit cost $_____
Contributing Factors: _____
_____
_____

8. Please provide typical or guideline unit costs of the following other construction items. Information on either costs per unit length or other dimensions, or as percentages of other cost items may be provided based on your agency's actual experience or preliminary cost estimating procedures.

ESTIMATED COST OF CONSTRUCTION

	Cost per mile, station or other unit dimension	or	Cost as percentage of other construction item*
Drainage	$_____/_____		_____%_____
Appurtenances	$_____/_____		_____%_____
Traffic control during construction	$_____/_____		_____%_____
Signing, striping, permanent traffic control	$_____/_____		_____%_____
Erosion control, other environmental mitigation	$_____/_____		_____%_____
Landscaping, seeding, sodding, etc.	$_____/_____		_____%_____
Utility Relocation	$_____/_____		_____%_____
Miscellaneous costs	$_____/_____		_____%_____
Other major items (list)	$_____/_____		_____%_____
Preliminary and final engineering	$_____/_____		_____%_____
Construction engineering	$_____/_____		_____%_____
Legal, administrative, other non-construction costs	$_____/_____		_____%_____

*For example, drainage as 12% of earthwork cost

* * *

Our research includes evaluation of case studies of new and reconstructed highways in rural areas. Please provide one or more examples of recently reconstructed, newly constructed, and resurfaced or 3R-type recent projects in your state. Plan, profile, cross section, and cost estimate or bid documents; design study reports; or other supporting information would be helpful to us.

Please send whatever information you can to:

Mr. Kevin Slack
Jack E. Leisch & Associates
1890 Maple Avenue
Suite 200
Evanston, Illinois 60201
Phone: (708) 866-9490
Fax: (708) 866-6394

Your response by March 15 will be greatly appreciated. Please provide the name and phone number of an individual who can answer questions about your case studies or responses to the survey.

Contact: _____

Phone: _____

Table D-1
Response to Question #1:
What Is a Typical or Average Unit Cost of New Pavement for Highways Constructed or Reconstructed in Your State Under Typical Soil and Climate Conditions?

	Average Daily Traffic and Percent Heavy Vehicles					
	0-400 vpd (per square foot)		401-750 vpd (per square foot)		751-2000 vpd (per square foot)	
STATE	< 10%	> 10%	< 10%	> 10%	< 10%	> 10%
ALABAMA1	2.00	N/A	4.05	N/A	6.70	N/A
ALABAMA2	0.61	0.61	0.61	0.89	1.01	1.01
ALASKA*						
CALTRANS*						
COLORADO	0.71	0.89	0.89	0.98	1.07	1.16
CONNECTICUT	3.50	3.50	3.50	3.50	3.50	3.50
IDAHO	0.80	0.80	0.80	0.80	0.80	0.80
ILLINOIS	2.60	2.60	2.60	2.60	2.60	2.60
IOWA	0.83	0.96	1.39	1.80	2.07	2.12
KANSAS*						
KENTUCKY	1.06	1.26	1.22	1.51	1.47	1.80
LOUISIANA	0.82	0.85	0.82	0.85	0.82	0.85
MARYLAND	1.80	2.00	2.00	2.30	2.30	2.55
MINNESOTA**	0.80	0.80	0.95	1.00	1.15	1.35
NEW HAMPSHIRE	0.67	0.67	0.67	0.67	0.67	0.67
NEW MEXICO	3.38	4.76	4.81	6.33	8.14	9.38
NEW YORK	2.84	2.84	2.84	2.84	2.84	2.84
NORTH CAROLINA	0.63	0.74	0.74	0.80	0.80	0.92
NORTH DAKOTA	0.48	0.61				0.66
OHIO*						
OKLAHOMA	1.02	1.25	3.50	4.50	4.50	4.75
RHODE ISLAND	0.20	0.20	0.20	0.20	0.20	0.20
SOUTH CAROLINA	4.35	4.60	4.35	4.60	4.35	4.60
SOUTH DAKOTA***	3.70	3.70	3.70	5.07	5.07	5.07
TENNESSEE	2.00	2.50	2.50	3.17	2.90	4.21
TEXAS1 (WEST)	0.84	0.87	0.87	0.91	0.89	0.93
TEXAS2 (EAST)	1.14	1.18	1.18	1.21	1.19	1.24
VIRGINIA	0.69	0.93	0.93	1.32	1.32	1.56
WASHINGTON*						
WEST VIRGINIA	1.13	1.70	1.48	2.22	1.96	2.94
WISCONSIN	1.25	1.40	1.30	1.50	1.60	1.70
TOTAL	39.85	42.21	47.89	51.56	59.91	59.40
LOW	0.20	0.20	0.20	0.20	0.20	0.20
HIGH	4.35	4.76	4.81	6.33	8.14	9.38
MEAN	1.53	1.69	1.92	2.15	2.40	2.38
MEDIAN	1.04	1.18	1.30	1.50	1.60	1.70

* No response
** Costs based on equivalent single axle loads (ESAL)
*** $3.70 - AC: $5.07 - PCC

Table D-2
Response to Question #2:
What Is a Typical or Average Unit Cost of Resurfacing Existing Highways in Your State Under Typical Soil and Climate Conditions?

	Average Daily Traffic and Percent Heavy Vehicles					
	0-400 vpd (per square foot)		401-750 vpd (per square foot)		751-2000 vpd (per square foot)	
STATE	< 10%	> 10%	< 10%	> 10%	< 10%	> 10%
ALABAMA1	0.30	N/A	0.00	N/A	0.00	N/A
ALABAMA2	0.23	0.23	0.23	0.23	0.23	0.23
ALASKA*						
CALTRANS*						
COLORADO	0.08	0.08	0.08	0.27	0.27	0.36
CONNECTICUT	0.55	0.55	0.55	0.55	0.80	0.80
IDAHO	0.66	0.66	0.66	0.66	0.66	0.66
ILLINOIS	0.40	0.40	0.40	0.40	0.40	0.40
IOWA	0.20	0.25	0.30	0.40	0.45	0.50
KANSAS*						
KENTUCKY	0.21	0.31	0.21	0.31	0.21	0.31
LOUISIANA	0.51	0.55	0.51	0.55	0.51	0.55
MARYLAND	0.20	0.25	0.25	0.40	0.40	0.55
MINNESOTA**	0.25	0.25	0.00	0.00	0.40	0.40
NEW HAMPSHIRE	0.04	0.07	0.07	0.07	0.14	0.32
NEW MEXICO	0.48	3.01	4.41	5.74	6.89	7.76
NEW YORK	1.76	1.76	1.76	1.76	1.76	1.76
NORTH CAROLINA	0.10	0.20	0.10	0.20	0.20	0.20
NORTH DAKOTA	0.00	0.38	0.00	0.59	0.32	0.48
OHIO*						
OKLAHOMA	0.20	0.28	0.39	0.50	0.50	0.66
RHODE ISLAND	0.17	0.17	0.17	0.17	0.17	0.17
SOUTH CAROLINA	0.35	0.40	0.35	0.40	0.35	0.40
SOUTH DAKOTA	0.51	0.51	0.51	0.51	0.51	0.51
TENNESSEE	0.22	0.22	0.22	0.26	0.26	0.50
TEXAS1 (WEST)	0.05	0.05	0.05	0.05	0.27	0.27
TEXAS2 (EAST)	0.05	0.05	0.05	0.05	0.27	0.27
VIRGINIA	0.16	0.16	0.16	0.23	0.23	0.23
WASHINGTON*						
WEST VIRGINIA	0.15	0.39	0.24	0.47	0.34	0.70
WISCONSIN	0.20	0.30	0.35	0.40	0.40	0.55
TOTAL	8.03	11.48	12.02	15.17	16.94	19.53
LOW	0.04	0.05	0.05	0.05	0.14	0.17
HIGH	1.76	3.01	4.41	5.74	6.89	7.76
MEAN	0.32	0.46	0.52	0.63	0.68	0.78
MEDIAN	0.21	0.28	0.25	0.40	0.35	0.48

* No response
** Costs based on equivalent single axle loads (ESAL)

Table D-3
Response to Question #3:
What Is a Typical or Average Unit Pavement Cost of Widening Existing Highways in Your State Under Typical Soil and Climate Conditions?

STATE	Average Daily Traffic and Percent Heavy Vehicles: 0-400 vpd (per square foot) < 10%	0-400 vpd > 10%	401-750 vpd (per square foot) < 10%	401-750 vpd > 10%	751-2000 vpd (per square foot) < 10%	751-2000 vpd > 10%
ALABAMA1	0.45	N/A	0.55	N/A	0.60	N/A
ALABAMA2	0.69	0.69	0.69	0.69	0.69	0.69
ALASKA*						
CALTRANS*						
COLORADO	0.71	0.89	0.89	0.98	1.07	1.16
CONNECTICUT	3.50	3.50	3.50	3.50	3.50	3.50
IDAHO	0.80	0.80	0.80	0.80	0.80	0.80
ILLINOIS	2.20	2.20	2.20	2.20	2.20	2.20
IOWA	2.00	2.20	2.25	2.50	3.00	3.50
KANSAS*						
KENTUCKY	1.06	1.26	1.22	1.51	1.47	1.80
LOUISIANA	1.67	1.67	1.67	1.67	1.67	1.67
MARYLAND	2.20	2.50	2.50	2.75	2.75	3.00
MINNESOTA*						
NEW HAMPSHIRE	0.89	0.89	0.89	0.89	0.89	0.89
NEW MEXICO	3.38	4.76	4.81	6.33	8.14	9.38
NEW YORK	3.55	3.55	3.55	3.55	3.55	3.55
NORTH CAROLINA	0.65	0.78	0.78	0.82	0.82	0.94
NORTH DAKOTA*						
OHIO*						
OKLAHOMA**	1.43	1.85	1.85	2.39	2.39	3.19
RHODE ISLAND	0.20	0.20	0.20	0.20	0.20	0.20
SOUTH CAROLINA	4.30	4.30	4.30	4.30	4.30	4.30
SOUTH DAKOTA	1.58	1.58	1.58	1.58	1.58	1.58
TENNESSEE	0.52	0.60	0.60	0.71	0.67	0.89
TEXAS1 (WEST)	1.09	1.13	1.13	1.18	1.15	1.21
TEXAS2 (EAST)	1.48	1.53	1.53	1.58	1.55	1.61
VIRGINIA	1.04	1.40	1.40	1.99	1.99	2.34
WASHINGTON*						
WEST VIRGINIA	0.48	0.64	0.64	0.80	1.60	2.08
WISCONSIN	1.40	1.50	1.50	1.75	1.75	2.00
TOTAL	37.26	40.41	41.02	44.66	48.32	52.47
LOW	0.20	0.20	0.20	0.20	0.20	0.20
HIGH	4.30	4.76	4.81	6.33	8.14	9.38
MEAN	1.55	1.76	1.71	1.94	2.01	2.28
MEDIAN	1.25	1.50	1.45	1.58	1.59	1.80

* No response
** Values based on less than 20 % and greater than 20 % heavy vehicles

Table D-4
Response to Questions #4 and #5:
4. What Is the Intended Service Life of New Pavement Construction and Resurfaced Pavement?
5. What Is a Typical or Average Unit Cost of New Shoulders for Highways Constructed or Reconstructed in Your State Under Typical Soil and Climate Conditions?

STATE	Question #4 Service Life (years): New Pavement	Resurfaced Pavement	Question #5 Shoulders (per square foot): Paved	Gravel/ Unpaved	Turf/ Unstabilized
ALABAMA1	20.00	12.00			
ALABAMA2	12.00	8.00		0.33	
ALASKA*					
CALTRANS*					
COLORADO	20.00	10.00	0.89		
CONNECTICUT (AV)	20.00	13.50	3.50		
IDAHO	18.00		0.80	0.55	
ILLINOIS (AV)	20.00	8.00	1.25	0.40	0.15
IOWA	30.00	15.00	1.60	0.37	0.06
KANSAS*	20.00	10.00	1.25	0.65	0.15
KENTUCKY (AV)	20.00	6.00	1.15	0.77	0.22
LOUISIANA (AV)	13.50	9.00	0.53	0.35	
MARYLAND	30.00	15.00	2.50		
MINNESOTA (AV)	18.00	13.50	0.60	0.55	
NEW HAMPSHIRE (AV	13.50	9.00	1.31	0.64	0.12
NEW MEXICO	20.00	10.00	4.76	3.38	
NEW YORK	14.00	9.00	1.27		
NORTH CAROLINA	20.00	10.00	1.50	0.15	
NORTH DAKOTA	20.00	20.00	1.44	0.85	
OHIO*					
OKLAHOMA	20.00	8.00	1.50	1.00	
RHODE ISLAND	20.00	10.00	0.20		
SOUTH CAROLINA	20.00	10.00	1.00		0.10
SOUTH DAKOTA	33.00	18.00	1.88	1.75	1.37
TENNESSEE	20.00	10.00	0.65	0.57	0.60
TEXAS (AV)	15.00	10.00			
VIRGINIA	10.00	10.00	0.67	0.48	
WASHINGTON*					
WEST VIRGINIA	20.00	5.00	0.47	0.10	
WISCONSIN	20.00	15.00	1.26	1.58	
TOTAL	507.00	274.00	31.98	14.47	2.77
AVERAGE	20.28	11.42	1.45	0.85	0.40

* No Response
(AV) - Average of Range for Service Lives

Table D-5
Response to Question #6:
What Is a Typical Unit Cost of Earthwork
for Construction of New Highways for the Following Conditions
(Include Excavation, Transport, Placement, and Compaction)?

	Quantity			Cost					
				Larger (per cubic yard [CY])		Average (per cubic yard [CY])		Smaller (per cubic yard [CY])	
STATE	Larger	Average	Smaller	Low	High	Low	High	Low	High
ALABAMA1	1 mil CY	10-45k CY	< 1k CY	1.45		2.00		6.75	
ALABAMA2						6.50			
ALASKA*									
CALTRANS*									
COLORADO	5 miles	2 miles	1 mile	1.50	3.50	2.50	4.50	3.50	5.50
CONNECTICUT	1.15 miles	0.04 mile	0.66 mile	4.00	5.45	2.00	8.50	3.50	7.00
IDAHO				1.40		1.69		8.00	
ILLINOIS						3.36			
IOWA	10 miles	5 miles	1 mile	0.90		1.29		1.50	
KANSAS	10 miles	5 miles	1 mile	2.30		4.00		7.00	
KENTUCKY	>1 mil CY	1mil-100k CY	100k-1k CY	2.07		2.77		6.19	
LOUISIANA	10 miles	5 miles	0-1 mile	5.00		6.00		8.00	
MARYLAND	200k CY	75k CY	1.5k CY	3.00		8.00		12.00	
MINNESOTA*									
NEW HAMPSHIRE	4 miles	1.5 miles	0.25 mile	3.00	3.75	3.75	4.25	4.25	5.00
NEW MEXICO	10 miles	5 miles	<1 mile	1.70	1.80	2.16	2.54	10.00	12.00
NEW YORK***				8.30	39.50	9.45	48.92	10.57	58.33
NORTH CAROLINA	7 miles	3 miles	<0.5 mile	1.00	3.00	2.00	4.00	4.00	7.00
NORTH DAKOTA	20+ miles	10 miles	<1 mile	0.75			0.80	1.50	
OHIO*									
OKLAHOMA**	5+ miles	1-5 miles	<1 mile	2.90		3.50		4.50	
RHODE ISLAND				2.00		3.50		5.00	
SOUTH CAROLINA	>75k CY	75k- 1k CY	<1k CY	2.75		3.50		5.00	
SOUTH DAKOTA	10 miles	7 miles		0.73		0.80		2.08	
TENNESSEE	9 miles	3 miles	1 mile	0.90	2.10	1.15	2.35	3.75	4.50
TEXAS*									
VIRGINIA	>50k CY	50k-10k CY	<10k CY	3.00	6.00	3.50	8.50	4.50	10.50
WASHINGTON				1.20	3.00	5.00	10.00	7.00	15.00
WEST VIRGINIA	2.78 miles	1.02 miles	0.28 mile	3.00		1.02		8.25	
WISCONSIN	>5 miles	1-5 miles	<1 mile	1.37	1.43	1.88	3.10	1.96	3.43

* No response

** Values based on less than 20 %, greater than 20 % heavy vehicles

*** Project locale has greater influence than project size

CY = cubic yard

Table D-6
Response to Question #7:
What Range of Earthwork Unit Costs Has Your Agency Encountered?

State	Earthwork (Unit Costs) Low	High	Contributing Factors
ALABAMA1	1.00	10.00	Quantity, rock (type material).
ALABAMA2	0.50	30.00	
ALASKA*			
CALTRANS*			
COLORADO	1.00	10.00	Terrain, altitude, rolling, moutain & plain,size, traffic, etc.
CONNECTICUT	2.00	7.50	Construction competition and quantity, haul distance.
IDAHO	0.50	20.00	Low unit cost is due to large quantities.
ILLINOIS	1.96	20.76	
IOWA	0.52	18.00	Unit costs of $5-$18, when contractor furnished borrow and haul.
KANSAS	1.50	10.00	Length of project, location.
KENTUCKY	1.50	20.00	Type of rock, haul dist., cost of waste areas, geo. features, etc.
LOUISIANA	2.00	10.00	Length of project, land use, local condition, etc.
MARYLAND	2.50	25.00	Historic-based on country and quantity volume.
MINNESOTA*			
NEW HAMPSHIRE	2.50	6.25	Location of project, material avail/disposal site, urban vs. rural.
NEW MEXICO	1.80	12.00	Type of material, haul distance.
NEW YORK	2.50	327.80	Costs for hauling and/or disposal in NYC and on L.I. drive costs up.
NORTH CAROLINA	1.00	15.00	Urban sites, soil types and price-quantity relationships.
NORTH DAKOTA	0.73	4.00	Transport distance, wet conditions, small quantity.
OHIO*			
OKLAHOMA**	2.00	10.00	Size and location of project, availability and type of material.
RHODE ISLAND	0.10	10.00	Size of project, haul dist., availability of material, etc.
SOUTH CAROLINA	1.85	10.00	Structure excavation, culverts, conc.footings, haul dist., etc.
SOUTH DAKOTA		5.40	Rock excavation.
TENNESSEE	0.85	5.50	Rock vs. Earth, Rural vs. Urban, New Location vs. Renovation,etc.
TEXAS*			
VIRGINIA	1.67	12.50	Quantity of excavation, location of work, bidding competition.
WASHINGTON	1.20	15.00	Amount and type of material.
WEST VIRGINIA	0.01	100.00	Quantity, percent of rock, waste site distance, geographic location.
WISCONSIN	0.85	15.00	Location and size of project.

* No response

** Values based on less than 20 % and greater than 20 % heavy vehicles

Table D-7
Response to Question #8:
Please Provide Typical or Guideline Unit Costs of the Following Other Construction Items

ESTIMATED COST OF CONSTRUCTION PER MILE, STATION, OR OTHER UNIT DIMENSION

STATE	DRAINAGE	APPURTENANCE	TRAFFIC CONTROL URING CONSTR	SIGN, STRIPE, PERMANANT TRAF.CONTROL	ROSION CONTRO OTHER ENVIR. MITIGATION	LANDSCAPING, SEEDING, SODDING, etc.	UTILITY RELOCATION
ALABAMA1	$150,000		$108,000	$28,000	$30,000	$9,500	$40,000
ALASKA*							
CALTRANS							
COLORADO	$17,900			$4,135		$4,000	
CONNECTICUT	1.50/s.f. paved	$100,000					$100,000
IDAHO	$662/ft-mile		$720/ft-mile	$700/ft-mile			$25,000
IOWA	$4.00/L.F.			$200		$500/acre	
KANSAS	$40,000	$2,300/acre	$4,000	$15,000	$500/acre	$1000/acre	$18,000
KENTUCKY							$200,000
LOUISIANA	$80/ft	$1700/each	$4,200	$3,200	$9.00/lb	$10.00/lb	
MARYLAND							
MINNESOTA*							
NEW HAMPSHIRE			$15,000	$3,000			
NEW MEXICO	$12,000		$9,000	$1,500		$802/acre	
NEW YORK	$42,000	$44,000	$1,800		$1,800	$5,000	$200
NORTH CAROLINA	$120,000		$8,000	$2,000	$14,000	$8,000	
NORTH DAKOTA	$18,000		$1,500		$1.15/sq.yd.	$180/acre	
OHIO*							
OKLAHOMA	$192,290	$109,762	$12,000	$7,626	$71,157		
RHODE ISLAND							
SOUTH CAROLINA	$21,000				$1,500	$9,000	
SOUTH DAKOTA	$19,300	$400/acre	$7,500	$750	$10,850	$3,880	$33,850
TENNESSEE							
TEXAS*							
VIRGINIA			$16,400	$5,000	$34,506	$7,650	$67,500
WASHINGTON	1.50-2.00/L.F.						
WEST VIRGINIA	$442,380	$220,724	$238,000	$101,000	$30,000	$23,000	$30/L.F.
WISCONSIN	$11,000		$3,100	$3,300	$1,885	$17,200	
TOTAL	$643,490	$474,486	$428,500	$174,711	$195,698	$87,230	$484,550
MEAN	$58,499	$118,622	$32,962	$13,439	$21,744	$9,692	$60,569
MEDIAN	$21,000	$104,881	$8,000	$3,300	$14,000	$8,000	$36,925

* No response

Table D-7 (continued)

STATE	MISC. COSTS	OTHER: GRUB AND CLEAR, GRADING	BORROW	STRUCTURE	BASE, SEAL COAT, SURFACING	PRELIMINARY AND FINAL ENGINEERING	ONSTRUCTIO ENGINEERING	LEGAL, ADMIN, OTHER NON-CONST. COSTS
ALABAMA1								
ALASKA*								
CALTRANS								
COLORADO		$8,500						
CONNECTICUT	$415,000		$7.00/cy	$175/sf Deck				$7000/contract
IDAHO	$1260/ft-mile	$6000/ft-mile			$8570/ft-mile	$1230/ft-mile	$3840/ft-mile	
IOWA								
KANSAS								
KENTUCKY								
LOUISIANA	$2000/each	$2000/acre						
MARYLAND								
MINNESOTA*								
NEW HAMPSHIRE								
NEW MEXICO							$4,800	$20,000
NEW YORK	$400							
NORTH CAROLINA								
NORTH DAKOTA								
OHIO*								
OKLAHOMA	$64,618				$415,448	$100,337		
RHODE ISLAND								
SOUTH CAROLINA		$10,500			$96,000			
SOUTH DAKOTA				$42.00/s.f.				
TENNESSEE								
TEXAS*								
VIRGINIA								
WASHINGTON								
WEST VIRGINIA	$91,000/cntrct	$173,000			$342,000			
WISCONSIN						$54,000	$24,500	
TOTAL	$480,018	$192,000	$0	$0	$853,448	$154,337	$29,300	$0
MEAN	$160,006	$64,000	$0	$0	$284,483	$77,169	$14,650	$0
MEDIAN	$64,618	$10,500			$342,000	$77,169	$14,650	

* No response

Table D-7 (continued)

ESTIMATED COST OF CONSTRUCTION AS A PERCENTAGE OF OTHER CONSTRUCTION ITEMS

STATE	DRAINAGE	PPURTENANCE	TRAFFIC CONTROL DURING CONSTR	SIGN, STRIPE, PERMANANT TRAF. CONTROL	ROSION CONTRO OTHER ENVIR. MITIGATION	LANDSCAPING, SEEDING, SODDING, etc.	UTILITY RELOCATION	MISC. COSTS
ALABAMA1	9.7 % of TC		7 % of TC	1.7 % of TC	0.75 % of TC			
ALABAMA2								
ALASKA*								
CALTRANS								
COLORADO			4-7 % of TC				1 % of TC	
CONNECTICUT			5 % of CI	1 % of CI	0.5 % of CI	0.5 % of CI		
IDAHO					1 % of TC	1 % of TC		
ILLINOIS	6.5 % of TC	8.3 % of TC	2.7 % of TC	0.7 % of TC		1.2 % of TC		7.4 % of TC
IOWA			4 % of TC		5 % of TC			
KANSAS								10.0 % of TC
KENTUCKY	10 % of EW	5 % of EW	2 % of EW	1 % of EW	1 % of EW	1 % of EW		10.0 % of EW
LOUISIANA	15 % of TC							
MARYLAND	20 % of All		2 % of All	2 % of All	8 % of All	3 % of All	1-3 % of All	
MINNESOTA*								
NEW HAMPSHIRE	15 % of CI	10 % of CI			2.5 % of CI			10 % of CI
NEW MEXICO								
NEW YORK				25 % of PC				
NORTH CAROLINA								15 % of CI
NORTH DAKOTA	25 % of EX		2 % of EX		4 % of EX	6 % of EX		
OHIO*								
OKLAHOMA	19 % of TC	11 % of TC	1.2 % of TC	1 % of TC	7 % of TC			6.5 % of TC
RHODE ISLAND								
SOUTH CAROLIN	14 % of TC				1 % of TC	6 % of TC		
SOUTH DAKOTA								
TENNESSEE	2 % of TC	4 % of TC	0.5 % of TC	0.05 % of TC	0.005 % of TC	0.008 % of TC	arying % of T	3 % of TC
TEXAS*								
VIRGINIA	22 % of TC							
WASHINGTON			2-10 % of TC	1-3 % of TC		1 % of TC		
WEST VIRGINIA								
WISCONSIN								

PC = Pavement Cost
EW= Earthwork Cost
EX = Excavation Cost

Table D-7 (continued)

OTHER: GRUB AND CLEAR, GRADING	CONCRETE SURFACES	STRUCTURES	BASE, SEAL COAT, SURFACING	OBILIZATIO	PRELIMINARY AND FINAL ENGINEERING	ONSTRUCTIO ENGINEERING	LEGAL, ADMIN, OTHER NON-CONST. COSTS
					7.5 % of TC	13 % of TC	
					8.0 % of TC	7 % of TC	
					14 % of TC	10 % of TC	20 % of Eng
					10 % of TC	15.5 % of TC	
					7.5-20 % of CI	12 % Bid Amt	2 % of CI
11 % of TC	5.2 % of TC	20.6 % of TC	21.2 % of TC		5 % of TC	10 % of TC	
					2-3 % of TC	2-6 % of TC	
					6 % of TC	7.5 % of TC	
					10 % of TC	10 % of TC	5 % of TC
				2.5 % of TC			
					5.0 % of TC		
				7-10 % of CI	10 % of TC	10-12 % of CI	20 % of Pre Eng
				10 % of Pvt	12 % of Pvt	23 % of Pvt	3 % of Pvt
					10 % of TC	10 % of TC	5 % of TC
			41 % of TC	3.5 % of TC	10 % of TC		
						15 % of TC	
7 % of TC			64 % of TC		7.5 % of TC	15 % of TC	
					1-7.5 % of TC	10 % of TC	
					10 % of TC	1.5 % of TC	
					8-10 % of TC	8-10 % of TC	2 % of TC
						10-15 % of TC	5 % of TC

APPENDIX E

DERIVATION OF CONSISTENCY BETWEEN LANE WIDTH, SHOULDER WIDTH, FUNCTIONAL CLASS, AND VOLUME

ANALYSIS APPLICATION

Design standards for lane width and shoulder width should be consistent with the basic operational requirements that they affect. The most basic of these is the relationship between lane width and shoulder width, and capacity.

For two-lane rural highways, capacity effects are as described in the 1985 *Highway Capacity Manual* published by the Transportation Research Board. The general relationship is:

$$SF_i = 2{,}800 \times (v/c)_i \times f_d \times f_w \times f_{HV} \qquad \textbf{(E-1)}$$

where:

SF_i = total service flow rate in both directions for prevailing roadway and traffic conditions, for level-of-service i, in vehicles per hour;

$(v/c)_i$ = ratio of flow rate to ideal capacity for level-of-service i, obtained from Table E-1;

f_d = adjustment factor for directional distribution of traffic, obtained from Table E-2;

f_w = adjustment factor for narrow lanes and restricted shoulder width, obtained from Table E-3;

f_{HV} = adjustment factor for the presence of heavy vehicles in the traffic stream, computed as:

$$1/[1 + P_T(E_T - 1) + P_R(E_R - 1) + P_B(E_B - 1)].$$

The relationship in Eq. E-1 expresses the service flow rate for any given level of service as a function of the geometric and traffic variables that influence it. Among these are the combined effect of lane and shoulder width, f_w, as summarized in Table E-3. Normal use of the equation is to solve for a service flow rate, thereby determining level of service.

One can use Eq. E-1 in a more unconventional manner to test the extent to which design standards for lane width and shoulder width are consistent with other design values and guidelines. Consider the following example:

$$f_w = \frac{SF_i}{[2800 \ x \ (v/c)_i \ x \ f_d \ x \ f_{HV}]}$$

One can solve for f_w, given assumed values for the other variables, relating to the full range of design conditions. For SF_i, it is necessary to establish a level of service. The 1990 AASHTO *Policy* recommends minimum levels of service as a function of terrain and functional classification. Values for the volume to capacity ratio, v/c, are a function of terrain, percent no-passing zones, and level of service. For analysis purposes, level terrain is assumed to produce, on average, 20 percent no-passing zones; rolling terrain 40 percent no-passing zones; and mountainous terrain 60 percent no-passing zones. Values for $(v/c)_i$ can thus be obtained from the *Highway Capacity Manual* (see Table E-1) . A value for f_d was obtained from the *Highway Capacity Manual*, assuming a 60/40 distributional split. Values for f_{HV} were calculated using heavy-vehicle passenger car equivalents specified in the *Highway Capacity Manual*, assuming two ranges of truck percentages—10 percent and 15 percent trucks.

A final analysis step involves conversion of daily traffic volumes (the basis for width design standards) to hourly volumes, on which capacity calculations are based. Assumptions for "PHF" (peak hour factor) and "K" (design percentage of ADT) were derived from the literature.

Table E-4 summarizes all traffic and design assumptions used in the analysis.

ANALYSIS RESULTS

The analysis produces values for f_w as a function of traffic volume for the full range of design conditions studied. The f_w values represent minimums, i.e., values at which the combined effects of lane and shoulder width produce at least the desired level of service. What actually is produced is a set of linear relationships between f_w and traffic volume.

Table E-5 gives the calculated values of f_w for the example case for 10- and 15-percent trucks, respectively. For reference purposes, the reader is referred to Table E-3, which expresses f_w as a function of lane width and shoulder width.

Note that, for very low traffic volumes (less than 750 vpd), f_w is very low—lower, in fact, than the corresponding value for 9-ft lanes and 0-ft shoulders. This confirms that, under low-traffic-volume conditions, the capacity effects of lane and shoulder width are not a factor in decisions regarding design widths.

As design traffic increases, however, particularly in more difficult terrain, and where trucks are a greater proportion of the traffic stream, values for f_w begin to reach limiting values. Consider, for example, Table E-5, 15 percent trucks with a design traffic of 1,500 vpd. For an arterial in rolling terrain, for lane and shoulder width to produce a minimally consistent operation in terms of capacity, a value of 0.78 or greater for f_w is necessary. Referring to Table E-3, this translates to either a 10-ft lane with 5-ft shoulders (interpolating to a value of 0.80 for f_w) or an 11-ft lane width with a 3-ft shoulder (again interpolating to a value of 0.80 for f_w). For mountainous terrain, f_w is 0.93; indicating a need for 11-ft lanes and 6-ft shoulders, or 12-ft lanes and 4-ft shoulders.

Tables E-6 and E-7 summarize the minimum lane and shoulder width combinations to produce operationally consistent conditions for design. These are used, in combination with the other research results, to produce recommended minimum design values for lanes and shoulders on low-volume, two-lane rural highways.

Table E-1
Level of Service for General Two-Lane Highway Segments

		v/c RATIO[a]																			
		LEVEL TERRAIN						ROLLING TERRAIN						MOUNTAINOUS TERRAIN							
	PERCENT TIME	AVG[b]	PERCENT NO PASSING ZONES						AVG[b]	PERCENT NO PASSING ZONES						AVG[b]	PERCENT NO PASSING ZONES					
LOS	DELAY	SPEED	0	20	40	60	80	100	SPEED	0	20	40	60	80	100	SPEED	0	20	40	60	80	100
A	≤ 30	≥ 58	0.15	0.12	0.09	0.07	0.05	0.04	≥ 57	0.15	0.10	0.07	0.05	0.04	0.03	≥ 56	0.14	0.09	0.07	0.04	0.02	0.01
B	≤ 45	≥ 55	0.27	0.24	0.21	0.19	0.17	0.16	≥ 54	0.26	0.23	0.19	0.17	0.15	0.13	≥ 54	0.25	0.20	0.16	0.13	0.12	0.10
C	≤ 60	≥ 52	0.43	0.39	0.36	0.34	0.33	0.32	≥ 51	0.42	0.39	0.35	0.32	0.30	0.28	≥ 49	0.39	0.33	0.28	0.23	0.20	0.16
D	≤ 75	≥ 50	0.64	0.62	0.60	0.59	0.58	0.57	≥ 49	0.62	0.57	0.52	0.48	0.46	0.43	≥ 45	0.58	0.50	0.45	0.40	0.37	0.33
E	> 75	≥ 45	1.00	1.00	1.00	1.00	1.00	1.00	≥ 40	0.97	0.94	0.92	0.91	0.90	0.90	≥ 35	0.91	0.87	0.84	0.82	0.80	0.78
F	100	< 45	—	—	—	—	—	—	< 40	—	—	—	—	—	—	< 35	—	—	—	—	—	—

[a] Ratio of flow rate to an ideal capacity of 2,800 pcph in both directions.
[b] These speeds are provided for information only and apply to roads with design speeds of 60 mph or higher.

Source: Transportation Research Board. "Highway Capacity Manual," *Special Report 209*, 1985.

Table E-2
Adjustment Factors for Directional Distribution on General Terrain Segments

Directional Distribution	100/0	90/10	80/20	70/30	60/40	50/50
Adjustment Factor, f_d	0.71	0.75	0.83	0.89	0.94	1.00

Source: Transportation Research Board, "Highway Capacity Manual," *Special Report 209,* 1985.

Table E-3
Adjustment Factors for the Combined Effect of Narrow Lanes and Restricted Shoulder Width (f_w)

Usable Shoulder Width[a] (feet)	12-foot Lanes		11-foot Lanes		10-foot Lanes		9-foot Lanes	
	LOS A-D	LOS E[b]1	LOS A-D	LOS E[b]	LOS A-D	LOS E[b]	LOS A-D	LOS E[b]
≥6	1.00	1.00	0.93	0.94	0.84	0.87	0.70	0.76
4	0.92	0.97	0.85	0.92	0.77	0.85	0.65	0.74
2	0.81	0.93	0.75	0.88	0.68	0.81	0.57	0.70
0	0.70	0.88	0.65	0.82	0.58	0.75	0.49	0.66

[a]Where shoulder width is different on each side of the roadway, use the average shoulder width.
[b]Factor applies for all speeds less than 45 mph.

Source: Transportation Research Board, "Highway Capacity Manual," *Special Report 209,* 1985.

Table E-4
Analysis Assumptions for Evaluation of Capacity Effects on Lane and Shoulder Widths

Rural Highway Type/Terrain	LOS[a]	Percent No-Passing[b]	V/C[c]	F_d[c]	Truck PCE[c]	Fh_v[d] 10% Trucks	Fh_v[d] 15% Trucks	PHF[c]	K_{DES}[b]
Arterial									
— Level	B	20	0.24	0.94	2.2	0.893	0.847	0.92	0.15
— Rolling	B	40	0.19	0.94	5.0	0.714	0.625	0.92	0.15
— Mountainous	C	60	0.23	0.94	10.0	0.526	0.426	0.94	0.15
Collector									
— Level	C	20	0.39	0.94	2.2	0.893	0.847	0.94	0.15
— Rolling	C	40	0.35	0.94	5.0	0.714	0.625	0.94	0.15
— Mountainous	D	60	0.40	0.94	12.0	0.476	0.377	0.95	0.15
Local									
— Level	D	20	0.62	0.94	2.2	0.909	0.870	0.95	0.15
— Rolling	D	40	0.52	0.94	5.0	0.714	0.625	0.95	0.15
— Mountainous	D	60	0.40	0.94	12.0	0.476	0.377	0.95	0.15

[a]Source: AASHTO, *A Policy on Geometric Design of Highways and Streets*, 1990.
[b]These values are assumed.
[c]Source: Transportation Research Board, "Highway Capacity Manual," *Special Report 209*, 1985.
[d]These values are calculated.

Table E-5
Minimum Values for Capacity Factor F_w to Accomodate Typical Design Assumptions for Two-Lane, Rural, Low-Volume Roads

Rural Highway Type/Terrain	Capacity Factor (f_w) for Average Daily Traffic Volumes							
	400 vpd		750 vpd		1,500 vpd		2,000 vpd	
	10% Trucks	15% Trucks	10% Trucks	15% Trucks	10% Trucks	15% Trucks	10% Trucks	15% Trucks
Arterial								
— Level	0.12	0.12	0.22	0.23	0.43	0.46	0.58	0.61
— Rolling	0.18	0.21	0.34	0.39	0.68	0.78	0.91	1.04
— Mountainous	0.20	0.25	0.38	0.46	0.75	0.93	1.00	1.24
Collector								
— Level	0.07	0.07	0.13	0.14	0.26	0.28	0.35	0.37
— Rolling	0.10	0.11	0.18	0.21	0.36	0.42	0.49	0.55
— Mountainous	0.13	0.16	0.24	0.30	0.47	0.60	0.63	0.79
Local								
— Level	0.04	0.04	0.08	0.08	0.16	0.17	0.21	0.22
— Rolling	0.06	0.07	0.12	0.14	0.24	0.28	0.32	0.37
— Mountainous	0.13	0.16	0.24	0.30	0.47	0.60	0.63	0.79

Table E-6
Minimum Lane and Shoulder Width Values to Produce Consistency in Design Capacity for Low-Volume Roads (Trucks ≤10% of ADT)[a]

Highway Type	Design ADT			
	1500 vpd		2000 vpd	
	Minimum f_w[b]	Lane Width/Shoulder Width (feet)	Minimum f_w[b]	Lane Width/Shoulder Width (feet)
Arterial				
-Level	0.43	9/0	0.58	9/3 10/0
-Rolling	0.68	9/6 10/2 11/1	0.91	11/6 12/4
-Mountainous	0.75	10/4 11/2 12/1	1.00	12/6
Collector				
-Level	0.26	9/0	0.35	9/0
-Rolling	0.36	9/0	0.49	9/0
-Mountainous	0.47	9/0	0.63	9/4 10/1 11/0
Local				
-Level	0.16	9/0	0.21	9/0
-Rolling	0.24	9/0	0.32	9/0
-Mountainous	0.47	9/0	0.63	9/4 10/1 11/0

[a]Table computed assuming trucks are 10 percent of ADT
[b]From Table E-5

Table E-7
Minimum Lane and Shoulder Width Values to Produce Consistency in Design Capacity for Low-Volume Roads (Trucks >10% of ADT)[a]

Highway Type	Design ADT			
	1500 vpd		2000 vpd	
	f_w[b]	Lane Width/Shoulder Width (feet)	f_w[b]	Lane Width/Shoulder Width (feet)
Arterial				
-Level	0.46	9/0	0.61	9/3 10/1
-Rolling	0.78	10/5 11/3 12/2	1.04[c]	12/6
-Mountainous	0.93	11/6 12/5	1.24[c]	12/6
Collector				
-Level	0.28	9/0	0.37	9/0
-Rolling	0.42	9/0	0.55	9/12 10/0
-Mountainous	0.60	9/3 10/1	0.79	10/5 11/3 12/2
Local				
-Level	0.17	9/0	0.22	9/0
-Rolling	0.28	9/0	0.37	9/0
-Mountainous	0.60	9/3 10/1	0.79	10/5 11/3 12/2

[a]Table computed assuming trucks are 15 percent of ADT
[b]From Table E-5
[c]Maximum lane and shoulder width values do not provide sufficient capacity for assumed conditions

APPENDIX F

GUIDELINES FOR DERIVATION OF CONSISTENCY BETWEEN DESIGN SPEED AND LANE WIDTH

Figure F-1 is derived from research by Lamm and Choueiri on the effects of alignment and cross section on speeds of vehicles on two-lane rural highways (*12*). It is used to assist in establishing a consistency between lane width design standards and design speed. Superimposed on Figure F-1 are data points describing maximum horizontal curves for design speeds of 30, 40, 50, and 60 mph for AASHTO e_{max} values of 0.08.

Wherever the predicted 85th-percentile speed from Lamm is significantly above the value for design speed, the corresponding lane width value is considered to potentially contribute to "over driving" of the curve, and is therefore termed "inconsistent."

In general, it is desirable that predicted 85th-percentile speeds be as close to the design speed as possible. A suggested criterion is that predicted speeds be within 5 mph of the design speed. The following discussion summarizes design speed and lane width considerations for 60-, 50-, 40-, and 30-mph design speeds.

DESIGN SPEEDS OF 60 MPH

Ten- and 11-ft lane widths result in predicted speeds less than 55 mph for controlling (i.e., maximum for design speed) curves. For curves flatter than controlling curves, 11-ft lane widths produce speeds within the 5-mph criterion.

The following conclusions are noted: (1) 12-ft lanes are appropriate; (2) 11-ft lanes may be appropriate in cases where controlling curvature is infrequent (i.e., level terrain); and (3) lanes of 10-ft width and narrower are inappropriate for a 60-mph design speed.

DESIGN SPEEDS OF 50 MPH

All lane widths are associated with predicted speeds well within the 5-mph criterion at the controlling curvature for 50 mph. Ten-foot lane widths produce predicted speeds within 5 mph for all curvature. Eleven- and 12-ft lane widths produce predicted speeds greater than 55 mph at about 50 to 65 percent of controlling curvature.

The following conclusions are noted: (1) 12-ft lanes are appropriate except in cases where horizontal alignment is mild (i.e., level terrain)—in such terrain, speeds too high may be encouraged; (2) 11-ft lanes are appropriate in essentially all cases; and (3) 10-ft lanes are appropriate in all cases.

DESIGN SPEEDS OF 40 MPH

Ten-foot lane widths produce predicted speeds within the 5-mph criterion for up to about 80 percent of controlling curvature. Eleven-foot lane widths produce 45-mph predicted speeds at controlling curvature only; and higher speeds (above the criterion) at all milder curves.

The following conclusions are noted: (1) 12-ft lanes are inappropriate, in that they encourage speeds much higher than 40 mph; (2) 11-ft lanes are appropriate only where terrain and geometry are such that controlling curvature is frequent and continuous, thereby keeping speeds within an acceptable range; (3) 10-ft lanes are appropriate; and (4) 9-ft lanes are appropriate (extrapolating).

DESIGN SPEEDS OF 30 MPH

Very low design speeds of 30 mph tend to be used in severely rolling or mountainous terrain. Controlling curvature is frequent. Ten-foot lane widths produce predicted speeds within the 5-mph criterion for up to about 80 percent of controlling curvature. Eleven-foot lane widths produce speeds within the criterion only at controlling curves.

The following conclusions are noted: (1) 12-ft lanes are inappropriate; (2) 11-ft lanes are appropriate only where terrain and geometry are such that controlling curvature is frequent and continuous; (3) 10-ft lanes are appropriate; and (4) 9-ft lanes are appropriate (extrapolating).

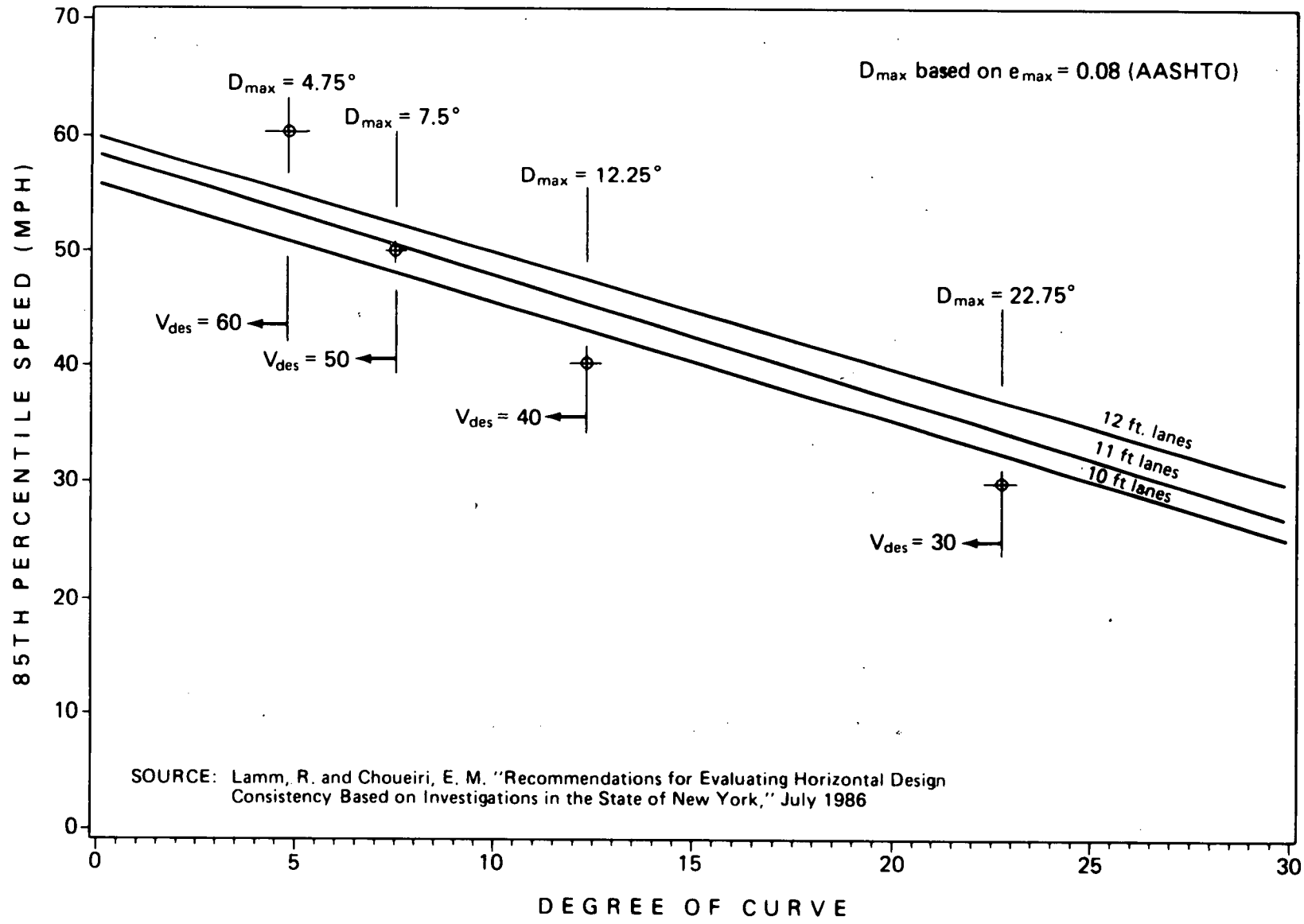


Figure F-1. Relationship between 85th percentile vehicle speed and horizontal curvature.

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