NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 247

EFFECTIVENESS OF CLEAR RECOVERY ZONES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Good Book Need More!

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **247**

EFFECTIVENESS OF CLEAR RECOVERY ZONES

JERRY L. GRAHAM and DOUGLAS W. HARDWOOD
Midwest Research Institute
Kansas City, Missouri

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- FACILITIES DESIGN
- TRANSPORTATION SAFETY
- OPERATIONS AND TRAFFIC CONTROL
- (HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. MAY 1982

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.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry: its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

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 Academy 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 Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 247

Project 17-5 FY '80
ISSN 0077-5614
ISBN 0-309-03413-2
L. C. Catalog Card No. 82-60287

Price: $7.20

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Special Notice

The Transportation Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America.

FOREWORD

By Staff
Transportation
Research Board

This report will be of particular interest to individuals at the federal, state, and local levels who are involved in the design of rural highways. The findings should also be useful to policy makers in the development of highway design criteria. Information is provided that will assist highway design engineers, safety specialists, and economists in the selection of the most cost-effective cross-section design for either a new highway or a reconstruction project. Specifically, the cost and safety aspects of clear roadside recovery areas are addressed. The evaluation methodology and illustrative case studies presented in the report are based on a substantial amount of field data collected during this research project, data from several previous studies, and data obtained through the use of a computer simulation model.

Current highway design criteria generally include a recommendation for an unobstructed roadside area with relatively flat slopes. Satisfying this criterion often results in higher construction costs due to extra cross-section widths, increased crossroad structure lengths, and additional right-of-way. Maintenance requirements may also be affected. Objective analyses of the actual effectiveness of clear recovery areas in reducing the frequency and severity of run-off-the-road accidents are necessary in order to assure cost-effective designs. The analysis should consider both cost and safety as related to road type, average daily traffic, vehicle speed, and highway geometrics.

This report documents Midwest Research Institute's study of the effectiveness of clear recovery zones. Accident and cost data were analyzed for two-lane highways, four-lane divided arterials, and four-lane freeways constructed under different roadside design policies. A cost-effectiveness methodology for choosing a roadside design and four illustrative design examples are described.

The researchers found that the cost-effectiveness of roadside design improvements can vary widely between highway sections because of differences in accident rates, traffic volumes, terrain, required construction quantities, unit construction costs, and right-of-way requirements. Based on these findings, they recommended that cost effectiveness be determined on a project-by-project basis and that site-specific data be used whenever possible. In this regard, users of this report should note that the accident and cost data are from States with relatively level terrain (Illinois, Michigan, and Minnesota) and, therefore, the data should not be considered as typical or average values. The data are presented primarily to illustrate the procedural steps for others to follow using data for their own local conditions.

It should also be recognized that the actual selection of roadside design involves many other considerations in addition to the cost-effectiveness analysis for a single highway section. For example, continuity of design along a route to avoid frequent changes in the cross section, compatibility of the roadside design to such other factors as horizontal curves and available right-of-way, and the feasibility of actually conducting a detailed analysis for each highway section must also be considered. Therefore, the methodology presented in this report is intended to be used as one step in the total design process recognizing that other factors also need to be fully considered.

With the current emphasis on reconstruction type projects and in view of continuing increases in construction costs, selection of the most cost-effective design is a primary concern. The methodology described in this report was developed in response to this concern.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was conducted under NCHRP Project 17-5 by Midwest Research Institute. The work was performed in the Center for Safety and Engineering Analysis directed by Dr. William D. Glauz.

Mr. Jerry L. Graham, Senior Traffic Engineer, was the principal investigator. Mr. Douglas W. Harwood, Senior Traffic Engineer, was a co-author of the report and directed the accident data analysis. Dr. John C. Glennon, Transportation Consultant, was the author of Appendix E of the report and served as a consultant to the project staff throughout the duration of the project. Dr. John W. Hutchinson, University of Kentucky, generously provided advice and guidance to the project staff in the early stages of the research. Other project staff members at Midwest Research Institute included Ms. Karin Bauer, Ms. Rosemary Moran, Mr. D. James Migletz, Mr. Joseph L. Fessler, and Ms. Debra Hodge.

The staffs of the Illinois Department of Transportation, the Minnesota Department of Transportation, and the Missouri Highway and Transportation Department were of great assistance during the collection and analysis of data for this project. The authors are especially grateful for the contributions of Mr. Thomas R. Bright, Mr. Carl Mayes, and Mr. John D. Blair of the Illinois DOT, Mr. Robert A. Kurpius of the Minnesota DOT, and Mr. Joseph G. Bushko and Mr. Keith McGowan, Missouri Highway and Transportation Department.

EFFECTIVENESS OF CLEAR RECOVERY ZONES

SUMMARY

The objectives of this research were to determine the safety effectiveness of clear recovery zones in reducing the number and severity of run-off-road accidents and to provide an approach for cost-effective application of clear recovery zones. The project scope included the consideration of rural two-lane highways, four-lane freeways, and four-lane divided nonfreeways. Intersections, interchange ramps, low-volume highways (ADT less than 750 vehicles per day) and highways with urban development were excluded.

Actual accident data were obtained and analyzed to compare three different roadside design policies, which have been called the 6:1 Clear Zone policy, the 4:1 Clear Zone policy, and the Nonclear Zone policy. These policies describe the roadside designs used outside of the highway shoulder; the policies vary in both embankment slopes and the presence of unprotected fixed objects. Highway sections constructed under all three roadside design policies were identified in the States of Illinois, Minnesota, and Missouri.

A field survey of a randomly selected sample of the study sections was conducted to characterize the roadside design policies in more detail and to determine whether the highway sections constructed under different policies had differences other than roadside design. This survey found that the roadway sections did represent distinct roadside design policies, but that neither the 6:1 nor the 4:1 Clear Zone policy was applied as uniformly as their names might suggest. Highway sections constructed under both policies had some foreslopes steeper than 4:1 and some unprotected fixed objects within the 30-ft clear recovery zones. The only major difference in the roadway cross-section geometrics was that 6:1 Clear Zone and 4:1 Clear Zone sections had wider shoulders than Nonclear Zone sections on two-lane highways and four-lane divided nonfreeways.

The primary measure of effectiveness for this study was the single-vehicle run-off-road accident rate. This measure of effectiveness was restricted to run-off-road accidents, because it would be questionable to presume a relationship between roadside design policy and accidents where no vehicle left the roadway. The measure of effectiveness was restricted to single-vehicle run-off-road accidents, and multiple-vehicle run-off-road accidents were excluded, both because single-vehicle run-off-road accidents are much more frequent on rural highways than multiple-vehicle run-off-road accidents, and because the severity of single-vehicle run-off-road accidents can be attributed in large degree to the roadside design. Single-vehicle run-off-road accidents involving both the outside of the roadway and the median on divided highways were considered.

Analysis of the accident data for the study sections found that roadside design policy has a statistically significant relationship to single-vehicle run-off-road accident rate for all of the highway types considered. To provide a reliable measure of the differences in accident rate between roadside design policies, the mean accident rates were adjusted to account for differences between the roadside design policies in the states where the study sections are located and the average daily traffic volumes (ADT) and shoulder widths of the study sections. The details of this adjustment are presented in Appendix D. For two-lane highways, the adjusted mean single-vehicle run-off-road accident rate was 0.254 accidents per million vehicle-miles for the 6:1 Clear Zone roadside design policy, 0.403 accidents per million vehicle-miles for the 4:1 Clear Zone policy, and 0.680 accidents per million vehicle-miles for the Nonclear Zone policy. On four-lane freeways, the mean rate was 0.182 accidents per million vehicle-miles on 6:1 Clear Zone sections and 0.289 on 4:1 Clear

Zone sections. Accident data for Nonclear Zone sections were not obtained on freeways, but an estimated single-vehicle run-off-road accident rate of 0.407 accidents per million vehicle-miles was derived from the NCHRP Report 148 roadside hazard model. On four-lane divided nonfreeways, the single-vehicle run-off-road accident rate was 0.155 accidents per million vehicle-miles on 6:1 Clear Zone sections, 0.319 accidents per million vehicle-miles on 4:1 Clear Zone sections and 0.607 accidents per million vehicle-miles on Nonclear Zone sections.

Analysis of the severity of single-vehicle run-off-road accidents found that the accident severity distribution did not vary between the roadside design policies on any of the three highway types studied. In particular, there was no shift toward less severe accidents on sections with improved roadside design policies. However, although the proportions of fatal, injury, and property-damage-only accidents did not vary between roadside design policies, the number of accidents occurring for each severity level was found to decrease as the roadside design policy improved.

The relationship between single-vehicle run-off-road accident rate and ADT was investigated within each combination of highway type and roadside design policy. For two-lane highways a statistically significant linear relationship was found between the single-vehicle run-off-road accident rate and ADT for each roadside design policy. Each of these relationships has a negative slope indicating that the run-off-road accident rate generally decreases with increasing traffic volume. No significant relationship between single-vehicle run-off-road accident rate and ADT was found for freeways or for four-lane divided nonfreeways.

The NCHRP Report 148 roadside hazard model was used to evaluate several roadside configurations that could not be examined with accident data. It was estimated that, for both two-lane highways and freeways, highway sections with a 20-ft Clear Zone roadside design policy would experience single-vehicle run-off-road accident rates approximately 10 percent higher than similar highways with a 30-ft Clear Zone roadside design policy. It was also estimated that if the 4:1 Clear Zone policy were more uniformly applied, with roadsides completely clear of unprotected fixed objects within 30 ft of the traveled way and no foreslopes steeper than 4:1, accident rate reductions of about 5 percent on freeways and of about 25 percent on two-lane highways could be obtained. Similar estimates were obtained for more uniform application of the 6:1 Clear Zone roadside design policy on freeways and on two-lane highways.

Four design examples were developed to illustrate the cost-effectiveness implications of the safety effectiveness measures developed in the study. The examples compare the average accident reduction benefits and typical construction costs for improving highways with one roadside design policy to another. The four design examples include a comparison of: Nonclear Zone and 4:1 Clear Zone roadside design policies for freeways; 4:1 Clear Zone and 6:1 Clear Zone roadside design policies for freeways; Nonclear Zone and 4:1 Clear Zone roadside design policies for two-lane highways; and, 4:1 Clear Zone and 6:1 Clear Zone roadside design policies for two-lane highways.

The results obtained from the design examples include the benefit-cost ratio for roadside design policy improvements as a function of ADT, and the "breakeven" ADT, at which the benefits and costs of the roadside design improvements are equal. Although the latter result suggests a minimum value of ADT at which roadside design policy improvements become cost-effective, a specific ADT level as a criterion on which roadside design policy can be based is not recommended because both the accident reduction benefits and construction costs may vary from site to site. Instead, a flexible approach to roadside design, based on a cost-effectiveness analysis for individual roadway sections or projects, is recommended. The benefit-cost evaluation procedure used for the design examples is suitable for this purpose. However, some highway agencies may prefer to use the recommended benefit-cost evaluation procedure to establish cost-effective roadside design policies for highways of similar highway type, traffic volume, and functional class.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

A clear recovery zone is a relatively flat roadside area free of unprotected fixed objects and other nontraversable hazards, intended to provide an opportunity for vehicles that leave the roadway to come to a safe stop or to return to the roadway. Since the late 1960's, a highway cross-section with 6:1 embankment slopes within a 30-ft clear recovery zone has been generally adopted for new construction and major reconstruction projects. However, many existing highways have clear recovery zones with 4:1 (steeper) embankment slopes or have no clear recovery zone at all. Recent design guidelines have suggested the need for clear recovery areas wider than 30 ft if embankment slopes steeper than 6:1 are used.

NCHRP Project 17-5, "Effectiveness of Clear Recovery Zones," has been conducted to help highway agencies with limited funds develop a rational basis for making cost-effective application of clear recovery zones. The NCHRP problem statement for this research follows.

PROBLEM STATEMENT

There is a critical need to evaluate the cost-effectiveness of the highway design standards that are currently in use because traffic accident deaths, injuries, and property damage are substantial and the funds available for construction or reconstruction of highways are generally declining.

If standards contain adequate flexibility, each design can be tailored to gain maximum cost-effectiveness. The total safety benefit will be increased by building each improvement in the most cost-effective way rather than attempting to use a rigid set of standards for all projects, regardless of cost.

The generally adopted highway cross-section, which includes an unobstructed area of relatively flat slopes outside the normal shoulder limits, has resulted in substantially increased construction costs. The extra width of cross-sections may entail larger grading costs, increased crossroad structure lengths, and additional right-of-way, in addition to affecting maintenance requirements. Some measures of the effectiveness of this clear recovery area in reducing the frequency and severity of run-off-road accidents are necessary in order to assure cost-effectiveness of design.

RESEARCH OBJECTIVES AND SCOPE

The objectives of NCHRP Project 17-5 were to determine the safety effectiveness of clear recovery zones of differing slopes and widths in reducing the number and severity of run-off-road accidents, and to describe a framework based on clear zone effectiveness that can be used in design practice to assure cost-effective application of clear recovery zones. The study was not intended to consider criteria for the installation of guardrail at specific sites or blanket fixed object removal programs; rather it was intended to evaluate the safety effectiveness of providing clear recovery zones by flattening slopes and/or removing or treating fixed objects.

The project scope included the consideration of several types of highways in rural areas including two-lane highways, four-lane freeways, and four-lane divided nonfreeways. Specifically excluded from consideration ~~were~~ intersections, interchange ramps, low-volume highways (ADT less than 750 vehicles per day) and highways with urban development.

RESEARCH APPROACH

The general research approach for NCHRP Project 17-5 was to determine the effectiveness of clear recovery zones from actual accident data for existing highway sections. Emphasis was placed on the use of existing data to the maximum possible extent because the project funding level did not permit extensive field data collection.

An early decision in establishing the research approach was that this study should not attempt to establish the incremental effects on safety of specific geometric design features, whether they are roadway features such as lane widths, shoulder widths, and horizontal curves or roadside features such as cut and fill slopes, embankment heights, and fixed objects. There were three reasons for this decision. First, previous attempts to determine the incremental effects of individual geometric features have had limited success, in part because many geometric features, such as steep slopes and fixed objects, often occur together making it difficult to separate their independent effects. Second, determining the incremental effects of roadside features would have required a detailed field inventory of the study sections, which would have been beyond the resources available to the study. Third, some of the specific roadside designs of interest to the study, such as clear zone widths other than 30 ft, have not been implemented on a widespread scale and, thus, could not have been studied even if a field inventory had been conducted.

An alternative approach is the comparison of the accident experience for highway sections constructed under different roadside design policies. This alternative approach was feasible precisely because certain roadside features often occur in conjunction with one another. At least three distinct roadside design policies have been used by highway agencies in the United States. These roadside design policies have been called 6:1 Clear Zone, 4:1 Clear Zone, and Nonclear Zone in this study. The policies vary in both the embankment slopes used and the presence of unprotected fixed objects outside of the highway shoulder, and are described further in Chapter Two and in Appendix C of this report. Highway sections constructed under all three roadside design policies were identified in three states (Illinois, Minnesota, and Missouri) for use in the study. A field survey of a randomly selected sample of the study sections was used to document the design differences between the roadside design policies.

The average safety effects of the three roadside design policies, as applied by highway agencies to the actual terrain in the field, can be determined if the highway sections constructed under different policies have no major differences other than roadside design or if such differences that do exist can be identified and accounted for. Thus, the objective of the analysis was not to determine the safety effects of an individual geometric feature (shoulder width, for example) but to assure that an effect of shoulder width was not mistaken for an effect of roadside design policy.

The primary measures of effectiveness (or dependent variables) for the study were the single-vehicle run-off-road accident rate for all accident severity levels and the fatal and injury single-vehicle run-off-road accident rate. These measures of effectiveness were restricted to run-off-road accidents, because it would be questionable to presume a relationship between roadside design policy and accidents where no vehicle left the roadway. The measure of effectiveness was restricted to single-vehicle run-off-road accidents, and multiple-vehicle run-off-road accidents were excluded, both because single-vehicle run-off-road accidents are much more frequent on rural highways than multiple-vehicle run-off-road accidents and because the severity of single-vehicle run-off-road accidents can be attributed in large degree to the roadside design. Single-vehicle run-off-road accidents involving both the outside (right side) of the roadway and the median (left side) on divided highways were considered.

The independent variables for the analysis, in addition to roadside design policy, were state, average daily traffic volume (ADT), and shoulder width. The basic technique used for the statistical evaluation was analysis of covariance.

The safety experience of roadside designs for which accident data were not obtained was estimated using the roadside hazard model presented in NCHRP Report 148 (9).

Four design examples were developed to illustrate the cost-effectiveness implications of the safety effectiveness measures developed in the study.

CHAPTER TWO

FINDINGS

Various researchers (most notably K. A. Stonex of the General Motors Proving Ground) conducted accident and vehicle dynamics research in the early 1960's that led to a number of recommendations on roadside design subsequently presented in the 1967 AASHO publication "Highway Design and Operational Practices Related to Highway Safety" (3) commonly known as the "Yellow Book." The recommendation that side slopes of 6:1 or flatter should be provided where possible and that a clear recovery area should be provided for 30 ft from the edge of the traveled way in rural areas has come to be called the 30-ft clear zone concept.

Since the adoption of the 30-ft clear-zone concept, several studies of the accident reduction effectiveness of the updated clear-zone criteria have been conducted. Studies performed by the Minnesota Department of Transportation (15), the Missouri State Highway Department (16), and the University of Illinois (7) are discussed and compared in the literature review in Appendix A of this report. These studies had varying conclusions about the safety effectiveness of clear recovery zones due to differences in the measures of effectiveness and the statistical techniques used.

PRELIMINARY ANALYSIS

Two existing accident data bases from previous Federal Highway Administration (FHWA) research studies were examined in a preliminary analysis to evaluate clear-zone effectiveness. These accident data bases were collected in a study by Calspan Field Services, Inc., entitled "Methodology for Reducing the Hazardous Effects of Highway Features and Roadside Objects" (20, 21) and a study by Midwest Research Institute (MRI) entitled "Effectiveness of Alternative Skid Reduction Measures" (4).

The Calspan data base was analyzed to determine the effect of clear zone characteristics on the severities of single-vehicle accidents. The analysis found no statistically significant relationship between the presence or absence of a clear zone, the embankment slope, or the height of cut or fill and the severity of single-vehicle accidents. However, the analysis was limited by the fact that no exposure data were available and only 5 percent of the accident sites had clear zones.

The Skid Reduction data base was used to evaluate the relationship between roadside obstacles and accident rates. A statistically significant relationship was found between single-vehicle accident rate and both length of bridge rail or guardrail and the number of roadside obstacles. When only single-vehicle run-off-road accidents were considered, the number of roadside obstacles was statistically significant, but not the length of guardrail or bridge rail. This analysis was limited by lack of reliable information on roadside slopes and the fact that obstacles within 30 ft of the edge of pavement were counted for freeways, but only obstacles within 10 ft were counted on two-lane highways or four-lane divided nonfreeways.

DATA BASE DEVELOPMENT

The preliminary analysis of these data bases and the review of previous studies on clear zone effectiveness made it clear that adequate data were not available to evaluate the incremental effects of individual roadside design features. However, there were available data bases identifying highway sections constructed under various roadside design policies that could be used to implement the research approach described in Chapter One. These existing data bases were obtained from the States of Illinois, Minnesota, and Missouri and were supplemented with additional data to produce an accident data base that contained study sections for three roadside design policies and three highway types, including two-lane highways, four-lane freeways, and four-lane divided nonfreeways. All of the study sections are located on highways in rural areas and had 55-mph speed limits. The entire data base (described in App. B) contains accident, geometric, and traffic volume data for 836 study sections covering 4,601 miles of highway with total exposure of over 41 billion vehicle-miles of travel. These highway sections experienced 11,649 single-vehicle run-off-road accidents over a study period averaging about 4.4 years.

ROADSIDE DESIGN POLICIES

The key to understanding the safety effectiveness measures developed in this study is to understand the roadside design policies that were evaluated. The policies have been given the designations 6:1 Clear Zone, 4:1 Clear Zone, and Nonclear Zone and are described briefly below. The policies vary in both the embankment slopes used and the presence of fixed objects outside of the highway shoulder. Figure 1 shows typical cross-sections for the three roadside design policies. The figure shows that the roadside slopes used for 6:1 and 4:1 design policies can, in some circumstances, be steeper than the nominal slope suggested by the name given to the policy. The roadside slopes used for nonclear highway sections are too highly variable to be illustrated by one typical cross-section. The field survey results reported in Appendix C provide more detail on the embankment slopes and fixed objects actually found on highways constructed under each policy.

The 6:1 Clear Zone roadside design policy has been generally used in freeway construction and some reconstruction projects on other types of highways since the late 1960's. Highways constructed under this policy generally have foreslopes of 6:1 or flatter within 30 ft of the traveled way. Embankment slopes of 4:1 or steeper are found on limited portions of these sections (up to 4 percent of the length on freeways and 12 percent of the length on two-lane highways, for example). The average embankment foreslope of 6:1 Clear Zone sections was found in the field survey to be 5.8:1 for two-lane highways, 6.9:1 for freeways, and 5.7:1 for four-lane divided nonfreeways. On higher fill embankments, the slope often becomes 4:1 or steeper beyond 30 ft from the traveled way. These sections are generally, but not completely, clear of roadside fixed objects (other than those of breakaway design or protected by guardrail) within the 30-ft clear zone. The mean fixed object coverage factor at 30 ft from the traveled way was found to be 10 percent for 6:1 Clear Zone sections on two-lane highways, 7 percent on freeways, and 4 percent on four-lane divided nonfreeways. (The fixed object coverage factor is a single measure that reflects the combined frequencies of both point and continuous objects on the roadside. The mean fixed object coverage, expressed as a percentage, roughly corresponds to the probability of striking a fixed object given that a vehicle runs a specified distance off the roadway.) These mean fixed object coverage factors represent the combined total for unprotected fixed objects, guardrail, and bridge rail.

The roadside design policy, called 4:1 Clear Zone, was in general use by many highway agencies before the 6:1 Clear Zone policy was recommended by AASHTO and is still in use for some projects today. The majority of the length of these sections have foreslopes of 4:1 or flatter within 30 ft of the traveled way, but the 4:1 design policies often permitted 3:1 or 2:1 foreslopes on fills higher than 10 to 15 ft. The average embankment foreslope of 4:1 Clear Zone sections was found to be 3.7:1 for two-lane highways, 4.3:1 for freeways and 4.2:1 for four-lane divided nonfreeways. Freeways constructed under the 4:1 Clear Zone policy are generally clear of unprotected fixed objects within 30 ft of the traveled way (in many cases, the result of roadside improvement programs since the original freeway construction). On two-lane highways, there are substantially more unprotected fixed objects within 30 ft of the traveled way on 4:1 Clear Zone sections than on 6:1 Clear Zone sections. The mean fixed object coverage factor at 30 ft from the traveled way for 4:1 Clear Zone sections was 17 percent on two-lane highways, 11 percent on freeways, and 23 percent on four-lane divided nonfreeways, including unprotected fixed objects, guardrail and bridge rail.

It should be apparent from the preceding discussion that neither the embankment slope nor the fixed object clearance aspects of the 6:1 Clear Zone and 4:1 Clear Zone roadside design policies are as uniform as the names given them in this study might suggest.

The Nonclear Zone roadside design policy is dominated by sections with 3:1 and 2:1 embankment slopes with some flatter slopes, and little or no control of unprotected fixed objects adjacent to the traveled way. The lack of control on fixed objects means that numerous trees, utility poles, and other objects are found within 30 ft of the traveled way on Nonclear Zone sections. Study sections with a Nonclear Zone roadside design policy were found on two-lane highways and four-lane divided nonfreeways, but not on freeways. The average embankment foreslope on Nonclear Zone sections was found to be 3.1:1 for two-lane highways, and 3.5:1 for four-lane divided nonfreeways. The mean fixed object coverage factor at 30 ft from the traveled way for Nonclear Zone sections, including unprotected fixed objects, guardrail and bridge rail, was found to be 24 percent for two-lane highways and 42 percent for four-lane divided nonfreeways.

ACCIDENT DATA ANALYSIS

A statistical analysis of the project accident data base found that roadside design policy has a statistically significant relationship to single-vehicle run-off-road accident rate for all highway types considered. The mean accident rates found for each highway type and roadside design policy are given in Table 1, including the single-vehicle run-off-road accident rate for all accident severity levels and for fatal and injury accidents only. These mean accident rates have been adjusted to account for the differences between roadside design policies in the states where the

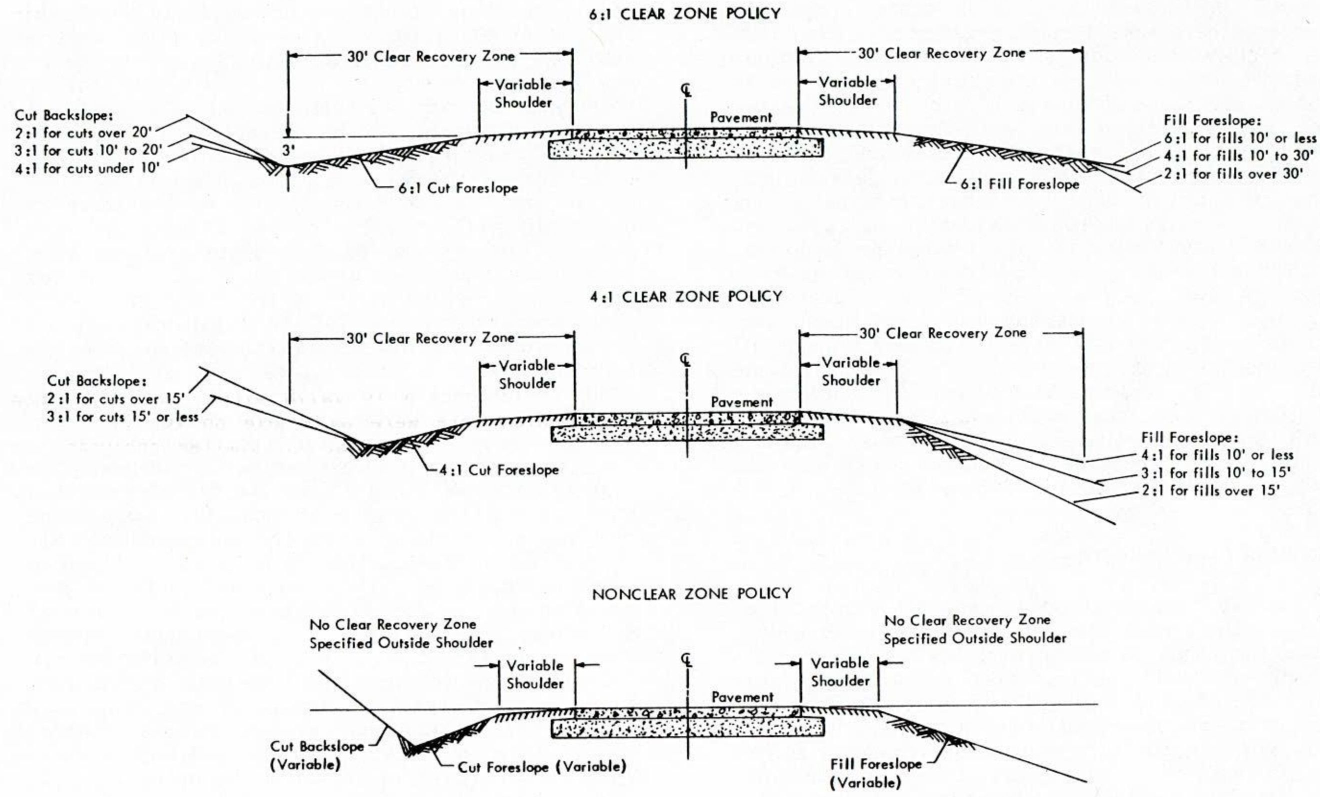


Figure 1. Typical cross-sections for roadside design policies on two-lane highways.

Table 1. Adjusted mean accident rates by highway type and roadside design policy.

Highway Type	Roadside Design Policy 6:1 CZ	4:1 CZ	NCZ	Differences Between Roadside Design Policies 6:1 vs. 4:1 Δ	Significance[a]	4:1 vs. NCZ Δ	Significance[a]
SINGLE-VEHICLE RUN-OFF-ROAD ACCIDENTS PER MILLION VEHICLE-MILES--ALL ACCIDENT SEVERITY LEVELS							
Two-Lane	0.254	0.403	0.680	0.149	SIG	0.277	SIG
Freeway	0.182	0.289	0.407[b]	0.107	SIG	0.118[b]	--
Four-Lane Divided (Nonfreeway)	0.155	0.319	0.607	0.164	SIG	0.288	SIG
SINGLE-VEHICLE RUN-OFF-ROAD ACCIDENTS PER MILLION VEHICLE-MILES--FATAL AND INJURY SEVERITY LEVELS							
Two-Lane	0.098	0.183	0.320	0.085	SIG	0.137	SIG
Freeway	0.068	0.100	0.149[b]	0.032	SIG	0.081[b]	--
Four-Lane Divided (Nonfreeway)	0.057	0.129	0.298	0.072	SIG	0.169	SIG

[a] Statistical significance at 95% confidence level.

[b] Based on estimates made with NCHRP Report 148 roadside hazard model rather than accident data analysis.

Table 2. Accident severity distribution for single-vehicle run-off-road accidents.

Highway Type	Roadside Design Policy	Fatal Accidents No.	%	Injury Accidents No.	%	Property-Damage Only Accidents No.	%	Total Accidents No.	%
Two-Lane	6:1 CZ	12	2.5	201	41.1	276	56.4	489	100.0
	4:1 CZ	48	3.0	720	44.5	850	52.5	1,618	100.0
	NCZ	22	1.4	684	43.0	886	55.6	1,592	100.0
Four-Lane Freeway	6:1 CZ	32	1.6	705	35.7	1,237	62.7	1,974	100.0
	4:1 CZ	71	1.5	1,638	34.8	2,999	63.7	4,708	100.0
Four-Lane Divided (Nonfreeway)	6:1 CZ	4	1.5	109	41.4	150	57.0	163	100.0
	4:1 CZ	15	1.8	348	42.9	448	55.2	811	100.0
	NCZ	2	1.0	95	49.0	97	50.0	194	100.0

study sections are located and the average daily traffic volume (ADT) and shoulder widths of the study sections. The entire statistical analysis procedure used to obtain these results is described in Appendix D.

All of the accident rates in Table 1 are derived directly from the accident data base assembled for the study, except for the accident rates for the Nonclear Zone (NCZ) design policy on freeways. No data were available for this situation, so an estimate of its accident rate was made using the roadside hazard model developed in NCHRP Report 148. This model was found to yield accident rates that were substantially higher than the actual accident rates for the study sections, but a method for adjusting the model results was developed and is presented in Appendix E. The roadside design that was assumed in determining the accident rate for a freeway Nonclear Zone section is essentially the same as for a two-lane highway Nonclear Zone section.

The differences between mean accident rates in Table 1 provide measures of effectiveness for improving a highway from one design policy to another. For example, upgrading a two-lane highway from a 4:1 Clear Zone design policy to a 6:1 Clear Zone design policy would be expected to reduce the single-vehicle run-off-road accident rate by 0.149 accidents per million vehicle-miles. Although the table does not explicitly show a measure of effectiveness for improving a highway with a Nonclear Zone policy to a 6:1 policy, this measure would be the sum of the differences between the Nonclear Zone and 4:1 Clear Zone policies and the 4:1 and 6:1 Clear Zone policies. It is emphasized that such measures of effectiveness are averages and, naturally, would be expected to vary from site to site because of the random occurrence of accidents.

The accident severity distribution by highway type and roadside design policy for single-vehicle run-off-road accidents is given in Table 2. It was determined in the statistical analysis that the accident severity distribution does not vary between roadside design policies. In particular, there was no statistically significant shift in the severity distribution toward less severe accidents on sections with improved roadside design policies. Thus, it was concluded that roadside design improvements are equally effective in reducing fatal, injury, and property-damage-only accidents. However, because there is no shift in the severity distribution, the accident rates given in Table 1 imply that the frequency of accidents in all severity classes--fatal, injury, and property-damage-only--decreases as the roadside design policy is improved.

The relationship between single-vehicle run-off-road accident rate and ADT was investigated within each combination of highway type and roadside design policy. For two-lane highways, a statistically significant linear relationship was found between single-vehicle run-off-road accident rate and ADT for each of the three roadside design policies. Each of these linear relationships has a negative slope, indicating that the run-off-road accident rate generally decreases with increasing traffic volume. A statistical test established that the slopes of the linear relationships for each roadside design policy were not significantly different, so that a single common slope could be used for all two-lane highways. The common slope has the value -0.041 accidents per million vehicle-miles per 1,000 vehicles per day (vpd) and implies the linear relationship:

$$AR = -0.041\ ADT + b_o$$

where AR = Single-vehicle run-off-road accident rate (accidents per million vehicle-miles);

ADT = Average daily traffic volume, 1,000 vpd; and,

b_o = A constant that depends on the roadside design policy.

This relationship is valid within the ADT range for which data were available on two-lane highways--750 to 5,000 vpd. A similar analysis for fatal and injury accident rate on two-lane highways found the common slope -0.026 accidents per million vehicle-miles per 1,000 vpd. No statistically significant linear relationship between single-vehicle run-off-road accident rate and ADT was found either for freeways or for four-lane divided nonfreeways.

A series of figures was developed to illustrate the effects of roadside design policy and ADT on single-vehicle run-off-road accident experience. Six graphs are presented in Appendix D to illustrate these relationships both for total accidents and for fatal and injury accidents on the three highway types (two-lane highways, four-lane freeways, and four-lane divided nonfreeways); one of these graphs is shown in Figure 2, as an example. These graphs illustrate the combined effects of the accident rate estimates in Table 1 and the accident rate-ADT relationships previously described. The accident experience in Figure 2 has been expressed as an accident frequency per mile per year, rather than as an accident rate, to clearly illustrate the magnitude of the average differences in roadside design polices; for this reason, the relationships shown in Figure 2 are nonlinear. The figure illustrates that, on a two-lane highway with an ADT of 2,000 vpd, there is an average of about 0.2 single-vehicle run-off-road accidents per mile per year for a 6:1 Clear Zone design policy, 0.3 accidents per mile per year for a 4:1 Clear Zone design policy, and 0.5 accidents per mile per year for a Nonclear Zone design policy. Thus, on the average, one could reduce about 0.2 accidents per mile per year by upgrading a roadside without a clear zone to a 4:1 Clear Zone design and 0.1 accidents per mile per year by upgrading a roadside with a 4:1 Clear Zone design to a 6:1 Clear Zone design.

Finally, the NCHRP Report 148 roadside hazard model was used to evaluate several roadside configurations that could not be examined with accident data. It was determined that, for both two-lane highways and freeways, highway sections with 20-ft clear zones would experience single-vehicle run-off-road accident rates approximately 10 percent higher than similar highway sections with 30-ft clear zones. It was also determined that, if the 4:1 Clear Zone design policy was more uniformly applied, with roadsides completely clear of unprotected fixed objects and no slopes steeper than 4:1, accident rate reductions of about 5 percent could be obtained on freeways and about 25 percent on two-lane highways. Similar results were

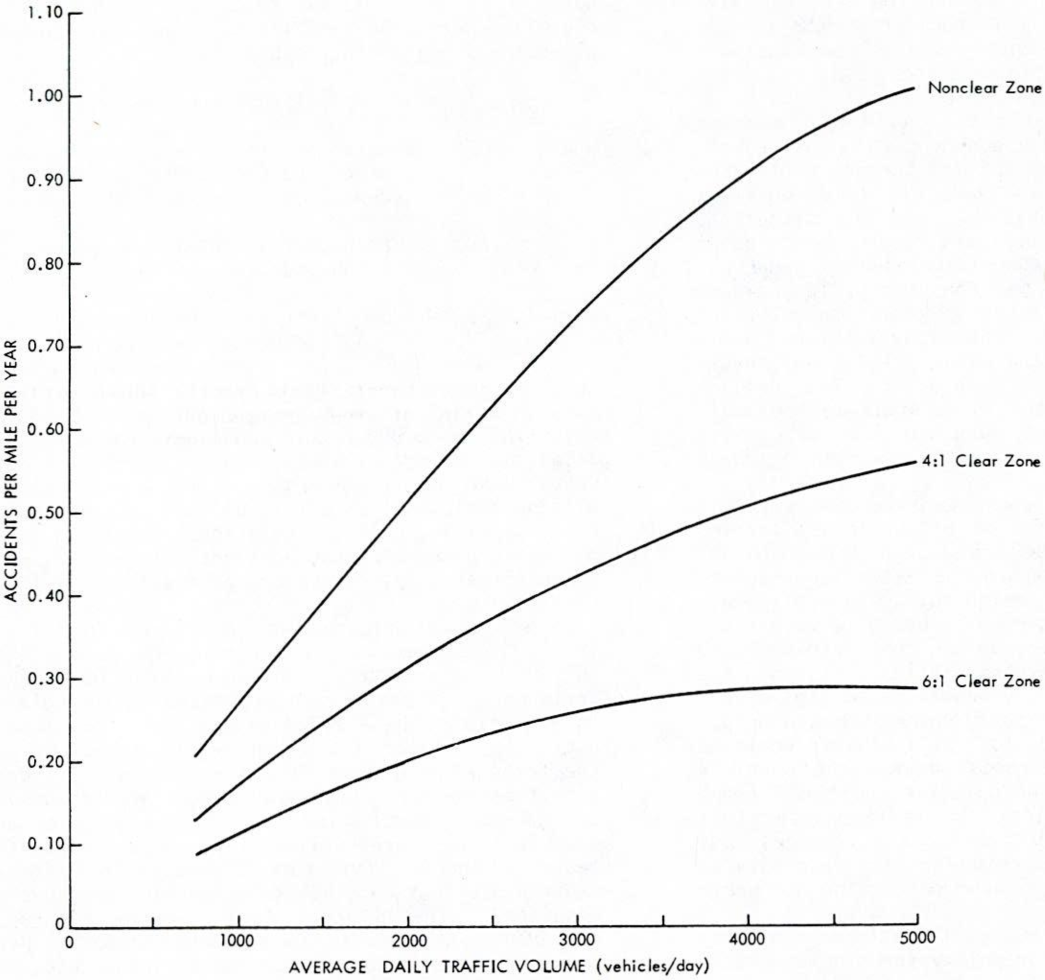


Figure 2. Relationship between single-vehicle run-off-road accidents per mile per year and ADT for two-lane highways.

obtained for a more uniform application of the 6:1 Clear Zone design policy on freeways and two-lane highways. These estimates are described in more detail in Appendix E.

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION

The findings reported in the previous chapter provide an indication of the safety effects of clear recovery zones and its components--embankment slope and width of clear area. The differences in single-vehicle run-off-road rate between highway sections with 4:1 Clear Zone and 6:1 Clear Zone roadside design policies are primarily due to differences in embankment slope, although there are a few fixed objects within the 30-ft clear area in both cases. The differences in accident rate between highway sections with Nonclear Zone and with 4:1 Clear Zone roadside design policies represent the effect of the presence or absence of a clear recovery area. This difference represents the combined effects of both embankment slope and fixed objects, although the NCHRP Report 148 model indicates that, even for Nonclear Zone sections, most of the roadside hazard results from the steeper embankment slopes rather than from fixed objects. The model was also used to estimate that a reduction in the width of the clear recovery area from 30 ft to 20 ft would increase the single-vehicle run-off-road accident rate by 10 percent for highway sections with either 4:1 or 6:1 embankment slopes.

These findings must be interpreted carefully to avoid either underestimating or overestimating their implications for roadside design. The findings leave no doubt that roadside design improvements can reduce the rate of occurrence for single-vehicle run-off-road accidents, which constitute about 43 percent of the nonintersection-related accidents on the highways studied. However, the magnitude of the safety effect of improving roadside design can be extremely small, often less than one accident per mile per year. Large expenditures for roadside design improvements may not be justified by such small safety effects. On the other hand, these safety benefits can be obtained over many years. The only rational method for resolving the tradeoffs between the accident reduction effectiveness of roadside improvements and their construction cost is cost-effectiveness analysis.

The most reliable findings from this study are those obtained directly from the analysis of accident data. The findings obtained with the NCHRP Report 148 model should be used more cautiously, because of uncertainty about basic input data for the model such as encroachment frequencies. During this study, it was found that the fatal and injury accident rates predicted by the NCHRP Report 148 model were substantially higher than those actually experienced by the study sections. The adjustment of the model results to obtain consistency with the accident rates observed in this study is recounted in Appendix E.

Four design examples have been developed and presented in Appendix F of this report to help readers interpret the cost-effectiveness implications of the findings obtained from the study. The purpose of these examples is not to suggest that the choice of roadside design policies can or should be based on a single design situation. It is recognized that both run-off-road accident rates and construction costs may vary from site to site. These examples are intended only to compare the average accident rate reductions and typical construction costs for improving highways with one roadside design policy to another.

The cost-effectiveness analysis technique used for the design examples was a benefit-cost comparison of the present worth of both accident cost savings and construction costs. The criterion used to compare benefits and costs is the benefit-cost (B/C) ratio. Roadside improvements are considered cost-effective or economically justified whenever the benefit-cost ratio equals or exceeds 1.0. The computation of the benefit-cost ratio was based on an analysis period of 20 years. Because the service lives of the major capital items in each improvement (earthwork and right-of-way) generally have service lives longer than 20 years, those items were assigned a residual value at the end of the analysis period. The accident reduction estimates used for the analysis were determined from the accident rates presented in Chapter Two and an assumed value for the average ADT over the 20-year analysis period. The discount rate used to obtain the present worth of future costs and benefits was 4 percent per year. The 4 percent discount rate represents the real, long-term cost of capital, over and above the inflation rate. This choice of rate allows the analysis to be conducted on a constant-dollar basis, with the effect of inflation excluded. The specific procedures used to determine the benefit-cost ratio are presented in Appendix F.

The differences between the roadside design policies in accident frequency per mile per year, and therefore in accident costs savings and the benefit-cost ratio, were found to increase with increasing traffic volume. Therefore, one method of illustrating the results of the benefit-cost analysis is to determine a "breakeven" ADT--the traffic volume at which the present worth of accident reduction benefits is exactly equal to the present worth of the improvement construction cost. The "breakeven" ADT represents the minimum traffic volume at which a roadside design improvement on an average highway section would be cost-effective. The "breakeven" ADT has been computed, for illustrative purposes, in generalizing the design examples presented in this report. However, the computation of the "breakeven" ADT is not essential when evaluating roadside design policies for an individual highway section with known ADT. To determine the economic justification for roadside design improvements in such a case, it is necessary only to compute the benefit-cost ratio for each incremental roadside design improvement (Nonclear Zone to 4:1 Clear Zone or 4:1 Clear Zone to 6:1 Clear Zone) and compare it to 1.0.

The four design examples include a comparison of: Nonclear Zone and 4:1 Clear Zone roadside design policies for freeways; 4:1 Clear Zone and 6:1 Clear Zone roadside design policies for freeways; Nonclear Zone and 4:1 Clear Zone roadside design policies for two-lane highways; and, 4:1 Clear Zone and 6:1 Clear Zone roadside design policies for two-lane highways. The results obtained from the benefit-cost evaluation for each design example are given in Table 3, including the expected accident rate reduction, cost savings per accident reduced, improvement construction cost, and breakeven ADT. For each example, the breakeven ADT was computed separately based on accident cost estimates developed by the National Safety Council (NSC) (18) and the National Highway Traffic Safety Administration (NHTSA) (17). The computation of the benefit-cost ratio for several traffic volume levels on each highway type is illustrated in Appendix F.

The design examples for freeways show that the improvement from a Nonclear Zone to a 4:1 Clear Zone roadside design policy becomes cost-effective in the ADT range from 3,820 to 5,410 vpd. Thus, based on assumed conditions of construction cost and terrain, the use of at least a 4:1 ~~Clear Zone roadside design policy is economically justified,~~ on the average, for all but a small portion of rural freeway mileage. The use of a 6:1 Clear Zone roadside design policy becomes cost-effective for rural freeways in the ADT range from 6,100 to 8,650 vpd. Although the results of these examples are not intended to provide a specific traffic volume level on which roadside design policy should be based, they do illustrate that there is no single roadside design policy that is the most appropriate in all situations on rural freeways. Thus, a flexible policy is needed where the most cost-effective roadside design is selected for each section of highway.

Table 3. Summary of benefit-cost evaluations for four design examples.

Roadside Design Policy Improvement:	Freeways		Two-Lane Highways	
	Nonclear Zone to 4:1 Clear Zone	4:1 Clear Zone to 6:1 Clear Zone	Nonclear Zone to 4:1 Clear Zone	4:1 Clear Zone to 6:1 Clear Zone
Expected Accident Rate Reduction (accidents per million vehicle-miles)	0.118	0.107	0.277	0.149
Accident Cost Savings ($ per accident reduced)				
based on NSC accident costs	$ 7,748	7,748	9,266	9,266
based on NHTSA accident costs	$10,977	10,977	14,502	14,502
Improvement Construction Cost ($ per mile)	$31,265	47,148	19,029-66,804	22,984
Residual Value of Improvement after 20 years ($ per mile)	$14,753	25,407	8,873	13,622
Breakeven ADT (vpd) for B/C = 1.0[a]				
based on NSC accident costs	5,410	8,650	1,180-4,930	2,450
based on NHTSA accident costs	3,820	6,100	750-3,150	1,560

[a] For computation see Tables F-3 through F-7.

The results of the design examples for two-lane highways are less clear cut than for freeways, because the roadside designs found on two-lane highways and the costs of roadside design improvements are more variable than for freeways. The construction cost for improving a two-lane highway with a Nonclear Zone roadside design policy to a 4:1 Clear Zone roadside design policy was found to be highly dependent on the number and type of roadside objects to be removed. Depending on the construction cost used and the selection of the NSC or NHTSA accident costs, the improvement from the Nonclear Zone policy to a 4:1 Clear Zone policy could become cost-effective anywhere in a broad ADT range from 750 vpd to 4,930 vpd. If a 4:1 Clear Zone design policy has been found to be justified for a highway section or if an existing highway already has a 4:1 Clear Zone design policy, a further improvement to a 6:1 Clear Zone design policy would become cost-effective in the range from 1,560 vpd to 2,450 vpd. There are situations on two-lane highways where either the 6:1 Clear Zone roadside design policy, the 4:1 Clear Zone roadside design policy, or the Nonclear Zone roadside policy may be the most cost-effective approach. Although the results obtained from the design examples for two-lane highways are more difficult to generalize than the results for freeways, the need to consider cost-effectiveness in determining the roadside design policy remains the same.

The findings of the accident study and the design examples illustrate that roadside design policies must be flexible. The cost-effectiveness of roadside design improvements can vary widely between highway sections based on accident rates, traffic volumes, terrain, required construction quantities, unit construction costs, and right-of-way requirements. There is a clear need for a roadside design process based on cost-effectiveness considerations rather than a single, fixed roadside design policy. The objective of this process should be the selection of the roadside design most suited to each individual highway section or to groups of highway sections that are similar in highway type, functional class, and traffic volume.

The benefit-cost evaluation procedure presented in Appendix F of this report provides a rational basis on which the selection of roadside design policies can be based. The input data for each benefit-cost evaluation should, to the maximum possible extent, be appropriate to the specific highway section being considered rather than to the generalized nature used in the design examples. For example, construction costs are known to vary between geographical locations. In addition, specific construction projects may be below average in construction costs, if the acquisition of additional right-of-way is not required or if the height of cut and fill embankments is small. On the other hand, construction costs may be increased substantially where high cut and fill embankments or rock cuts are encountered. Construction cost estimates for design decisions should be based on the existing roadside design and the actual terrain for the specific highway under consideration.

The safety measures of effectiveness developed in this study represent average conditions in the geographical areas studied--three states in the Midwestern region of the United States. Substantial state-to-state variations in accident rate were found, even among these three states located in the same part of the country. Therefore, although the results reported here can be used when no better data are available, highway agencies are encouraged to adapt these results to fit their local conditions when adopting roadside design policies. A more accurate evaluation will result if locations with extremely high or extremely low roadside accident experience can be identified and the measures of effectiveness for improving such locations adjusted accordingly. Such extreme locations can be identified either from actual roadside accident records over a substantial period of time, as was done to develop a program for treatment of roadside fixed objects in California (22), or from existing roadside hazard models including the NCHRP Report 148 model (9) and those developed by Maryland (12) and Michigan (5).

All of the highways studied are located in rural areas and have 55-mph speed limits. It is expected that the study sections are very similar in the actual operating speeds selected by drivers, at least with specific highway types. No findings have been obtained for urban highways or for rural highways with speed limits less than 55 mph. It would be expected, however, that if all geometric, traffic volume, and operating factors were equal that highways with lower speed limits and operating speeds would experience lower run-off-road accident rates.

The average accident rates obtained in this study should be applied to extended sections of highway, at least one mile in length. Short sections of highway and spot locations could experience accident rates much higher or much lower than those presented here. For example, the literature review and, in particular, the Maryland (12) and Michigan (5) studies indicate that roadside accidents have higher rates and severities on horizontal curves than on tangents. Thus, it appears that the provision of clear recovery areas should be given a priority on horizontal curves above that for tangents. It is possible that there are highway sections where the installation of clear recovery zones may be cost-effective on the outside of horizontal curves but not on tangents. However, this question cannot be resolved without accident and geometric (field inventory) data at a greater level of detail than that available in this study.

It should be noted that the single-vehicle run-off-road accident rates developed here for two-lane highways have been adjusted to represent a constant shoulder width for all three roadside design policies. No similar adjustment was found to be necessary for freeways or four-lane divided nonfreeways, possibly because the shoulder widths for such highways are much less variable than for two-lane highways. If shoulder improvements are contemplated in conjunction with a roadside design improvement, the accident reduction effects of the shoulder upgrading should also be considered. NCHRP Report 197 (23) provides measures of effectiveness for shoulder improvements and a complete review of the literature related to the safety effects of shoulders.

In summary, there is a need to formalize the process by which roadside design policies for particular sections of highway are chosen. The safety effectiveness measures developed in this study are one of the basic input elements for this process. This process should be based on cost-effectiveness so that one neither misses opportunities to provide clear recovery areas where they are economically justified, nor spends limited resources unwisely providing clear recovery areas where they are not economically justified.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

The major conclusion of this study is that there is a statistically significant relationship between single-vehicle run-off-road accident rate and the roadside design policy used outside of the highway shoulder. The study findings provide estimates of the single-vehicle run-off-road accident rates for highway sections with and without clear recovery zones and for clear recovery zones of varying slope and width. These measures of effectiveness are summarized in Table 1 of Chapter Two.

Four design examples illustrate a cost-effectiveness comparison of the average accident reduction benefits and typical construction costs for roadside design policy improvements. It is not suggested that roadside design policy decisions can be based on these four examples. However, the examples do illustrate that there are situations where it is most cost-effective to provide clear recovery zones with 6:1 slopes, other situations where it is most cost-effective to provide clear recovery zones with 4:1 slopes, and still other situations where it may not be cost-effective to improve roadside design outside the shoulder area, at all.

The major recommendation resulting from the research is that roadside design policies should be flexible to provide a a cost-effective roadside design for each highway section (e.g., each highway project). The benefit-cost evaluation procedure used for the design examples in this study is suitable for the evaluation of roadside design policies. The maximum return will be obtained from roadside design improvements if a cost-effectiveness analysis is conducted for individual highway sections. It is recommended that the average accident rates developed in this study be used to determine the benefits of roadside design policy improvements, unless more site-specific data can be obtained. Particular attention should be paid to adjusting the measures of effectiveness for sites that have extremely high or extremely low roadside accident rates. Site-specific estimates of the construction costs for roadside design improvements should also be used. However, it is recognized that agencies may, for legal and administrative reasons, desire to adopt policies that use consistent designs for highways of similar functional class and traffic volumes. Such policies can be developed by each agency for classes of similar highways in a manner analogous to the design examples presented here, based on estimates of construction costs, accident costs, interest rates, and service life appropriate for that agency. It is recommended that sufficient flexibility should be retained in such policies to allow modified designs for locations with extremely high or extremely low values of construction cost and/or effectiveness.

Further research concerning clear recovery zones and roadside design policy improvements are needed in three areas not addressed specifically by this study. First, there are indications in the literature that roadside accident rates and severities are especially high on horizontal curves. This effect should be quantified and incorporated in the roadside design decision-making process. Second, the relationships between roadside design and single- and multiple-vehicle accident experience at intersections, which were not addressed in this study, need to be determined. And, third, more complete data are needed on the costs and benefits of roadside design improvements, in areas other than accident reduction. In particular, the differences in routine maintenance costs (mowing, etc.), erosion control costs, and snow and ice control costs between sections with 4:1 and 6:1 embankment slopes should be quantified.

There are two other areas where further research and development efforts relating to general roadway and roadside design could be considered.

The 1977 AASHTO Barrier Guide (2) deals with the warrants for roadside traffic barriers (guardrail, etc.) at particular sites and with the proper structural designs for such barriers. It is recommended that this guide should be supplemented or replaced with a more general "Roadside Design Guide," which would address not only the warrants for barriers at specific sites, but also the broader question of appropriate roadside design policies over extended sections of highway.

Finally, practical procedures are needed to determine the most cost-effective mix of roadway and roadside improvements on our highway systems. For example, it makes little sense, except in extraordinary circumstances, to make any roadside improvements on highways with relatively low traffic volumes when there are higher volume highways in need of pavement widening, shoulder widening, and stabilization and/or roadside design improvements. Such procedures would enable highway agencies to optimize the investment of the limited available funds for safety improvements to achieve a maximum return.

REFERENCES

1. American Association of State Highway and Transportation Officials, "A Manual on User Benefit Analysis of Highway and Bus Transit Improvements--1977." Washington, D.C. (1978) 189 pp.
2. American Association of State Highway and Transportation Officials, "Guide for Selecting, Locating, and Designing Traffic Barriers--1977." Washington, D.C. (1977) 322 pp.
3. American Association of State Highway Officials, "Highway Design and Operational Practices Related to Highway Safety." Washington, D.C. (Feb. 1967) 71 pp.
4. Blackburn, R. R., et al., "Effectiveness of Alternative Skid Reduction Measures. Volume I - Evaluation of Accident Rate - Skid Number Relationships." Federal Highway Administration, Report No. FHWA-RD-79-22 (Nov. 1978) 241 pp.
5. Cleveland, D. E., and Kitamura, R., "Macroscopic Modeling of Two-Lane Rural Roadside Accidents." Transportation Research Record 681 (1978) 10 pp.
6. Council, F. M., et al., "Accident Research Manual." Federal Highway Administration, Report No. FHWA/RD-80/016 (Feb. 1980) 144 pp.
7. Dotson, V. E., "An Evaluation of the Thirty-Foot Clear Zone." Unpublished Master of Science Thesis, University of Illinois, Urbana, Ill. (1974) 82 pp.
8. Foody, T. J., and Long, M. D., "The Identification of Relationships Between Safety and Roadway Obstructions." Ohio Department of Transportation, Report No. OHIO-DOT-06-74 (Jan. 1974) 75 pp.
9. Glennon, J. C., "Roadside Safety Improvement Programs on Freeways--A Cost-Effectiveness Priority Approach." NCHRP Report 148 (1974) 64 pp.
10. Glennon, J. C., and Tamburri, T. N., "Objective Criteria for Guardrail Installation." Highway Research Record 162 (1967).
11. Glennon, J. C., and Wilton, C. J., "Effectiveness of Roadside Safety Improvements." Federal Highway Administration, Report No. FHWA-RD-75-23 (Nov. 1978) 67 pp.
12. Hall, J. W., and Mulinazzi, T. E., "Roadside Hazard Model." Transportation Research Record 681 (1978) 4 pp.
13. Hutchinson, J. W., and Kennedy, T. W., "Safety Considerations in Median Design." Highway Research Record 162 (1967) 29 pp.
14. Milliken, G. A., and Johnson, D. E., "Analysis of Messy Data." Unpublished paper prepared for an Institute of Professional Education Seminar, Washington, D.C. (June 1981) 298 pp.
15. Minnesota Department of Transportation, "Comparison of Accident Rates Related to 4:1 and 6:1 Inslopes on 2-Lane Rural Trunk Highways." Unpublished report (June 1980) 20 pp.
16. Missouri State Highway Commission, "Summary of Accident Experience on Sections of Road Constructed with 20-Foot 'Safety Zones'." Unpublished memorandum, 7 pp.
17. National Highway Traffic Safety Administration, "1975 Societal Costs of Motor Vehicle Accidents." Report No. DOT-HS-802-119 (Dec. 1976) 35 pp.
18. National Safety Council, "Estimating the Cost of Accidents." Bulletin T-113-80, Chicago (1980).
19. Ostle, B., Statistics in Research. Second Edition, Iowa State University Press, Ames (1963) 585 pp.
20. Perchonok, K., et al., "Hazardous Effects of Highway Features and Roadside Objects. Volume I - Literature Review and Methdology." Federal Highway Administration, Report No. FHWA-RD-78-102 (Sept. 1978) 123 pp.
21. Perchonok, K., et al., "Hazardous Effects of Highway Features and Roadside Objects.

Volume 2 - Findings." Federal Highway Administration, Report No. FHWA-RD-78-202 (Sept. 1978) 332 pp.
22. Rinde, E. A., "Conventional Road Safety. Phase I - A Study of Fixed Objects." California Department of Transportation, Report No. FHWA-CA-TE-79-1 (Aug. 1979) 87 pp.
23. Roy Jorgensen Associates, Inc., "Cost and Safety Effectiveness of Highway Design Elements." NCHRP Report 197 (1978) 237 pp.
24. SAS Institute, "SAS Users Guide." 1979 Edition, Cary, NC (1979) 494 pp.
25. Smith, S. A., et al., "Identification, Quantification, and Structuring of Two-Lane Rural Highway Safety Problems and Solutions." Federal Highway Administration, Final Report of Contract No. DOT-FH-11-9659 (Oct. 1981).
26. Stonex, K. A., "Roadside Design for Safety." Highway Research Board, Proc. Vol. 39 (1960) pp. 120-156.
27. Stonex, K. A., "Requirements of an Obstacle-Clear Roadside." Committee on Geometric Highway Design, Highway Research Board, Washington, D.C. (Jan. 1963) cited in Jones, T. O., et al., "Half a Century and a Billion Kilometres Safely." Society of Automotive Engineers, Paper No. 780621 (1979) 25 pp.

APPENDIX A

REVIEW OF LITERATURE AND CURRENT PRACTICE

Literature dealing with roadside safety was reviewed to determine the established relationships between clear zone characteristics and run-off-road accident rate and to identify accident data bases that would be suitable for further analysis. This appendix presents the results of the general literature review; the discussion and comparison of three clear zone effectiveness studies from the University of Illinois, Minnesota Department of Transportation, and the Missouri Highway and Transportation Department; and results of additional analyses conducted with two accident data bases collected in the FHWA projects, "Effectiveness of Alternative Skid Reduction Measures," and "Methodology for Reducing the Hazardous Effects of Highway Features and Roadside Objects."

HISTORY AND CURRENT PRACTICE

In the early 1960's, efforts were begun to reduce the alarming increase in traffic accidents. The single-vehicle accident problem received a great deal of attention because improvements to the roadway system were expected to reduce single-vehicle accidents substantially. The roadside was seen as the area most in need of improvement to prevent single-vehicle accidents.

Research completed during the 1960's that was instrumental in the development of roadside safety design included the studies of Stonex (26, 27), Hutchinson and Kennedy (13), and Glennon and Tamburri (10).

In a study reported in 1960, Stonex (26) presented the philosophy developed at the General Motors Proving Ground to create a safe workplace for testing vehicles. Because 72 percent of the accidents occurring at the proving ground between 1953 and 1958 involved vehicles leaving the roadway, the safety of roadside areas was analyzed as a general industrial safety problem. Tests were performed to determine safe ditch cross-sections and safe side slope designs. The study concluded that "for safe roadside design the slopes must be as flat as possible, not steeper than 6:1 and preferably flatter." The study also pointed out the hazards of guardrail installations (particularly ends of guardrails), and concluded, "hitting guardrail is an accident and installation of guardrail should be avoided wherever possible."

In a further study of 211 run-off-road accidents at the General Motors Proving Ground, Stonex (27) observed that 80 percent of the vehicles that ran off the road did not travel more than 29.5 ft (9 m) from the pavement and 90 percent did not travel more than 49.2 ft (15 m). The farthest distance from the roadway traveled by any vehicle was 101.7 ft (31 m). Based on this research, GM established a minimum clear roadside area of 98.4 ft (30 m) for their proving ground.

A 1966 study by Hutchinson and Kennedy (13), was a major breakthrough in understanding and predicting the nature of single-vehicle accidents. This study provided empirical data on the nature of roadside encroachments in freeway medians including the following relationships:

1. The frequency of roadside encroachments as a function of traffic volume.
2. The distribution of encroachment angles.
3. The distribution of lateral displacements of encroaching vehicles.

This study contributed to the eventual adoption of the 30-ft clear zone concept because it documented that very few vehicles encroached beyond 30 ft from the edge of the traveled way.

As an over-reaction to the early recognition of need for improved roadside safety, highway guardrail was thought by some to be a panacea. Despite the warnings of researchers including Stonex, large quantities of guardrail were placed either where none was needed, or where a minimum of slope grading could have totally eliminated the need for guardrail. The tragic side of what was otherwise a promising trend in roadside safety was an increase in the frequency of spectacular accidents with guardrails.

In 1966, Glennon and Tamburri (10) presented the first, and now widely used, objective criteria for guardrail installation. A mathematical model was developed to compare the relative safety of protective guardrail with various combinations of embankment slope and height. The relationship was based on the relative accident severity distributions for ran-off-embankment accidents and guardrail accidents.

The Special Traffic Safety Committee of the American Association of State Highway Officials was created in 1964 and issued a report in 1967 entitled "Highway Design and Operational Practices Related to Highway Safety" (3), commonly called the "Yellow Book." One of the two major subjects of this report was roadside design and appurtenances. Some of the recommendations of the Yellow Book were:

> In the development of plans for highway improvements, all elements of design should be reviewed to insure that any feature likely to be associated with injury or accident to the highway user is eliminated or minimized in its effect. Special attention must be directed to the safety characteristics on the roadside so that they too are the result of deliberate design and not an unpredictable byproduct of grading, drainage or other construction activity. . . .
>
> Embankment and cut slopes 6:1 or flatter can often be negotiated by a vehicle with some chance for recovery and these should therefore be provided where possible. . . .
>
> To increase safety when vehicles leave the pavement, a clear recovery area, free of physical obstruction, should be provided along the roadway 30 ft or more from the edge of the traveled way in rural areas. Corrective programs should be undertaken at once to eliminate from the roadside or to relocate to protected positions such hazardous fixed objects as trees, drainage structures, massive sign supports, utility poles, and other ground-mounted obstructions that are now exposed to traffic. Where this is impracticable, an adequate guardrail or other type of protection should be provided. . . .
>
> Many ground-mounted highway signs can be placed farther from the pavement, laterally, and still retain their effectiveness. Under favorable viewing conditions, a minimum distance of 30 ft from the edge of pavement to the edge of sign is recommended. The detailed location of all individual signs and sign supports should be subjected to a field review of existing highway conditions prior to installation whenever possible to assure maximum effectiveness and safety.

This report also presented a basic roadside design philosophy which can be paraphrased as:

1. Remove unnecessary objects.
2. Move those objects that cannot be removed. This includes moving to a protected location or moving laterally.
3. Reduce the impact severity of those obstacles that cannot be moved. This includes flattening side slopes and installing breakaway devices.
4. Protect the driver from those obstacles that cannot otherwise be improved by using attenuation or deflection devices.

The combination of 6:1 embankment slopes and a 30-ft roadside area clear of unprotected fixed objects proposed by the Yellow Book became known as the 30-ft clear zone concept. Until that time, most highways had clear recovery areas with 4:1 slopes, with steeper slopes permitted on higher cuts and fills, or had no clear recovery area at all. After 1967, the 30-ft clear zone concept became widely accepted for new freeway construction and was also applied for some new construction and reconstruction projects on other types of highways, especially those involving the use of Federal-Aid funds. Extensive programs for removing, relocating, or protecting the driver from roadside fixed objects were undertaken, primarily on freeways. However, the cost-effectiveness of flattening slopes and removing fixed objects to provide a clear recovery area as part of reconstruction and rehabilitation projects has remained a controversial issue.

A further modification of policy on clear recovery areas occurred in 1977 with the publication of the AASHTO "Guide for Selecting, Locating and Designing Traffic Barriers" (2). Figure A-1, taken from the barrier guide, is used to determine the suggested clear zone width based on vehicle operating speed and embankment slope. As seen in the figure, fill slopes steeper than 6:1 may require a clear zone width greater than 30 ft. If the required width clear of fixed objects is not present and these objects cannot be removed, a barrier may be warranted. The AASHTO Barrier Guide also contains procedures for increasing the clear zone width on the outside of curves and for decreasing the clear zone width for highways with traffic volumes below 6,000 vpd. The guide recognizes that the suggested criteria represent a significant change from previous guidelines and may be impractical in some situations such as limited right-of-way conditions. However, the suggested criteria do emphasize the fact that flat, unobstructed roadsides are highly desirable.

CLEAR ZONE EFFECTIVENESS STUDIES

Since the adoption of the 30-ft clear zone concept, several studies of the accident reduction effectiveness of the updated clear zone criteria have been conducted. The major emphasis of these studies was on the effect of embankment slope (4:1 vs. 6:1) rather than on the width of the clear area free of fixed objects. Three studies, performed by the Minnesota Department of Transportation, the Missouri Highway and Transportation Department, and the University of Illinois, are described and compared in this section.

The Minnesota Department of Transportation conducted a study of run-off-road accidents occurring on rural, two-lane highways with 55-mph speed limits (15). The accident experience of roadways with 6:1 foreslopes were compared with roadways having 4:1 foreslopes. Both the 6:1 and 4:1 study sections had 30-ft clear zones and were selected by personnel in Minnesota's district offices to be comparable in lane width, shoulder width, and other geometric features. The study included 24

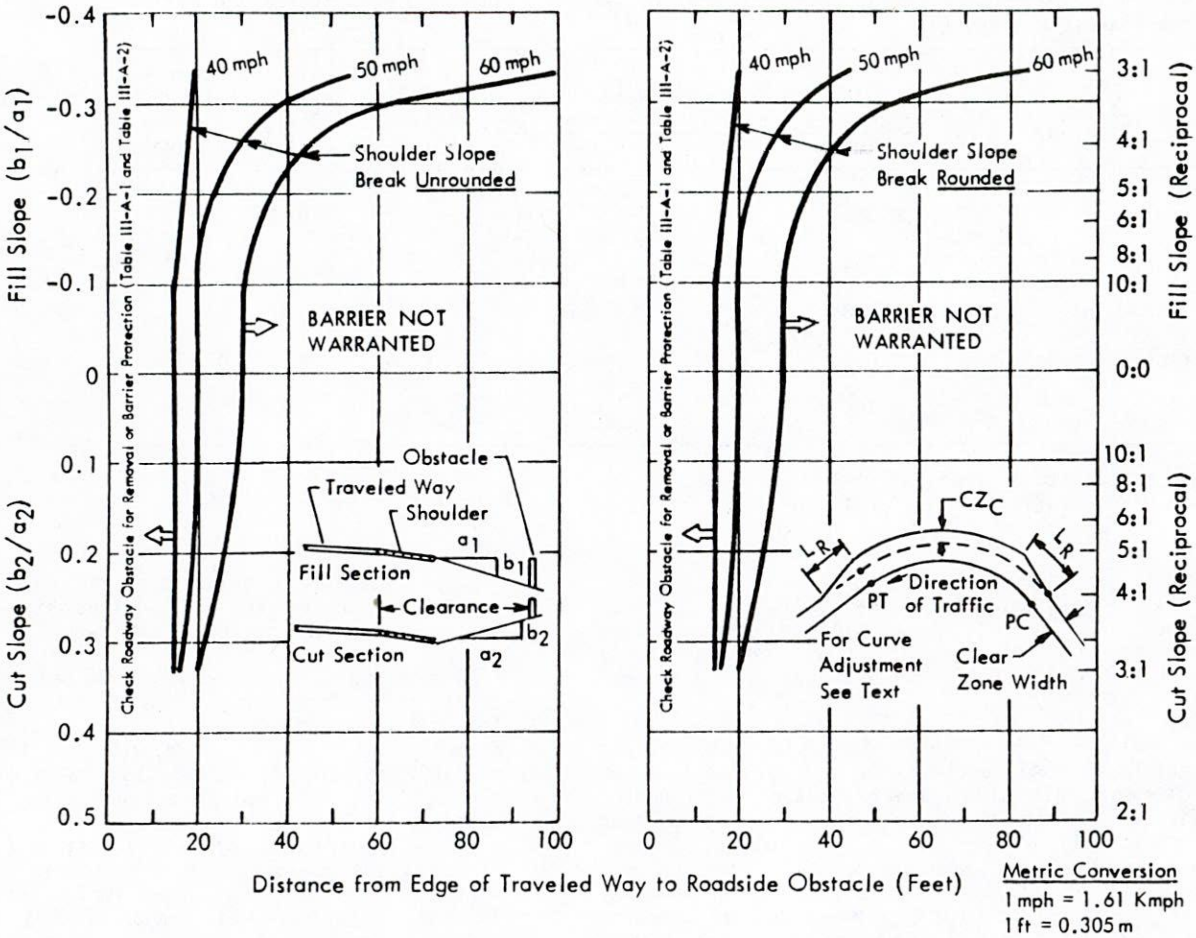


Figure A-1. Clear zone width, speed, and slope criteria.

sections (215 miles of highway) with 6:1 foreslopes and 23 sections (234 miles of highway) with 4:1 foreslopes.

The data that were analyzed included all run-off-road accidents that were reported on the study sections between January 1, 1977, and December 31, 1979. Accidents were classified by severity using three levels: fatal, injury, and property-damage-only. The average daily traffic volume (ADT) of each route was used to calculate an accident rate (expressed as accidents per million vehicle-miles).

The fatal, injury, property-damage-only (PDO), and total accident rates for the sections having 4:1 foreslopes were all larger than the corresponding rates for the roadway sections having 6:1 foreslopes. The total accident rate and the accident rates for corresponding severity levels were compared statistically between the 4:1 and 6:1 sections using the t-test. (The Beherns-Fisher procedure was employed because the variances of accident rate were unequal for the 4:1 and 6:1 sections.) The results indicated that the injury, fatal plus injury, and total accident rates were significantly different for the 4:1 and 6:1 sections, at the 95 percent confidence level. There were no significant differences between the fatal or property-damage-only accident rates for the two types of roadway sections. Table A-1 gives the mean accident rates from the Minnesota DOT study.

A benefit-cost analysis was performed by the Minnesota DOT using the analysis results. Because costs for constructing highways with 6:1 foreslopes are greater than for constructing highways with 4:1 foreslopes, this analysis considered the circumstances under which reduced accident costs would justify the increased construction costs. The benefits and costs were compared on the basis of present worth, using an improvement service life of 20 years and a discount rate of 9 percent. The analysis results found that the 6:1 slopes generally became more cost-effective than 4:1 slopes at higher volume levels between 2,000 and 4,000 vpd.

The following recommendations were developed by the Minnesota DOT from their study:

1. A maximum foreslope of 4:1 was recommended for normal use on new construction and major reconstruction projects on rural two-lane highways.
2. Foreslopes of 6:1 or flatter should be provided on the outside of all horizontal curves with a degree of curvature greater than or equal to 2°, when design year ADT exceeds 2,000 vpd.
3. A benefit-cost analysis should be performed for new construction or major reconstruction projects if the ADT exceeds 2,000 vpd to determine

Table A-1. Mean run-off-road accident rates by severity level and roadside design policy from Minnesota study (15).

Severity Level	Mean Accident Rate (accidents per million vehicle-miles) 6:1 Sections	4:1 Sections	Statistical Significance of Differences Between Roadside Design Policies (at 95% confidence level)
Fatal	0.004	0.009	NS
Injury	0.054	0.113	SIG
Fatal & Injury	0.058	0.122	SIG
Property-Damage-Only	0.096	0.145	NS
Total	0.154	0.266	SIG

SIG = Statistically significant
NS = Not statistically significant

whether 6:1 foreslopes are justified.

4. Foreslopes of 6:1 may help lower maintenance costs by reducing erosion problems and snow and ice control costs. These cost reductions should also be considered when performing a benefit-cost analysis.

Another study of roadside design policies was performed in Missouri in the mid-1970's. The results of this study are presented in an unpublished memorandum of the Missouri Highway and Transportation Department (16). This study compared the accident experience of roadway sections constructed with 20-ft "safety zones" and roadway sections constructed with similar design standards but without 20-ft "safety zones." (The 20-ft safety zone is an obstacle-free area extending 20 ft beyond the shoulder of the road; therefore, if a road has a 10-ft shoulder, there would be a 30-ft clear recovery area from the edge of the traveled way.) The sections with safety zones generally had 6:1 embankment slopes, whereas the sections without safety zones had embankment slopes of 4:1 or steeper.

Comparisons between accident rates for roadways with and without safety zones were made for four highway types (Interstate, primary dual-lane, primary two-lane, and supplementary); four accident types (multiple-vehicle collisions, roadside obstacle collisions, overturning accidents, and total accidents); and three severity levels (fatal, injury, and PDO). The mean accident rates found in these comparisons are given in Table A-2. The conclusions drawn by the authors of this study were:

1. There was no statistically significant difference in the overall accident rate or severity between sections with and without safety zones for any of the highway types.

2. Collisions with roadside obstacles decreased with the addition of a safety zone, but were accompanied by a corresponding increase in collisions between vehicles. In sections with lower traffic volumes, much of this increase occurred at intersections. The authors felt the increase might be due to driver confusion when confronted with the wide expanse of cleared right-of-way.

3. There was a significant decrease in accidents on snow or ice on two-lane highways, although the total accident rate was not lowered.

The authors concluded that the addition of a 20-ft "safety zone" did little or nothing to lower the accident rate or to lessen the severity of accidents. It appeared that, with the increase in multiple-vehicle accidents, the number of persons and vehicles involved in accidents may have increased.

A 1974 University of Illinois study (7) evaluated various improvements in roadside safety design policies that had been implemented by the Illinois Department of Transportation over the preceding years. Study sections were selected on four Interstate routes (I-57, 70, 72 and 74) in one highway district in Illinois. The study sections included 211.19 miles of rural freeway. Of this mileage, 90.57 miles were constructed to the latest safety standards with 6:1 embankment slopes and a 30-ft clear recovery zone; 89.15 miles were constructed with 4:1 embankment slopes and had not been upgraded since the adoption of the safety standards. The latter sections had generally clear roadsides, but did not conform to the standards in some respects including the treatment of sign supports, culvert headwalls, and bridge piers and wing walls.

Accident and traffic volume data were obtained from the Illinois Department of Transportation for the period from January 1, 1968, to June 30, 1973. The entire study period was not used for all sections because many of the sections were opened to traffic during the study period. Roadway data were obtained from a review of construction and design plans on microfilm, from a review of straight line diagrams, and from a field inventory of the sections. The field inventory data included: cross-section elements, guardrail length and location; headwall location and offset; and structure locations.

A comparison of accident experience between sections with 6:1 and 4:1 embankment slopes was conducted using the data for three of the four Interstate routes. The accident experience for these sections is given in Table A-3. (Interstate Route 70 was omitted from the analysis, apparently because of the extremely small exposure for 4:1

Table A-2. Accident rates by highway type and roadside design policy from Missouri study (16).

Highway Type:	Interstate		Primary Dual-Lane[a]		Primary Two-Lane[b]		Supplementary[c]	
Roadside Design Policy:	Pre-Safety Zone[d]	Safety Zone[e]	Pre-Safety Zone	Safety Zone	Pre-Safety Zone	Safety Zone	Pre-Safety Zone	Safety Zone
Length of study sections (miles)	75.0	74.9	112.5	120.2	69.3	70.8	170.3	170.8
Exposure in study period (million vehicle-miles)	551.8	564.6	457.2	479.8	196.1	181.4	168.1	168.9
Multiple-vehicle collisions								
Fatal & Injury accident rate[f]	0.051	0.055	0.116	0.106	0.153	0.215	0.184	0.237
PDO accident rate	0.123	0.108	0.210	0.252	0.413	0.485	0.363	0.397
Total accident rate	0.174	0.163	0.326	0.358	0.566	0.700	0.547	0.634
Roadside obstacle collisions								
Fatal & Injury accident rate	0.045	0.044	0.079	0.056	0.117	0.055	0.137	0.112
PDO accident rate	0.124	0.094	0.133	0.079	0.184	0.110	0.143	0.125
Total accident rate	0.169	0.138	0.212	0.135	0.301	0.165	0.280	0.237
Overturning accidents								
Fatal & Injury accident rate	0.047	0.050	0.039	0.044	0.036	0.033	0.054	0.036
PDO accident rate	0.040	0.028	0.044	0.044	0.056	0.050	0.029	0.029
Total accident rate	0.087	0.078	0.083	0.088	0.092	0.083	0.083	0.065
All accidents								
Fatal & Injury accident rate	0.143	0.149	0.234	0.207	0.305	0.303	0.375	0.384
PDO accident rate	0.287	0.230	0.387	0.374	0.654	0.645	0.535	0.551
Total accident rate	0.430	0.379	0.621	0.581	0.959	0.948	0.910	0.935

[a] Four-lane divided highways without access control.

[b] Two-lane highways on state primary system (numbered routes).

[c] Two-lane highways on state supplementary or secondary system (lettered routes).

[d] Pre-safety zones sections generally with embankment slopes 4:1 or steeper.

[e] Safety zone sections generally with 6:1 embankment slopes.

[f] Accidents per million vehicle-miles.

Table A-3. Single-vehicle run-off-road accident experience from University of Illinois study (7).

Route	Total Section Length (miles)		Total Exposure (million vehicle-miles)		Accident Frequency		Accident Rate (accidents per million vehicle-miles)	
	6:1	4:1	6:1	4:1	6:1	4:1	6:1	4:1
I-57	14.20	40.53	105.2	569.6	27	259	0.257	0.455
I-70	49.32	0.41	417.5	7.3	149	2	0.357	0.274
I-72	10.59	5.34	52.0	28.9	17	14	0.327	0.484
I-74	16.46	42.87	63.2	132.2	20	36	0.317	0.272
Total	90.57	89.15	637.9	738.0	213	311	0.333	0.421

sections.) A two-way analysis of variance using the factors slope and route found neither factor to be statistically significant. A similar analysis for multiple-vehicle accident rate found the same result.

The author of the report also made a further comparison of the accident experience for I-70, which consisted almost entirely of 6:1 sections, with the accident rate for the other three routes, which included some sections with steeper slopes and narrow medians in addition to the 4:1 and 6:1 sections. Overall, I-70 had the best safety record with respect to both single-vehicle run-off-road and multiple-vehicle accidents, although there is no indication in the report whether this finding was statistically significant. This finding, contrasted with the lack of statistical significance previously reported, suggests that there are benefits from improving less desirable roadside designs on freeways than either the 4:1 or 6:1 sections evaluated here.

Finally, before-and-after evaluations were conducted at two highway sections with 4:1 embankment slopes where roadside safety appurtenances were improved. The improvements at these sites included installation of breakaway signs, replacement of culvert headwalls, and protection of bridge supports and wing walls with guardrail. An increase in single-vehicle run-off-road accident rate from before to after the improvement was observed at both sites. The injury accident rate increased at one site, but decreased at the other. However, all of these changes were found to be not statistically significant. The total accident frequency and vehicle-miles of exposure in the before/after evaluation were relatively small, so that no reliable conclusions could be drawn, but the authors noted a tendency for increased guardrail involvement in accidents after the improvement.

The results of the three studies comparing 6:1 and 4:1 slopes are summarized in Table A-4. The three studies used varying statistical techniques. Only the Missouri study covered all types of highways. Missouri found no significant difference in accident rates for any type of highway. The University of Illinois study found no significant difference in accident rate for freeways. Minnesota found a statistically significant difference between 4:1 and 6:1 slopes on two-lane highways. Despite these varying conclusions, it is interesting to note that the relative differences in single-vehicle accident rate are quite consistent between the three studies. In both the Minnesota and Missouri studies, the roadside accident rates for two-lane highways are about 60 to 70 percent higher for sections with 4:1 slopes than for sections with 6:1 slopes. In both the University of Illinois and Missouri studies the roadside accident rates for freeways are about 25 to 30 percent higher for sections with 4:1 slopes than for sections with 6:1 slopes. This consistency of findings suggests that, with a larger data base and more sophisticated analysis techniques, the observed effects might be found to be statistically significant.

ROADSIDE IMPROVEMENT PRIORITY STUDIES

A number of studies have been conducted in order to determine the most cost-effective method of improving roadsides with steep slopes and/or fixed objects close to the traveled way.

NCHRP Report 148, "Roadside Safety Improvement Programs on Freeways," (9) established a cost-effectiveness approach for programming roadside safety improvements. The cost-effectiveness approach was used so that the costs and benefits of alternative corrective treatments for freeways could be compared on a common basis. A probabilistic hazard index model was developed to evaluate the effectiveness of roadside safety improvements. Inputs to the model include roadside encroachment rates of vehicles, the percentile distribution of the lateral displacement for encroaching vehicles, the lateral location of the roadside embankments and obstacles, obstacle sizes, and the accident severity associated with embankments and obstacles. The hazard index computed is the expected number of fatal and nonfatal injury accidents per year. The effectiveness of an improvement is estimated by the change in the hazard index from before to after the improvement. The NCHRP Report 148 model has been expanded by Glennon and Wilton (11) to include estimates of the input data for all types of highways. This model has been used in Appendix E to compute expected accident rates for roadside design situations where accident data were not available.

Another roadside hazard model was formulated in a study of single-vehicle fixed-object accidents sponsored by the Maryland State Highway Administration (12). This model is intended to assess the relative hazard posed by various configurations of roadside fixed objects. The five major parameters included in the model are:

1. Distance of the object from the road edge.

Table A-4. Summary of studies comparing 6:1 and 4:1 embankment slopes.

Study	Highway Type	Accident Measure Used	Accident Rate (accidents per million vehicle miles) 6:1	4:1	Statistical Test Used	Conclusions
Minnesota (15)	Two-Lane	Run-off-road accident rate	0.154	0.266	t-Test[a]	Both total and fatal and injury accident rate were significantly lower for 6:1 sections.
Missouri (16)	Primary two-lane[b]	Total accident rate	0.948	0.959	Chi-square	No statistically significant change in overall accident rate or severity. Collisions with roadside obstacles decreased, but collisions between vehicles increased.
		Multiple-vehicle accident rate	0.700	0.547		
		Single-vehicle accident rate[c]	0.248	0.412		
	Freeway[b]	Total accident rate	0.379	0.430		
		Multiple-vehicle accident rate	0.174	0.163		
		Single-vehicle accident rate[c]	0.205	0.267		
University of Illinois (7)	Freeway	Single-vehicle run-off-road accident rate	0.333	0.421	Analysis of Variance	No statistically significant change in single-vehicle run-off-road or multiple-vehicle accident rate.

[a] t-Test using Beherns-Fisher procedure for unequal variances.

[b] See Table A-2 for other highway types.

[c] Combination of overturning and fixed object collision accidents from Table A-2.

2. Prevailing speed of traffic on the roadway.
3. Severity index (proportion of fatal and injury accidents) associated with the object type.
4. Traffic volume.
5. Geometric conditions, including grade, curvature, and locational factors.

The Maryland roadside hazard model has been used by its developers to predict the relative roadside hazard for various combinations of speed, object type, distance, and geometric parameters for a roadway with an ADT of 8,000 vpd. An important finding of this effort was that locations on the outside of horizontal curves were dominant in the group of locations predicted to have the highest roadside hazard. Similarly, in the development of a roadside hazard model for the Michigan Department of State Highways and Transportation, Cleveland and Kitamura (5) found that the severity of fixed object accidents was higher on horizontal curves than on tangents for all types of objects. These findings emphasize the priority that should be placed on roadside design at horizontal curves.

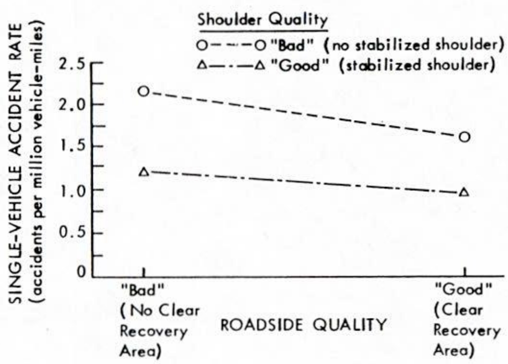
The California Department of Transportation (22) recently completed an evaluation of the cost-effectiveness of fixed object correction programs on nonfreeway facilities. Treatment of four types of fixed objects was considered. These objects were bridge rail ends, utility poles, traffic sign posts, and trees. The study found that accidents involving collisions with the end of a bridge rail had the highest severity of all fixed objects studied. It was recommended that bridge approach guardrail should be installed at all unprotected bridge ends on highways with ADT exceeding 2,000 vpd. The study identified 160 bridges that should receive priority treatment for improvement.

Trees were the most numerous fixed objects found on California roadsides. It was found that the frequency of crashes into the average tree is small, but that individual trees close to the traveled way and some rows of trees may be frequently involved in accidents. A program of systematic investigations at the 25 highest tree accident locations was recommended to determine if countermeasures (such as transplanting, removing with replanting, installing guardrail, and improving delineation) were feasible.

The second most numerous type of fixed object was utility poles. It was established that a blanket program to remove or relocate all roadside utility poles would not be cost-effective. However, a systematic investigation of the cost-effectiveness of moving utility poles was recommended for 67 specific miles of highway having the highest utility pole accident experience.

Finally, the cost-effectiveness of treating traffic sign posts was examined. It was recommended that all large timber or steel sign posts in rural areas be removed, be made breakaway, or, as a last choice, be protected with guardrail. In urban areas, as many signs as possible should be treated, recognizing that breakaway signs may be hazardous in areas where pedestrians are present and that moving large steel traffic signs is not generally cost-effective.

A 1974 study (8) of roadside accidents on Ohio's rural two-lane highways analyzed roadway features and roadside appurtenances that influence single-vehicle accident frequency and/or severity. The study specifically addressed the relative effectiveness of improving roadway width, shoulder quality, and roadside quality. Shoulder quality was defined as the presence or absence of a stabilized shoulder. Roadside quality was defined as the presence or absence of a 12- to 15-ft clear recovery area outside of the shoulder. Figure A-2 shows the results obtained in Ohio for the effect of roadside quality on accident rate compared to the effect of roadway width and shoulder quality. The abscissa in each graph represents the ranges of roadside quality from "bad" (no clear recovery area) to "good" (clear recovery area present); the ordinate is the single-vehicle accident rate per million vehicle-miles. It was concluded from these data that, although there was some small benefit to be obtained from improvement of roadside quality, larger benefits could be obtained from improvement of shoulder quality and roadway width. In particular, an accelerated program of shoulder stabilization was recommended.



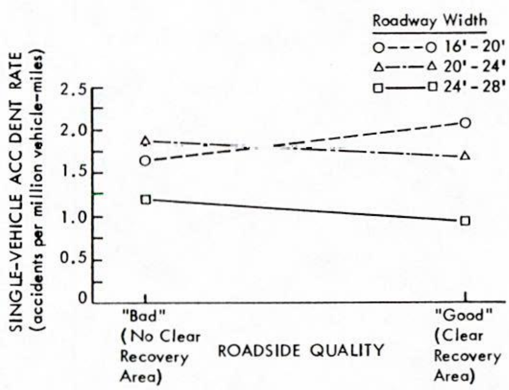


Figure A-2. Relationships between single-vehicle accident rate, roadside quality, and shoulder quality, and roadway width developed by the Ohio Department of Transportation (8).

PRELIMINARY ANALYSIS OF EXISTING ACCIDENT DATA BASES

Two large accident data bases were identified at the beginning of this project as having information that might be used to determine the safety effectiveness of clear recovery areas. These data bases were collected during recent Federal Highway Administration research contracts. The first data base was collected in a study entitled, "Methodology for Reducing the Hazardous Effects of Highway Features and Roadside Objects," performed by Calspan Field Services, Inc. (20, 21). The other data base was collected by Midwest Research Institute in the study, "Effectiveness of Alternative Skid Reduction Measures" (4). On further investigation, it was determined that neither data base was well suited to the needs of this study. The results of a preliminary investigation of each of these data bases are reported in this section.

Calspan Data Base

The goal of the Calspan study was to develop relationships between roadway and roadside factors and accident severity. Consequently, data were obtained on the characteristics of individual accident sites rather than for expanded sections of highway. The lack of exposure data, including descriptions of locations that did not have accidents, limits the applicability of the data base to the present study where measures of both accident rate and accident severity are needed. Nevertheless, some analyses were performed on the Calspan data base to learn anything possible about the influence of clear recovery zones on accident severity.

The Calspan data base contains detailed information on 7,972 single-vehicle accidents that occurred in six states. Many of these accidents occurred on highway sections that fall within the scope of this study, although about 40 percent of these accidents were on roads with ADT below 400. Over 375 data elements on driver, roadway, and roadside characteristics were obtained for each accident.

A computer tape containing the data base was obtained, and, as a first step in analyzing the data base, a reduced data set containing only 50 of the 375 variables studied by Calspan was created. The selected variables included the major descriptors of roadway geometrics, roadside features, and traffic volume. The 50 variables selected are given in Table A-5. Next, accidents on highways with ADT less than 750 vpd and highways whose ADT was unknown were eliminated. Exclusion of highways with low or unknown ADT removed 3,557 accidents from the original 7,972 accidents in the Calspan data base, leaving 4,145 accident cases for further analysis.

Table A-5. Variables retained for analysis of Calspan data base.

Accident State	Outside Shoulder Type
Accident Number	Inside Shoulder Type
Year	Median Type
Month	Median Surface
Date	Median Barrier
Day	Median Barrier Offset
Hour	Outside Shoulder Width
Vehicle Type	Inside Shoulder Width
Driver Injury	Median Width
Severest Occupant Injury	Vertical Curve
Number Occupants	Gradient Description
Light Conditions	Degree of Horizontal Curve
Weather Conditions	Direction of Curve
Road Conditions	Curve Description
Speed	Degree of Curve
Access Control	Length of Curve
Right-of-Way Width	Outside Guardrail
Fencing	Inside Guardrail
Cross-Section Classification	Outside Guardrail Offset
Safety Zone Width	Inside Guardrail Offset
Sideslopes	Utility Pole Type
Height of Cut or Fill	Utility Pole Offset
Roadway Division	Posted Speed Limit
Number of Through Lanes	Design Speed
Number of Auxiliary Lanes	Average Daily Traffic

Cross-tabulations for each variable with ADT were made to determine if the distribution for the sample of 4,415 selected accidents differed from the data base as a whole. This analysis found that, for most variables, the distribution of the reduced data set was not noticeably different from the original data set. One variable, access control, did show a difference in the two groups, probably because most of the sites excluded because of low traffic volume were highways without access control.

The relationship of many of the variables in the Calspan data base to the severity of the single-vehicle accidents, as measured by the severity of driver injury, was tested in a series of two-way contingency tables. The two-way contingency tables were evaluated for independence of the two factors using the chi-square statistic. This statistic is computed as:

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{s} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

where χ^2 = Chi-square statistic;

O_{ij} = Observed frequency for i^{th} level of the first factor and j^{th} level of the second factor;

E_{ij} = Expected frequency for i^{th} level of the first factor and j^{th} level of second factor, assuming independence of the two factors;

r = Number of levels for first factor; and

s = Number of levels for second factor.

For large numbers of observations, this statistic has a chi-square distribution with (r-1) (s-1) degrees of freedom.

A large value of χ^2 is regarded as evidence that the two factors are not independent, but related. A level of significance (α) can be determined from each χ^2value and its associated degrees of freedom. This level of significance decreases with increasing χ^2. The confidence that the factors are related increases with increasing χ^2 and, therefore, the hypothesis of independence is rejected when the value of χ^2 is large.

The results of analysis of the Calspan data are summarized in Table A-6. The resulting values of χ^2 and α are shown in the table for 14 factors whose independence from the severity of driver injury was tested. Eight of the factors tested (e.g., state, road condition, and speed) were statistically significant at the α = 0.05 (95% confidence) level and, therefore, are not independent of the severity of driver injury. The only factor related to roadside design that was significant was cross-section classification. However, the factors of prime interest to this study (safety zone width, side slope ratio, and height of cut or fill) are all not statisticaly significant, indicating that there is little relationship of these factors to the severity of driver injury (i.e., the hypothesis of independence cannot be rejected).

Table A-6. Calspan data analysis results.

Factor Tested vs. Severity of Driver Injury	Chi-Square Value[a]	Level of Significance (α)[a]
1. Reporting State	342.4	0.0001
2. Period of Year (bimonthly)	39.9	0.0051
3. Period of Week	38.7	0.0001
4. Vehicle Type	5.7	0.2244
5. Light Conditions	33.5	0.0299
6. Road Conditions	82.9	0.0001
7. Speed	228.2	0.0001
8. Access Control	16.2	0.0391
9. Cross-Section Classification (cut, fill, bridge, etc.)	48.4	0.0022
10. Safety Zone Width	12.3	0.4204
11. Side Slope Ratio	12.7	0.6912
12. Height of Cut or Fill	35.2	0.3190
13. Gradient Description	26.4	0.3342
14. Curve Description	15.3	0.0527

[a] Large chi-square values and small α levels indicate that the hypothesis of independence should be rejected.

The analysis of the Calspan data base provides no indication that accident severity is influenced by the presence or absence of a clear recovery area, by embankment slope or by embankment height. However, in interpreting these results, it must be recognized that almost 95 percent of the accidents in the Calspan data base occurred at locations without a clear zone, and about 65 percent of the accidents involved collisions with fixed objects. Thus, the sample of clear zone accidents is not large and no comparison of embankment slopes at locations relatively clear of fixed objects is possible.

Skid Reduction Data Base

The second data base analyzed was collected by Midwest Research Institute in the Federal Highway Administration study, "Effectiveness of Alternative Skid Reduction Measures." In addition to skid resistance, the data base describes the geometrics, roadside obstacles, and accidents of approximately 2,300 miles of highway in 15 states. The usefulness of the Skid Reduction data base for this study was limited because it did not contain a reliable measure of embankment slope.

A computer program was developed to process the Skid Reduction data base and obtain roadside obstacle and accident descriptors for 242 miles of freeway, 168 miles of multi-lane nonfreeways, and 1,931 miles of two-lane highway. The accident descriptors compiled by the program include the single-vehicle accident rate and the single-vehicle run-off-road accident rate. The roadside obstacle descriptors compiled by the program include the length of guardrail and bridge rail and the number of roadside obstacles on each section. Because each section considered by the program was exactly 0.5 miles in length, these roadside obstacle descriptors can be interpreted as equivalent to the extent of guardrail and bridge rail and the number of roadside obstacles per unit length. One inconsistency in the data is that roadside obstacles within 30 ft of the traveled way were counted on freeways, but only obstacles within 10 ft of the traveled way were counted on multi-lane nonfreeways and two-lane highways.

The objective of this analysis was to determine the relationship between roadside obstacles and accident rate and severity. In the most simplistic terms, it might be assumed that the presence or absence of roadside obstacles does not influence accident rate, but only accident severity. However, fixed-object collision accidents are more severe and tend to be reported more often than noncollision accidents, so there could be a relationship between reported accident rate and roadside obstacles.

The statistical technique that was used to investigate roadside obstacle relationships is a combination of analysis of variance and regression analysis known as analysis of covariance. Analysis of covariance determines the relationship between a quantitative dependent variable and one or more quantitative independent variables (known as covariates) within cells defined by one or more nonquantitative factors. Regression relationships between the dependent variable and the covariate(s) are developed for each cell of the analysis framework, and the cell-to-cell variations in slopes and intercepts of these regressions are investigated. The dependent variables used in the analyses of the Skid Reduction data base were single-vehicle accident rate and single-vehicle run-off-road accident rate. The independent variables used to define the cells of various analysis frameworks included highway type, traffic volume, lane width, and shoulder width. The covariates included number of roadside obstacles, percentage of length with guardrail or bridge rail, and other geometric variables, for comparative purposes.

Eight complete analyses of covariance were performed. Two of these analyses are illustrated here. Table A-7 presents an analysis using number of roadside obstacles as the covariate, and Table A-8 presents an analysis using percentage of length with guardrail or bridge rail. On the surface, the results of these analyses appear hopeful because both the number of roadside obstacles and the percentage of length with guardrail or bridge rail were found to have a statistically significant relationship to single-vehicle accident rate. However, for a number of reasons that will be described below, these results do not appear too useful.

Although there was a statistically significant relationship between single-vehicle accident rate and the covariates considered, this relationship is not very strong. For example, number of roadside obstacles explains only about 1 percent of the variation in single-vehicle accident rate. This effect is weaker than some other geometric variables that were available, such as number of horizontal curves per unit length.

Despite this weak relationship, if the analysis results are taken literally, the number of roadside obstacles can have a major effect on the single-vehicle accident rate. The common slope of the regression line given in Table A-7 implies the relationship:

$$SVAR = a_o + 0.034\ N$$

where: SVAR = Single-vehicle accident rate, accidents per million vehicle-miles; and

a_o = A constant that depends on highway type and traffic volume; and

N = Number of roadside obstacles per half-mile.

The relationship implies, for example, that the addition of 40 roadside obstacles in a 0.5-mile section could increase the single-vehicle accident rate by 1.36 accidents per million vehicle-miles, or more than the mean single-vehicle accident rate (0.966 accidents per million vehicle-miles). It is probable that the number of roadside obstacles

Table A-7. Analysis of covariance with number of roadside obstacles.

Dependent variable: Single-vehicle accident rate
Factors: Highway type, traffic volume
Covariate: Number of roadside obstacles
Total No. of cases: 4,682

TRAFFIC VOLUME	Highway Type: Freeway	Highway Type: Multi-Lane Nonfreeway	Highway Type: Two-Lane
Under 10,000 vpd			
Over 10,000 vpd			

Common slope for cell regressions = 0.034
r = 0.159 r^2 = 0.025

ANALYSIS OF VARIANCE

Source of Variation	Sum of Squares	DF	Mean Square	F	Statistical Significance at 95% Confidence Level
Main Effects	258.911	3	86.304	23.016	SIG
Highway Type	48.715	2	24.358	6.496	SIG
Traffic Volume	36.560	1	36.560	9.750	SIG
Covariates	187.444	1	187.444	49.989	SIG
Number of Roadside Obstacles	187.444	1	187.444	49.989	SIG
Interactions	8.025	2	4.013	1.070	NS
Highway Type-Traffic Volume	8.025	2	4.013	1.070	NS
Explained	454.383	6	75.73	20.196	SIG
Residual	17,529.855	4,675	3.750		
Total	17,984.238	4,681			

Table A-8. Analysis of covariance with percent of length with guardrail or bridge rail.

Dependent variable: Single-vehicle accident rate
Factors: Highway type, traffic volume
Covariate: Percent of length with guardrail or bridge rail
Total No. of cases: 4,682

TRAFFIC VOLUME	Highway Type: Freeway	Highway Type: Multi-Lane Nonfreeway	Highway Type: Two-Lane
Under 10,000 vpd			
Over 10,000 vpd			

Common slope for cell regressions = 0.008
r = 0.133 r^2 = 0.018

ANALYSIS OF VARIANCE

Source of Variation	Sum of Squares	DF	Mean Square	F	Statistical Significance at 95% Confidence Level
Main Effects	258.911	3	86.304	23.016	SIG
Highway Type	48.715	2	24.358	6.496	SIG
Traffic Volume	36.560	1	36.560	9.750	SIG
Covariates	56.048	1	56.048	14.834	SIG
Percent of Length with Guardrail or Bridge Rail	56.048	1	56.048	14.834	SIG
Interactions					
Highway Type-Traffic Volume	5.270	2	2.635	0.697	NS
Explained	320.230	6	53.372	14.125	SIG
Residual	7,664.008	4,675	3.778		
Total	17,984.238	4,681	3.842		

is acting, in part, as a surrogate for other variables related to the general quality of the geometrics that also influence single-vehicle accident rate. This result illustrates one of the pitfalls that can be encountered in determining the incremental effects of a single geometric element or roadside feature. The accident analysis performed in this study has been structured to avoid this pitfall (see App. D).

Finally, single-vehicle run-off-road accident rate was used as the dependent variable for a reduced data set from six states where this variable was available. These analyses found no statistically significant effect of the percentage of length with guardrail or bridge rail, although the effect of number of roadside obstacles was still statistically significant.

APPENDIX B

DESCRIPTION OF PROJECT DATA BASE

This appendix describes the data base that was assembled in this project to evaluate the differences in accident experience between groups of highway sections with different roadside design policies. The discussion includes the identification of study sections, based to the maximum possible extent on existing data; the collection of data on the roadside design, roadway geometrics, and accident experience from cooperating highway agencies; and the processing of the data obtained. The accident analysis conducted with this data base is described in Appendix D.

IDENTIFICATION OF STUDY SECTIONS

The project data base includes study sections for three highway types (two-lane highways, four-lane freeways, and four-lane divided nonfreeways) and for three roadside design policies (6:1 Clear Zone, 4:1 Clear Zone, and Nonclear Zone). Originally, it was planned to include only two-lane highways and freeways in the study, but data on four-lane divided nonfreeways (i.e., four-lane divided highways without full control of access) were readily available from one state and, therefore, these data were also used. Excluded from the study were highways with urban development and highways with average daily traffic volumes (ADT) less than 750 vehicles per day (vpd). All of the sections had 55-mph speed limits and shoulders at least 4 ft in width. Lane widths were either 11 ft or 12 ft.

Study sections were obtained for each desired highway type and roadside design policy combination except for the Nonclear Zone policy on freeways. Although freeway sections with slopes steeper than 4:1 can be found, extensive roadside safety improvements on freeways over the last 15 years have greatly reduced, if not eliminated, the extent of rural freeways with unprotected roadside fixed objects within the 30-ft clear area. Because it was not possible to determine the accident experience for Nonclear Zone sections on freeways, the development of an estimate for the accident experience of this design is included in Appendix E.

Study sections were classified as 6:1 Clear Zone, 4:1 Clear Zone, or Nonclear Zone on the basis of the roadside design policy used by the highway agency to construct that highway section (illustrated, for example, by the typical cross-section included in the construction plans). Sections constructed under 4:1 and 6:1 Clear Zone policies were distinguished by the nominal or specified design slope within 30 ft of the traveled way. The findings of the field survey in Appendix C illustrate that the roadside slopes actually found in the field for sections built under the 4:1 and 6:1 Clear Zone policies actually vary considerably from the nominal slopes suggested by the names of the policies.

To minimize the data collection effort, it was decided to collect data in states that had existing data bases for evaluating roadside designs. An extensive existing data base was found in Missouri and smaller data bases were found in Illinois and Minnesota. These existing data bases were supplemented and expanded through cooperative efforts between MRI and the state highway agency staffs. Previous studies of clear recovery zone design policies in each of these three states are described in Appendix A. The Missouri data that were used for this study included many of the same highway sections as the previous state study, but the accident data were from a more recent time period. The Illinois data base used for this study included all of the sections from the previous University of Illinois study and many more but, as in Missouri, the accident data were for a more recent time period. The same accident data for a 3-year period used in the previous Minnesota study were also used in this study, but the data base was supplemented with additional highway sections and a fourth year of accident data. The identification of study sections in each state is described below.

Illinois

A 1974 study conducted at the University of Illinois (7) identified 4:1 and 6:1 Clear Zone sections on freeways in one of the nine districts of the Illinois Department of Transportation. The data from the Dotson study included 90.57 miles of freeway with a 6:1 Clear Zone design and 89.15 miles with a 4:1 Clear Zone design. Through the cooperation of the Illinois Department of Transportation, the authors identified freeway sections with 4:1 and 6:1 Clear Zone designs in seven of the other eight highway districts and two-lane highway sections constructed under all three roadside design policies throughout the state.

A preliminary screening of candidate freeway sections was conducted by determining the date the freeway was constructed. In general, freeways in Illinois constructed prior to 1967 have 4:1 embankment slopes (many freeways constructed with 4:1 slopes prior to 1967 did not originally meet current safety standards concerning fixed objects, but have since been upgraded), whereas freeways constructed since 1969 have 6:1 Clear Zone designs. The years 1967 and 1968 were a transition period when both 4:1 and 6:1 design policies were in use. Candidate two-lane highway sections were determined from lists of widening and resurfacing projects constructed in the late 1960's and early 1970's; some of these projects included flattening of slopes and removal of fixed objects, while others did not modify the roadside slopes and fixed objects in any way. In each case, the original construction plans and typical cross-sections (and plans for any more recent upgrading) were reviewed, and selected sections were visited in the field to classify each study section as 6:1 Clear Zone, 4:1 Clear Zone, or Nonclear Zone. The review of the construction plans on microfilm was performed by the MRI project staff with the assistance of the Illinois DOT Division of Design.

The total mileage of study sections on freeways in Illinois is 733 miles (366 miles on 6:1 Clear Zone sections and 367 miles on 4:1 Clear Zone sections). The total mileage on two-lane highways was 262 miles (108 miles on 6:1 Clear Zone sections, 44 miles on 4:1 Clear Zone sections, and 110 miles on Nonclear Zone sections). The total number of study sections in Illinois is 222, with an average length of about 4.5 miles. The boundaries of these sections were defined by the project limits for the original construction by major points of change in ADT, such as intersections or interchanges, and by county lines.

Minnesota

Study sections for 4:1 and 6:1 Clear Zone design policies on two-lane highways in Minnesota were available from a previous evaluation of roadside slopes by the Minnesota Department of Transportation (15). This study included 215 miles of two-lane highway with 6:1 slopes and 234 miles with 4:1 slopes. Most of this mileage was suitable for use in the current study. Candidate study sections for freeways and for two-lane highways without clear zones were identified by the district offices of the Minnesota Department of Transportation using criteria established by MRI. The sections recommended by the district offices were reviewed using the Minnesota DOT photolog to make the final selections.

The total mileage of study sections on freeways in Minnesota is 609 miles (268 miles for 6:1 Clear Zone sections and 341 miles for 4:1 Clear Zone sections). The total mileage on two-lane highways is 705 miles (208 miles on 6:1 Clear Zone sections, 218 miles on 4:1 Clear Zone sections, and 279 miles on Nonclear Zone sections). The number of study sections in Minnesota is 124, with an average section length of about 10.6 miles.

Missouri

The largest existing data base available to the study was from Missouri. The Missouri Department of State Highways and Transportation had assembled accident data for an extensive set of roadways including 1,181 miles of two-lane highways (361 miles of 6:1 Clear Zone sections and 820 miles of 4:1 Clear Zone sections); 479 miles of four-lane freeways (191 miles of 6:1 Clear Zone sections and 288 miles of 4:1 Clear Zone sections); and, 381 miles of four-lane divided nonfreeways (177 miles of 6:1 Clear Zone sections and 204 miles of 4:1 Clear Zone sections).

The data base assembled by Missouri did not contain Nonclear Zone sections. Criteria for these sections were established by MRI, and at our request Missouri identified 222 miles of suitable Nonclear Zone sections on two-lane highways and 28 miles on four-lane divided nonfreeways.

The four-lane divided nonfreeway sections, which were studied only in Missouri, included sections consisting of the roadways in both directions of travel and sections which included only the roadway in one direction of travel. The latter situation occurred for many four-lane divided nonfreeways because the roadways in each direction were built at different times under different roadside design policies. In order to be comparable to the two-way sections, the length and traffic volume for one-way sections were converted to an equivalent two-way length (half of the one-way length) and an equivalent two-way traffic volume (twice the one-way volume). The total exposure (vehicle-miles of travel) for one-way sections is not affected by this conversion. The problem of one-way sections did not arise on freeways or on two-lane highways.

There were a total of 490 study sections in Missouri. The average length of these sections was approximately 4.7 miles.

COLLECTION OF ACCIDENT, GEOMETRIC, AND TRAFFIC DATA

After the study sections were identified, and the roadside design policy of each section was determined, the next step was to select a study period for each section and to obtain data on its traffic accident experience, roadway geometrics, and traffic volumes. These data were obtained with the cooperation of the state highway agencies in Illinois, Minnesota, and Missouri and entered into the project data base. The collection of each type of data is discussed in the following.

Study Period

A study period, for which both traffic accident and volume data were available, was selected for each study section. In general, a study period of 5 years from January 1, 1975, to December 31, 1979, was used for sections in Illinois and Missouri. A 4-year study period from January 1, 1977, to December 31, 1980, was used for sections in Minnesota.

If any study section was either not open to traffic during a given calendar year or was undergoing major construction activity, that year was excluded from the study. For example, on a 6:1 Clear Zone freeway section first opened to traffic during 1977, the study period would not include the years 1975, 1976, and 1977. Each calendar year was either used in its entirety or not used at all. The Minnesota sections had been prescreened to assure that all four calendar years of data could be used for each section. The average length of the study period was 4.1 years in Illinois, 4.6 years in Missouri, and 4.0 years in Minnesota.

The study period for sections in Minnesota overlapped the study period used in the previous Minnesota DOT study for 3 of the 4 years. Thus, for 6:1 and 4:1 Clear Zone sections on two-lane highways, the same data as used in the previous study were used again. The data for freeway sections and Nonclear Zone sections on two-lane highways were newly acquired. The study period used for sections in Missouri and Illinois did not overlap with the study period for the previous studies at all.

Accident Experience

A record of each traffic accident that occurred on each study section during the study period was obtained from the cooperating states. As a minimum, the following data were obtained for each accident:

- Location
- Date
- Severity
- Number of vehicles involved
- Run-off-road involvement
- Fixed object collision involvement
- Intersection or ramp involvement

The location and date were used to assure that each accident was on the study section and within the study period. The severity data were used to determine accident severity distributions and fatal and injury accident rates. The number of vehicles involved was used to distinguish single- and multiple-vehicle accidents. The run-off-road involvement was used to distinguish accidents involving the roadside from those where the involved vehicles remained on the roadway; accidents involving the roadsides on both the right and left side of the road were considered, but no attempt was made to distinguish on which side the errant vehicle ran off the road. Fixed object collision involvement was used to classify single-vehicle run-off-road accidents as either fixed-object collision or noncollision accidents. Finally, intersection or ramp involvement was used to identify accidents related to, or occurring at, an intersection or ramp.

The accident data obtained from the Missouri Department of Highways and Transportation were coded from hard copy accident reports by the Department staff. The accident data for Illinois and Minnesota were provided directly from their computerized accident records systems. In all cases, these data were provided to MRI in machine-readable form (on magnetic tape).

Geometric and Traffic Data

Geometric and traffic data were obtained for each highway section. The geometric data collected for all highway sections included lane width (or, in some cases, the total width of the traveled way) and outside shoulder width. For divided highways, the inside (median) shoulder width and the median width were also obtained. The traffic data collected included the roadway speed limit and average daily traffic volume as determined by the state's regular volume counting program.

Traffic and geometric data for sections in Missouri were determined for each section by state highway personnel and provided to MRI.

For sections in Illinois lane widths, shoulder widths, and median widths were obtained by MRI personnel during the section identification process. Traffic volume data for Illinois were taken from ADT maps for 1975, 1977, and 1979. Traffic volumes for 1976 and 1978 were obtained by linear interpolation.

Both geometric and traffic data for sections in Minnesota were obtained from the computerized roadway information system maintained by the state. These data were supplemented with traffic volume data from a Minnesota ADT map.

PROCESSING OF PROJECT DATA BASE

A series of computer programs were written to convert the raw accident, geometric, and traffic data obtained from the states into a form suitable for statistical analysis. Separate, but similar, programs were required for the data from each state, because the accident data were received in different formats.

The processing program for each state had two separate input files: the accident file obtained from the state and a section description file prepared by MRI. The minimum contents of the accident file were described in the previous section. The section description file contained one record describing the location, roadway geometrics, roadside design, and traffic volumes for each section including: route, county, milepost limits, length, lane width, outside shoulder width, inside shoulder width, median width, roadside design policy, and average daily traffic volume for each year of the study period. The section description data were used to screen the accident data and select only those accidents on the study section and within the study period.

The output of the processing program for each state was a file containing location, roadway geometrics, roadside design, traffic volume, and accident data for individual study sections. This output file contained one record for each study section for each year of the study period; thus, the accident experience of a section for one year constituted one observation in the statistical analysis. The section description data contained in the output file were the same as in the input file. The output file contained data on the annual frequency of the following types of accidents.

- Total accidents
- Multiple-vehicle accidents
- Single-vehicle accidents
- Single-vehicle run-off-road accidents
- Single-vehicle run-off-road noncollision accidents
- Single-vehicle run-off-road fixed-object accidents

The accident frequencies for each type of accident were broken down into three accident severity classes: fatal accidents, injury accidents, and property-damage-only accidents.

PROJECT DATA BASE SUMMARY

The physical extent and traffic exposure for the project study sections are summarized in Table B-1 and the accident experience in the data base is summarized in Table B-2. The section length, traffic exposure, and accident data are broken down by highway type, roadside design policy, and state.

Table B-1 shows the number of study sections in each category, the average duration of the study period, the average ADT of the sections, the total length, and the total travel (exposure) on the study sections during the study period. Missing rows in the tables illustrate that there are no study sections representing the Nonclear Zone design policy on freeways and that four-lane divided nonfreeway sections were evalauted in Missouri only.

There were over 41 billion vehicle-miles of travel on the study sections. Although there were 2,370 miles of two-lane highway and 1,820 miles of freeway in the data base, there was over 2.5 times more exposure on the freeway study sections because of higher traffic volumes.

The ADT data show that for all highway types the traffic volumes were higher on 4:1 sections than on 6:1 sections. It is expected that this is because many highway sections built or rebuilt under the 4:1 design policies in the early 1960's had relatively high traffic volumes; those sections with less urgent traffic demands were constructed or reconstructed later when 6:1 design policies had been implemented.

Table B-1. Summary of project study sections.

Highway Type	Roadside Design Policy	State	No. of Study Sections	No. of Section-Years	Average Duration of Study Period (years)	Average[a] ADT (vpd)	Total[b] Length (miles)	Total Travel in Study Period (million veh-miles)
Two-Lane	6:1 Clear Zone	Illinois	25	97	3.88	3,006	107.40	457.28
		Minnesota	28	112	4.00	1,791	208.49	545.16
		Missouri	99	442	4.46	1,950	360.60	1,144.67
			152	651	4.28	2,031	676.49	2,147.11
	4:1 Clear Zone	Illinois	8	37	4.63	2,578	44.40	193.43
		Minnesota	26	104	4.00	2,415	217.59	767.13
		Missouri	172	845	4.91	2,922	820.22	4,295.86
			206	986	4.79	2,778	1,082.21	5,256.42
	Nonclear Zone	Illinois	21	84	4.00	3,255	110.17	523.57
		Minnesota	35	140	4.00	2,067	279.38	843.39
		Missouri	35	163	4.65	3,282	222.09	1,237.14
			91	387	4.25	2,745	611.64	2,604.10
TWO-LANE TOTALS			449	2,024	4.51	2,564	2,370.34	10,007.63
Freeway	6:1 Clear Zone	Illinois	72	279	3.88	8,720	366.02	4,520.45
		Minnesota	11	44	4.00	8,169	268.30	3,200.05
		Missouri	13	55	4.23	7,547	191.23	2,228.15
			96	378	3.93	8,401	825.55	9,948.65
	4:1 Clear Zone	Illinois	96	417	4.34	11,427	367.16	6,646.07
		Minnesota	24	96	4.00	8,947	341.25	4,457.63
		Missouri	31	154	4.97	9,720	287.86	5,075.78
			151	667	4.42	10,066	996.27	16,179.48
	Nonclear Zone	Illinois	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--
		Missouri	--	--	--	--	--	--
FREEWAY TOTALS			247	1,045	4.23	9,289	1,821.82	26,128.13
Four-Lane Divided (Nonfreeway)	6:1 Clear Zone	Illinois	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--
		Missouri	56	207	3.70	7,212	176.73	1,721.38
			56	207	3.70	7,212	176.73	1,721.38
	4:1 Clear Zone	Illinois	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--
		Missouri	69	309	4.48	8,677	204.30	2,898.78
			69	309	4.48	8,677	204.30	2,898.78
	Nonclear Zone	Illinois	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--
		Missouri	15	64	4.27	6,645	28.05	290.49
			15	64	4.27	6,645	28.05	290.49
FOUR-LANE DIVIDED TOTALS			140	580	4.14	7,944	409.08	4,910.65
ENTIRE DATA BASE			836	3,649	4.36	5,605	4,601.24	41,046.41

[a] Equivalent two-way ADT for one-way portions of four-lane divided nonfreeways.

[b] Equivalent two-way mileage for one-way portions of four-lane divided nonfreeways.

Table B-2. Summary of accident experience in project data base.

Highway Type	Roadside Design Policy	State	All Accidents[a]				Multiple-Vehicle Accidents[a]				Single-Vehicle Accidents			
			F	I	PDO	TOT	F	I	PDO	TOT	F	I	PDO	TOT
Two-Lane	6:1 Clear Zone	Illinois	12	134	270	416	6	62	98	166	6	72	172	250
		Minnesota	7	96	278	381	4	44	120	168	3	52	158	213
		Missouri	19	256	450	725	13	128	148	289	6	128	302	436
			38	486	998	1,522	23	234	366	623	15	252	632	899
	4:1 Clear Zone	Illinois	7	85	256	348	1	40	131	172	6	45	125	176
		Minnesota	25	210	482	717	17	88	206	311	8	122	276	406
		Missouri	131	1,058	1,923	3,112	79	384	669	1,132	52	674	1,254	1,980
			163	1,353	2,661	4,177	97	512	1,006	1,615	66	841	1,655	2,562
	Nonclear Zone	Illinois	23	391	664	1,078	9	133	198	340	14	258	466	738
		Minnesota	21	405	792	1,218	13	137	335	485	8	268	457	733
		Missouri	37	527	789	1,353	28	239	333	600	9	288	456	753
			81	1,323	2,245	3,649	50	509	866	1,425	31	814	1,379	2,224
TWO-LANE TOTALS			282	3,162	5,904	9,348	170	1,255	2,238	3,663	112	1,907	3,666	5,685
Freeway	6:1 Clear Zone	Illinois	36	887	1,726	2,649	18	385	589	992	18	502	1,137	1,657
		Minnesota	20	335	977	1,332	7	128	335	470	13	207	642	862
		Missouri	21	254	580	855	8	110	194	312	13	144	386	543
			77	1,476	3,282	4,836	33	623	1,118	1,774	44	853	2,165	3,062
	4:1 Clear Zone	Illinois	77	1,667	3,171	4,915	47	671	1,109	1,827	30	996	2,062	3,088
		Minnesota	22	591	2,041	2,654	12	202	615	829	10	389	1,426	1,825
		Missouri	69	792	1,651	2,512	20	278	572	870	49	514	1,079	1,642
			168	3,050	6,863	10,081	79	1,151	2,296	3,526	89	1,899	4,567	6,555
	Nonclear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	--	--	--	--	--	--	--	--	--	--	--	--
			--	--	--	--	--	--	--	--	--	--	--	--
FREEWAY TOTALS			245	4,526	10,146	14,917	112	1,774	3,414	5,300	133	2,752	6,732	9,617
Four-Lane Divided (Nonfreeway)	6:1 Clear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	11	227	475	713	7	99	161	267	4	128	314	446
			11	227	475	713	7	99	161	267	4	128	314	446
	4:1 Clear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	31	555	1,177	1,763	12	176	447	635	19	379	730	1,128
			31	555	1,177	1,763	12	176	447	635	19	379	730	1,128
	Nonclear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	5	129	223	357	3	31	76	110	2	98	147	247
			5	129	223	357	3	31	76	110	2	98	147	247
FOUR-LANE DIVIDED TOTALS			47	911	1,875	2,833	22	306	684	1,012	25	605	1,191	1,821
ENTIRE DATA BASE			574	8,599	17,925	27,098	304	3,335	6,336	9,975	270	5,264	11,589	17,123

Highway Type	Roadside Design Policy	State	Single-Vehicle Run-Off-Road Accidents				Single-Vehicle Run-Off-Road Noncollision Accidents				Single-Vehicle Run-Off-Road Fixed Object Collision Accidents			
			F	I	PDO	TOT	F	I	PDO	TOT	F	I	PDO	TOT
Two-Lane	6:1 Clear Zone	Illinois	5	62	113	180	3	23	46	72	2	39	67	108
		Minnesota	2	36	40	78	0	23	20	43	2	13	20	35
		Missouri	5	103	123	231	5	91	106	202	0	12	17	29
			12	201	276	489	8	137	172	317	4	64	104	172
	4:1 Clear Zone	Illinois	4	38	72	114	0	12	19	31	4	26	53	83
		Minnesota	5	76	88	169	2	47	34	83	3	29	54	86
		Missouri	39	606	690	1,335	33	542	588	1,163	6	64	102	172
			48	720	850	1,618	35	601	641	1,277	13	119	209	341
	Nonclear Zone	Illinois	10	233	344	587	2	93	99	194	8	140	245	393
		Minnesota	5	176	230	411	2	86	77	165	3	90	153	246
		Missouri	7	275	312	594	7	271	302	580	0	4	10	14
			22	684	886	1,592	11	450	478	939	11	234	408	653
TWO-LANE TOTALS			82	1,605	2,012	3,699	54	1,188	1,291	2,533	28	417	721	1,166
Freeway	6:1 Clear Zone	Illinois	15	440	756	1,211	9	276	410	695	6	164	346	516
		Minnesota	6	143	291	440	5	82	141	228	1	61	150	212
		Missouri	11	122	190	323	11	116	177	304	0	6	13	19
			32	705	1,237	1,974	25	474	728	1,227	7	231	509	747
	4:1 Clear Zone	Illinois	22	893	1,524	2,439	6	485	771	1,262	16	408	753	1,177
		Minnesota	7	263	683	953	5	140	263	408	2	123	420	545
		Missouri	42	482	792	1,316	33	424	659	1,116	9	58	133	200
			71	1,638	2,999	4,708	44	1,049	1,693	2,786	27	589	1,306	1,922
	Nonclear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	--	--	--	--	--	--	--	--	--	--	--	--
			--	--	--	--	--	--	--	--	--	--	--	--
FREEWAY TOTALS			103	2,343	4,236	6,682	69	1,523	2,421	4,013	34	820	1,815	2,669
Four-Lane Divided (Nonfreeway)	6:1 Clear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	4	109	150	263	4	101	119	224	0	8	31	39
			4	109	150	263	4	101	119	224	0	8	31	39
	4:1 Clear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	15	348	448	811	13	310	369	692	2	38	79	119
			15	348	448	811	13	310	369	692	2	38	79	119
	Nonclear Zone	Illinois	--	--	--	--	--	--	--	--	--	--	--	--
		Minnesota	--	--	--	--	--	--	--	--	--	--	--	--
		Missouri	2	95	97	194	2	93	92	187	0	2	5	7
			2	95	97	194	2	93	92	187	0	2	5	7
FOUR-LANE DIVIDED TOTALS			21	552	695	1,268	19	504	580	1,103	2	48	115	165
ENTIRE DATA BASE			206	4,500	6,943	11,649	142	3,215	4,292	7,649	64	1,285	2,651	4,000

[a] Excluding multiple-vehicle intersection-related accidents.

Study sections in Missouri constitute the majority of the two-lane highway sections, with almost 60 percent of the mileage. The mileages of freeway sections are more balanced, but Illinois freeways constitute about 40 percent of the total.

Table B-2 shows the accident experience for each study section category, including all of the accident types and severity levels determined by the processing programs. Multiple-vehicle accidents related to intersections and interchange ramps have been excluded from these totals.

In total, the study sections experienced 27,098 accidents during the study period. About 60 percent of the accidents on two-lane highways were single-vehicle accidents, whereas nearly 65 percent of the freeway accidents were single-vehicle accidents.

Single-vehicle run-off-road accident experience was the primary measure of effectiveness in the study. There were 11,649 such accidents in the project data base: 3,694 on two-lane highways, 6,682 on freeways, and 1,268 on four-lane divided nonfreeways. Single-vehicle run-off-road accidents constitute about 43 percent of the total nonintersection-related accident experience on the highways studied.

The analysis of the accident data is discussed in detail in Appendix D.

APPENDIX C

FIELD SURVEY PROCEDURE, DEFINITIONS, AND ANALYSIS

INTRODUCTION

A field survey was conducted to compare the design characteristics of highway sections in the project data base constructed under three different roadside design policies: 6:1 Clear Zone, 4:1 Clear Zone, and Nonclear Zone. The field survey covered a randomly selected sample of highway sections for each roadside design policy and each highway type: two-lane highways, four-lane freeways, and four-lane divided nonfreeways.

The purpose of the field survey was: (1) to verify some of the geometric data obtained in the office from each state; (2) to characterize the actual roadside designs resulting from each design policy (as applied to the actual terrain in the field) including the distribution of cut and fill sections, embankment slope, and fixed objects; (3) to establish that the highways in each category are comparable in all major respects except for roadside design (or, if they differ, to establish the nature and extent of the difference); and (4) to provide data on typical cross-sections for use in developing design examples in Appendix F. In fulfillment of the first objective, no major discrepancies between the office data and field survey data were found. The analysis to achieve the second and third objectives is discussed in the following.

One hundred and thirty sites were selected at random for inclusion in the field survey. Each site consisted of 2 miles of highway where field measurements were made at a series of 10 points spaced at 0.2-mile intervals along one side of the roadway. This series of 10 measurement points at a site is shown in Figure C-1. Because the series of 10 measurement points was repeated at a total of 130 sites, field survey measurements were made at a total of 1,300 distinct points on the roadside.

The sample of field survey sites was stratified by highway type and roadside design policy, as shown in Table C-1, to assure that a sample of appropriate size for statistical testing would be available for each highway type-roadside design policy combination. Twenty survey sites (10-point sequences) were selected for each highway type and roadside design policy combination on two-lane highways and freeways. Four-lane divided nonfreeways were considered less critical to the study; the total mileage of four-lane divided nonfreeways was less than for either of the other highway types and they were all located in one state rather than three. For these reasons, only 10 survey sites were selected for each roadside design policy on four-lane divided nonfreeways.

The exact location of the starting point for each site and the direction of travel were predetermined in the office by a random selection process. A listing of the cumulative mileages of study sections was prepared for each highway type and roadside design policy combination. Each survey site was chosen by a randomly generated starting point from the cumulative mileage listing and a randomly selected direction of travel. The starting point was shifted only if the 2-mile section of roadway to be measured overlapped another selected survey site in the same direction of travel or ran off the end of the section. In this selection procedure, the probability of a survey site being located on a particular study section is directly proportional to the length of that section, and each 2-mile section in a given highway type and roadside design policy combination

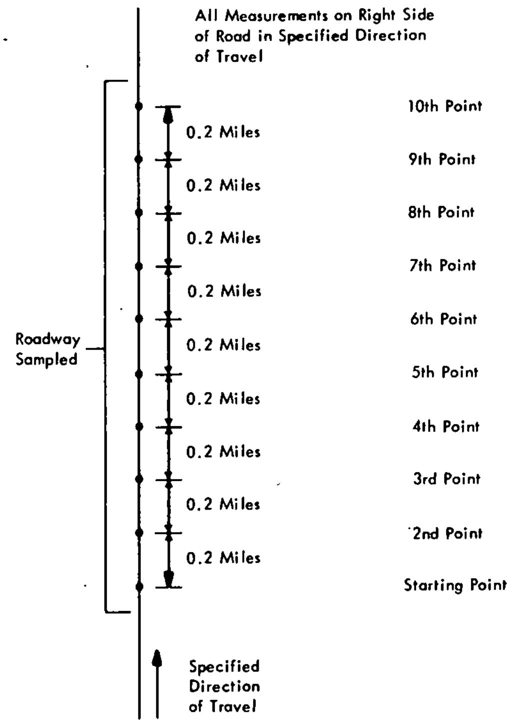


Figure C-1. Measurement point sequence.

Table C-1. Sampling plan for field survey.

Roadside Design Policy	Highway Type: Two-Lane	Freeway	Four-Lane Nonfreeway
6:1 Clear Zone	20 sites 200 survey points	20 sites 200 survey points	10 sites 100 survey points
4:1 Clear Zone	20 sites 200 survey points	20 sites 200 survey points	10 sites 100 survey points
Nonclear Zone	20 sites 200 survey points	-[a]	10 sites 100 survey points

[a] No freeway sections without clear zones are included in the project data base.

had an approximately equal chance of being selected. Thus, the sample for each highway type and roadside design policy combination is statistically representative of all sections in the data base within that category.

Some changes to the predetermined locations of the 10 measurement points for each site were necessary in the field. For example, if one of the predetermined points fell exactly at an intersection, a driveway, a curb, or an overpass, the field crew was authorized to move that one measurement point up to 300 ft to find a more suitable point to make a roadside design measurement. At interchanges, the 10-point sequence was interrupted and resumed beyond the interchange.

Field survey measurements were made by a two-person crew traveling in a 1/2-ton van equipped with a fifth-wheel for accurate distance measurement. The field crew members were not highway engineers, but most had previous experience in other types of field surveys. Prior to the start of the field survey, the crew members were trained, both in the office and on actual study sections that were not part of the randomly selected sample. The quality of the survey data was monitored carefully to ensure consistency between crews. The survey work was completed in five weeks with two, 2-member crews working in separate locations.

The field measurements made at each survey point are given in Table C-2. The field survey data were recorded manually in the field and were later keypunched and processed by computer. The remainder of this appendix describes each data item, the procedures used to collect it, the codes used to record it, and the results of the data analysis.

Table C-2. Data elements recorded in field survey.

Location Identification

- Section number
- State
- County
- Route
- Milepost, log mile or reference point
- Direction of travel
- Highway type
- Roadside design policy

Roadway Geometrics

- Horizontal curvature (tangent/curve less than or equal to 3°/curve greater than 3°)
- Lane width (LW)[a]
- Outside shoulder width (OSW)
- Outside shoulder material
- Inside (median) shoulder width
- Inside (median) shoulder material
- Median width

Roadside Design

Cut Sections

- Slope of foreslope (FS)
- Length of foreslope (FL)
- Ditch type
- Ditch width (DW)
- Slope of backslope (BS)
- Length of backslope (BL)
- Height of cut (backslope height) (BH)

Fill Sections

- Slope of foreslope (S1, S2, S3)
- Length of foreslope (L1, L2, L3)
- Height of fill (foreslope height) (FH)

Fixed Objects

- Number and type of point objects within 10 ft of traveled way.
- Length and type of continuous objects within 10 ft of traveled way.
- Number and type of point objects within 20 ft of traveled way.
- Length and type of continuous objects within 20 ft of traveled way.
- Number and type of point objects within 30 ft of traveled way.
- Length and type of continuous objects within 30 ft of traveled way.
- Number and type of point objects within 50 ft of traveled way.
- Length and type of continuous objects within 50 ft of traveled way.

[a] Symbols refer to data elements illustrated in Figures C-2 and C-3.

FIELD SURVEY DATA DEFINITIONS

The field survey data items are discussed below in six distinct categories: location identification; roadway geometrics; general roadside design; detailed roadside design for cut sections; detailed roadside design for fill sections; and fixed objects.

Location Identification

The data items recorded to identify the location of each of the 1,300 measurement points in the survey were: section number (an arbitrary, identification number assigned by MRI); state; county; route number; milepost, log mile or other reference mileage; and direction of travel. The highway type (two-lane highway/freeway/four-lane divided nonfreeway) and roadside design policy (6:1 Clear Zone/4:1 Clear Zone/Nonclear Zone) were also recorded to identify the cell of the sampling plan to which each measurement belonged.

Roadway Geometrics

The roadway geometrics at the measurement point were recorded including: horizontal curvature; lane width; outside shoulder width; outside shoulder material; inside shoulder width; inside shoulder material; and median width. It was found that, in many cases, only the horizontal curvature varied throughout the 10-point sequence of measurement points at a given 2-mile section. Each roadway geometric element is discussed below.

Horizontal Curvature

Each measurement site was classified in the field as being located on tangent or a horizontal curve. Curves were also classified as flat (less than or equal to 3° curvature) or sharp (greater than 3° curvature) based on visual estimates and the measurement of 100-ft chord offsets. However, the visual estimates were found to be unreliable; therefore, the classification of horizontal curves by degree of curvature was not used.

Lane Width

Lane width was measured to the nearest foot. On roadways without a well-defined center line, the total pavement width was measured and divided by two. For safety reasons, the survey crews were instructed not to enter the traveled way; the lane width measurements, therefore, were made with an optical rangefinder.

Outside Shoulder Width

Shoulder width was determined to the nearest foot with a measurement wheel, similar to a bicycle wheel with a revolution counter. For paved or aggregate shoulders, the shoulder width was well defined and easily measured; however, for grass shoulders, the outside edge of the shoulder was not clearly defined because of rounding between the grass shoulder and the foreslope. Shoulder width measurements on grass shoulders involved judgments by the field survey crew and were often as much as 2 ft wider than the shoulder widths indicated in highway agency research.

Outside Shoulder Material

The shoulder material was recorded in six categories: paved, gravel, bituminous mixture, stabilized, grass, and other.

Inside Shoulder Width

The width of the inside (or median) shoulder on divided highways was measured to the nearest foot using the optical rangefinder.

Inside Shoulder Material

The same six categories were used for inside (or median) shoulder material as for outside shoulder material.

Median Width

The width of the median was measured for divided highways using the optical rangefinder from the outside shoulder of the highway. For safety reasons, the survey crews were instructed not to cross the traveled way to enter the median.

General Roadside Design

The general roadside design category consists of a single data item. The roadside design at the measurement point was classified as a cut section, a fill section, or as a guardrail or bridge rail section. A cut section was defined as a location where the roadway is lower than the surrounding terrain. In contrast, a fill section is a location where the roadway is higher than the surrounding terrain. Detailed data collected on the roadside design for cut and fill sections are described in the next two sections.

A location was classified as a guardrail section if guardrail was present at the measurement point. The general roadside design (cut or fill) behind a guardrail was not recorded because the guardrail prevents errant vehicles from traversing this area. Bridge rail was treated in a manner similar to guardrail.

Detailed Roadside Design for Cut Sections

The roadside design data obtained for cut sections included foreslope length and slope; depth of ditch; ditch shape and width; backslope length and slope; and backslope embankment height. Figure C-2 represents a typical cut section and illustrates the design elements that were measured or computed for the measured data. The measurements were made exactly at the 0.2-mile-interval measurement points unless this point had to be moved by the field crew for one of the reasons discussed earlier in this appendix. Each design element is discussed below.

Foreslope Length and Slope

The foreslope for a cut section extends from the outside edge of the shoulder to the ditch. The length of the foreslope was measured along the slope with a measurement wheel. The slope of foreslope was measured by placing either a 5-ft or 10-ft long, 2 in. x 4 in. wooden beam along the slope and determining the angle of its slope to the horizontal with a carpenter's protractor. (A carpenter's protractor is a liquid-filled device with a pointer that, when placed on a surface, indicates the angle between the surface and the horizontal; it might be used by a carpenter to determine the slope of a roof, for example.) The cotangent of this angle is the embankment slope expressed in the more familiar ratio form; for example, an angle of 9.5° corresponds to a 6:1 embankment slope (i.e., cot 9.5° ≅ 6).

Depth of Ditch

The depth of ditch refers to the vertical rise from the toe of the foreslope (or bottom of the ditch) to the outside edge of the shoulder. This distance was not measured in the field, but was computed from the foreslope slope and length as:

$$DD = FL \sin \alpha$$

where DD = Depth of ditch, feet;

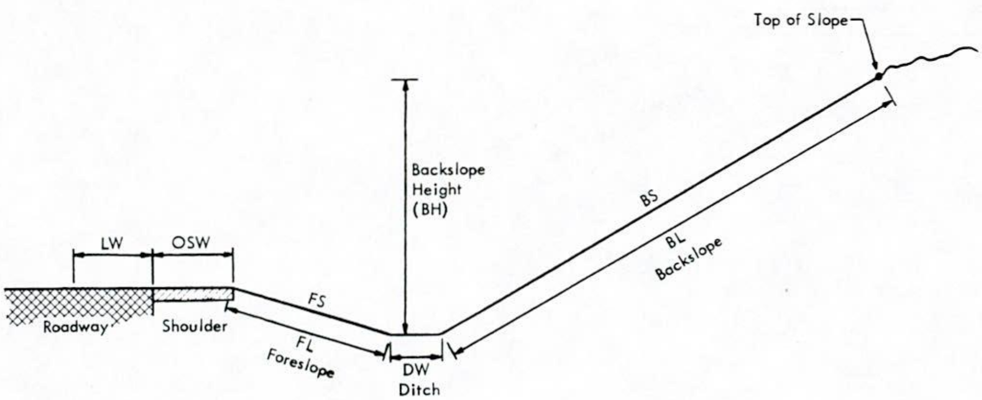
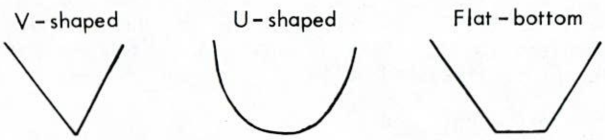


Figure C-2. Field survey data elements for a typical cut section.

FL = Foreslope length, feet; and
α = Angle between foreslope embankment and horizontal.

Ditch Shape. The shape of the ditch was classified into one of the three categories: V-shaped; U-shaped, and flat-bottom. The following sketches illustrate these shapes:



The ditch width was measured (for flat-bottom ditches only) using the measuring wheel.

Backslope Slope, Length and Height

The backslope for a cut section is the embankment extending up from the ditch to the natural ground line (top of the slope). The length of the backslope was measured along the slope with a measurement wheel. The slope of the backslope was measured with the same combination of a 2 in. x 4 in. beam and a carpenter's protractor that was used to measure foreslopes. The backslope height was measured directly for most backslopes using a hand level and a range pole graduated in 1-ft increments. For backslopes whose height was too great to measure effectively in this manner, the backslope height was computed from the length and slope.

Detailed Roadside Design for Fill Sections

The roadside design data obtained for fill sections included the foreslope length and slope for as many as three distinct segments of the embankment and the total embankment height. Figure C-3 represents a typical fill section and illustrates the design elements that were measured. These measurements were made exactly at the 0.2-mile-interval measurement points. Each design element is discussed below.

Foreslope Length and Slope

The foreslope of a fill section is the embankment extending from the outside edge of the shoulder down to the natural ground line (toe of the slope). The foreslope length was measured along the slope with a measurement wheel. The slope of the foreslope was measured with a 2 in. x 4 in. beam and a carpenter's protractor.

Many fill embankments cannot be represented by a single slope. For example, it is not unusual to have a break point, where the slope increases, at a distance of 30 ft from the traveled way. The field survey procedure allowed each fill embankment to be represented as realistically as possible using one, two, or three separate segments. Where more than one segment was used, separate measurements of length and slope were made for each segment.

Fill Embankment Height

The fill embankment height is the vertical rise from the toe of the foreslope to the outside edge of the shoulder. This height was measured in the field using a hand level and a range pole graduated in 1-ft increments.

Fixed Objects

Fixed objects were recorded in the field survey for a 200-ft interval extending 100 ft in either direction from the point where slope measurements were made. A record was made of all fixed objects within 50 ft of the traveled way. Figure C-4 illustrates the areas for which fixed objects were recorded in zones within 10 ft, 20 ft, 30 ft, and 50 ft of the traveled way.

Fixed objects were classified as either continuous objects or point objects. Any object over 10 ft long was classified as a continuous object; any object less than 10 ft long was classified as a point object. Continuous objects such as guardrail, bridge rail, or rock cuts were represented by their total length within the 200-ft interval. Point objects such as signs, utility poles, or trees were represented by the total number of objects within the 200-ft longitudinal interval; however, if two or more point objects were located

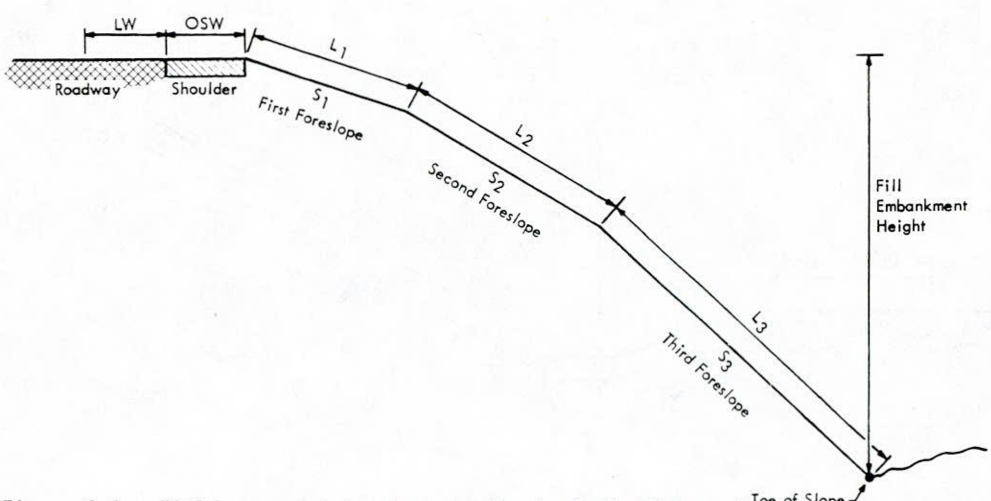


Figure C-3. Field survey data elements for typical fill section.

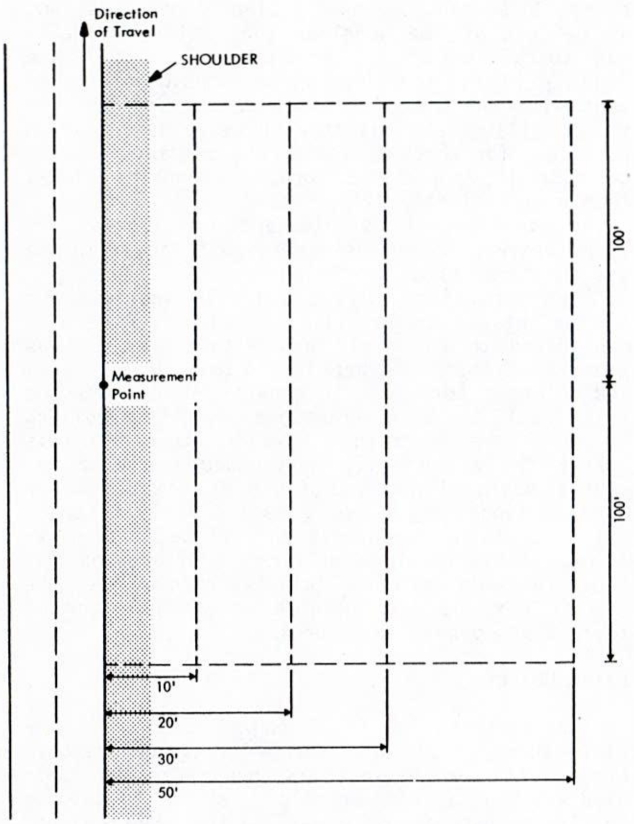


Figure C-4. Areas included in fixed-object survey.

within 10 ft of one another, they were counted as a single object. Fixed objects that cannot be struck by an errant vehicle because they are shadowed by guardrail or on top of a rock cut were not counted; some minor objects that do not usually result in a reported accident, if struck, were also excluded. The following guidelines on which objects to include or exclude were provided to the field crew:

Count	Don't Count
Most signs (see exceptions at right)	Delineators
Utility poles	Small signs on single metal channels
Luminative supports	Breakaway signs
Trees greater than 4 in. diameter	Small single-post mailboxes
Multiple or massive mailboxes	Trees less than 4 in. diameter
Culvert headwalls	Brush
Bridge columns and abutements	Objects shadowed by guardrail
Fences	
Rock outcroppings	
Rock cuts	
Guardrail	
Bridge rail	
Concrete barriers	

Separate records were made of both point and continuous fixed objects for each of the four zones shown in Figure C-4. Thus, a total of eight data items were recorded:

1. Number of point objects within 10 ft of the traveled way.
2. Length of continuous objects within 10 ft of the traveled way.
3. Number of point objects within 20 ft of the traveled way.
4. Length of continuous objects within 20 ft of the traveled way.
5. Number of point objects within 30 ft of the traveled way.
6. Length of continuous objects within 30 ft of the traveled way.
7. Number of point objects within 50 ft of the traveled way.
8. Number of continuous objects within 50 ft of the traveled way.

Note that the data for point and continuous fixed objects are cumulative (i.e., all objects in the zone within 10 ft of the roadway are also in the zone within 20 ft of the roadway, etc.).

For analysis purposes, it was necessary to define a single measure that combines the effects of point and continuous objects. The fixed object coverage factor is the quantity developed to reflect the combined effects of both types of objects. The fixed object coverage factor, expressed as a percentage, roughly corresponds to the probability of striking a fixed object given that a vehicle runs a specified distance off the road. For example, a coverage factor of 20 percent at 30 ft implies that a vehicle that runs at least 30 ft off the road has a probability of 0.20 of striking a fixed object within 30 ft of the road.

The rules for estimating the fixed object coverage factor from the number of point objects and the longitudinal extent of continuous objects within a 200-ft interval are given in Table C-3. These rules are based on the procedures for estimating roadside hazards in NCHRP Report 148 and include an allowance for the fact that the areas of risk (hazard envelopes) for roadside objects in a short 200-ft section are likely to overlap.

Table C-3. Estimation of fixed object coverage factor from fixed object frequency in a 200-ft interval.

Number of Point Objects	Total Length of Continuous Objects (ft)	Coverage Factor (%)
0	0	0
1	1-10	19
2	11-50	35
3	51-80	50
4	81-100	64
5	101-125	77
6	126-150	89
7 or more	151 or more	100

Estimation Rules

1. Include all point and continuous objects within a specified distance from the traveled way.

2. Two point objects close together are counted as one.

3. When both point and continuous fixed objects are present the coverage factors are added.

4. The maximum coverage factor is 100%.

5. The resulting coverage factor is the estimated probability of hitting an object given that a vehicle runs the specified distance off the road.

ANALYSIS OF FIELD SURVEY DATA

The field survey data were analyzed to compare the actual roadside design resulting from each policy (as applied to the actual terrain in the field) with the nominal roadside design policy and to establish that the highway sections used to evaluate the roadside design policies are comparable in all major respects except for roadside design policy (or, if they differ, to establish the nature and extent of the difference).

The analysis results are summarized in Table C-4 for two-lane highways, Table C-5 for freeways, and Table C-6 for four-lane divided nonfreeways. For each highway type, statistical tests were used to identify statistically significant differences between the roadside design policies. Statistical tests for differences between means were performed using Duncan's multiple range test in conjunction with one-way analysis of variance. Differences in proportions were tested using the Z-test (based on the standard normal approximation to the binomial distribution). A discussion of the field survey results is presented for three general kinds of design elements: embankment slopes, fixed objects, and roadway geometrics.

Roadside Embankments

An evaluation was conducted to compare the actual embankment slopes for each roadside design policy with both the nominal (or design slope) and with the actual slopes resulting from other policies. The field survey results confirmed that the embankment slopes constructed under the three roadside design policies do differ in the expected manner (i.e., 6:1 Clear Zone sections generally have 6:1 foreslopes, 4:1 Clear Zone sections generally have 4:1 foreslopes, and Nonclear Zone sections generally have foreslopes steeper than 4:1). However, it was found, as expected, that 6:1 and 4:1 Clear Zone sections both contain some locations with foreslopes steeper than the nominal slope. All of the roadside embankment comparisons discussed below consider only sites where embankments are not protected by guardrail. Sites with guardrail or bridge rail are considered in the later discussion of fixed objects.

Statistically significant differences were found between the mean slope of fill foreslopes for all comparisons between roadside design policies except for the comparison between 4:1 Clear Zone and Nonclear Zone sections for four-lane nonfreeways. When the mean slope for all slopes (both cut and fill) were compared, statistically significant differences were found between all roadside design policies for each highway type. For example, the mean slope of foreslopes on two-lane highways was found to be approximately 5.8:1 for 6:1 Clear Zone sections, 3.7:1 for 4:1 Clear Zone sections, and 3:1 for Nonclear Zone sections.

The foreslopes of 6:1 and 4:1 Clear Zone sections have slightly steeper average slopes than the names of the policies imply because at a few locations, typically on higher fills, steeper slopes were used for economic reasons or because of right-of-way restrictions. The proportion of foreslopes of 3:1 or steeper was tested to illustrate the magnitude of this phenomenon. Significant differences in the proportion of foreslopes of 3:1 or steeper were found between all roadside design policies on each highway type. For two-lane highways, 6 percent of the 6:1 Clear Zone sites, 30 percent of the 4:1 Clear Zone sites, and 45 percent of the Nonclear Zone sites, actually had foreslopes of 3:1 or steeper. All of the findings of the foreslope comparisons were consistent with the expected findings and the analysis results illustrate that the three roadside design policies, for which accident rate comparisons will be made in Appendix D, produce roadside slopes that are distinctly different.

No statistically significant differences were found between the roadside design policies in the average slope of cut backslopes.

The proportions of cut and fill sections and the heights of cut and fill embankment were also considered in the field survey analysis. It was hoped that these measures would provide a general indicator of terrain. In general, lower cuts and fills would be expected as one moved from rolling to more level terrain. However, this trend is likely to be partially confounded for more recently designed highways (such as the 6:1 Clear Zone sections) by higher cuts and fills that result from tighter controls on vertical alignment. A few statistically significant differences between roadside design policies were found, but the use of cut and fill heights as an indicator of terrain was generally inconclusive.

Fixed Objects

The analysis of fixed object data from the field survey found a pattern of fixed object coverage factor at various distances from the traveled way that appears anomalous, at first, but actually corresponds quite well to the practical effects of the roadside design policies, as they have been applied. The fixed object coverage factors for two-lane highways will be discussed here, as an example. For fixed objects within 10 ft and within 20 ft of the traveled way, there were no significant differences in the coverage factor between the 6:1 Clear Zone and Nonclear Zone sections, but both of these types of sections differed significantly from the 4:1 Clear Zone sections. Although it may seem strange that the 6:1 Clear Zone and Nonclear Zone sections should not differ in fixed object coverage, consider that the predominant fixed objects close to the traveled way are guardrail and bridge rail. The observed differences can be explained simply, as follows: 6:1 Clear Zone sections do not have much guardrail because they do not need it; 4:1 Clear Zone sections need more guardrail and they have it; Nonclear Zone sections also need more guardrail than 6:1 Clear Zone sections, but they do not have it and, therefore, expose the motorist to steeper slopes. This interpretation is confirmed by the comparison of the percentage of sites with guardrail or bridge rail reported in Table C-4 (3 percent for 6:1 Clear Zone sections; 8 percent for 4:1 Clear Zone sections; and, 3 percent for Nonclear Zone sections).

For fixed objects within 30 ft of the traveled way, all three roadside design policies are significantly different from one another in fixed object coverage factor. It should be noted that none of the "Clear Zone" sections is completely clear of fixed objects within the 30-ft clear zone. The 6:1 Clear Zone sections on two-lane highways have a 10.2 percent coverage factor at 30 ft (2.5 percent due to guardrail or bridge rail and 7.7 percent due to other objects). The fixed object coverage factor at 30 ft for the 4:1 Clear

Table C-4. Summary of field survey results for two-lane highways.

Field Survey Element	Value by Roadside Design Policy			Statistical Tests for Significant Differences [a]		
	6:1 CZ	4:1 CZ	NCZ	6:1 CZ vs 4:1 CZ	4:1 CZ vs NCZ	6:1 CZ vs NCZ
Roadside Embankment						
Mean Slope for Fill Foreslopes[b]	10.19°(5.6:1)	16.28°(3.4:1)	18.67°(3:1)	SIG	SIG	SIG
Mean Slope for Cut and Fill Foreslopes	9.79°(5.8:1)	15.22°(3.7:1)	17.77°(3.1:1)	SIG	SIG	SIG
Percentage of Foreslopes 3:1 or Steeper[c]	6.00	30.00	45.00	SIG	SIG	NS[e]
Percentage of Cut Sections[d]	34.87	46.99	43.85	SIG	NS	SIG
Mean Slope for Cut Backslopes	15.21°(3.7:1)	16.93°(3.3:1)	16.91°(3.3:1)	NS	NS	NS
Mean Height for Fill Embankments (ft)[f]	6.11	5.72	5.11	NS	NS	NS
Mean Height for Cut Backslopes(ft)[g]	5.70	7.62	4.00	NS	SIG	NS
Mean Height of Cuts and Fills (ft)	5.97	6.59	4.63	NS	SIG	SIG
Fixed Objects						
Percentage of Sites with Guardrail or Bridge Rail	2.50	8.50	2.60	SIG	SIG	NS
Mean Fixed Object Coverage Factor at 10 ft (%)	2.03	6.95	2.48	SIG	SIG	NS
Mean Fixed Object Coverage Factor at 20 ft (%)	3.41	12.39	7.23	SIG	SIG	NS
Mean Fixed Object Coverage Factor at 30 ft (%)	10.17	17.31	23.97	SIG	SIG	SIG
Mean Fixed Object Coverage Factor at 50 ft (%)	19.35	25.27	40.41	NS	SIG	SIG
Roadway Geometrics						
Percentage of Tangent Sections	89.50	89.00	85.90	NS	NS	NS
Mean Lane Width (ft)	11.50	11.55	11.50	NS	NS	NS
Mean Shoulder Width (ft)	10.55	9.95	7.85	NS	SIG	SIG

[a] SIG = Statistically significant difference; NS = not statistically significant at 95% confidence level unless otherwise specified.

[b] Comparisons of means performed by one-way analysis of variance and Duncan multiple range test.

[c] Comparisons of percentages performed by Z-test for difference of proportions.

[d] Only sites without guardrail or bridge rail considered.

[e] Statistically significant at 90% confidence level.

[f] Measured in vertical plane from outside edge of shoulder to toe of slope.

[g] Measured in vertical plane from bottom of ditch to top of slope.

Table C-5. Summary of field survey results for four-lane freeways.

Field Survey Element	Value by Roadside Design Policy		Statistical Tests for Significant Differences[a]
	6:1 CZ	4:1 CZ	6:1 CZ vs 4:1 CZ
Roadside Embankments			
Mean Slope for Fill Foreslopes[b]	8.20°(6.9:1)	13.49°(4.2:1)	SIG
Mean Slope for Cut and Fill Foreslopes	8.19°(6.9:1)	13.24°(4.3:1)	SIG
Percentage of Foreslopes 3:1 or Steeper[c]	0.00	9.00	SIG
Percentage of Cut Sections[d]	7.37	21.74	SIG
Mean Height for Fill Embankments (ft)[e]	6.44	6.00	NS
Mean Height for Cut Backslopes (ft)[f]	16.85	9.32	SIG
Mean Height for Cuts and Fills (ft)	7.21	6.72	NS
Fixed Objects			
Percentage of Sites with Guardrail or Bridge Rail	5.00	8.00	NS
Mean Fixed Object Coverage Factor at 10 ft (%)	4.45	5.54	NS
Mean Fixed Object Coverage Factor at 20 ft (%)	5.30	9.71	NS[g]
Mean Fixed Object Coverage Factor at 30 ft (%)	6.50	11.07	SIG
Mean Fixed Object Coverage Factor at 50 ft (%)	8.34	16.30	SIG
Roadway Geometrics			
Percentage of Tangent Sections	85.00	84.50	NS
Mean Lane Width (ft)	12.00	11.95	NS
Mean Outside Shoulder Width (ft)	10.90	10.55	SIG
Mean Inside Shoulder Width (ft)	5.28	4.10	SIG
Mean Median Width (ft)	68.93	69.20	NS

[a] SIG = Statistically significant difference; NS = not significant at 95% confidence level unless otherwise specified.

[b] Comparisons of means performd by one-way analysis of variance and Duncan multiple range test.

[c] Comparisons of percentages performed by Z-test for difference of proportions.

[d] Only sites without guardrail or bridge rail considered.

[e] Measured in vertical plane from outside edge of shoulder to toe of slope.

[f] Measured in vertical plane from bottom of ditch to top of slope.

[g] Statistically significant at 90% confidence level.

Table C-6. Summary of field survey results for four-lane divided nonfreeways.

Field Survey Element	Value by Roadside Design Policy: 6:1 CZ	4:1 CZ	NCZ	Statistical Tests for Significant Differences[a]: 6:1 CZ vs 4:1 CZ	4:1 CZ vs NCZ	6:1 CZ vs NCZ
Roadside Embankments						
Mean Slope for Fill Foreslopes[b]	9.85°(5.8:1)	13.67°(4.1:1)	15.23°(3.7:1)	SIG	NS	SIG
Mean Slope for Cut and Fill Foreslopes	9.91°(5.7:1)	13.31°(4.2:1)	16.06°(3.5:1)	SIG	SIG	SIG
Percentage of Foreslopes 3:1 or Steeper[c]	0.00	14.00	42.00	SIG	SIG	SIG
Percentage of Cut Sections[d]	42.00	60.22	61.29	SIG	NS	SIG
Mean Slope for Cut Backslopes	17.43°(3.2:1)	15.34°(3.6:1)	16.27°(3.4:1)	NS	NS	NS
Mean Height for Fill Embankments (ft)[e]	6.48	5.81	5.86	NS	NS	NS
Mean Height for Cut Backslopes (ft)[f]	6.13	5.80	3.92	NS	NS	NS
Mean Height of Cuts and Fills (ft)	6.33	5.81	4.68	NS	NS	SIG
Fixed Objects						
Percentage of Sites with Guardrail or Bridge Rail	0.00	7.00	5.10	SIG	NS	SIG
Mean Fixed Object Coverage Factor at 10 ft (%)	0.35	4.50	5.14	SIG	NS	SIG
Mean Fixed Object Coverage Factor at 20 ft (%)	1.68	10.51	23.35	SIG	SIG	SIG
Mean Fixed Object Coverage Factor at 30 ft (%)	4.08	22.75	41.88	SIG	SIG	SIG
Mean Fixed Object Coverage Factor at 50 ft (%)	6.50	33.69	49.68	SIG	SIG	SIG
Roadway Geometrics						
Percentage of Tangent Sections	91.00	89.00	91.80	NS	NS	NS
Mean Lane Width (ft)	11.90	11.80	11.70	NS	NS	NS
Mean Outside Shoulder Width (ft)	11.90	10.40	7.80	NS	SIG	SIG
Mean Inside Shoulder Width (ft)	4.30	4.80	5.20	NS	NS	NS
Mean Median Width (ft)	N/A	N/A	N/A	-	-	-

[a] SIG = Statistically significant difference; NS = not statistically significant at 95% confidence level unless otherwise specified.

[b] Comparison of means performed by one-way analysis of variance and Duncan multiple range test.

[c] Comparisons of percentages performed by Z-test for difference of proportions.

[d] Only sites without guardrail or bridge rail considered.

[e] Measured in vertical plane from outside edge of shoulder to toe of slope.

[f] Measured in vertical plane from bottom of ditch to top of slope.

Zone sections is 17.3 percent. This increase in fixed object coverage factor resulted mostly from additional guardrail on the the 4:1 Clear Zone sections; on these sections, guardrail accounted for 8.5 percent of the 17.3 percent coverage factor. The frequency of point objects unprotected by guardrail was also higher on the 4:1 Clear Zone sections, but the increase in point objects had a much smaller influence on the coverage factor; the coverage factor due to fixed objects other than bridge rail or guardrail increased from 7.7 percent on the 6:1 Clear Zone sections to 8.8 percent on the 4:1 Clear Zone sections. The Nonclear Zone sections have the most objects within 30 ft of the traveled way; the coverage factor at 30 ft for Nonclear Zone sections is 24.0 percent (2.6 percent due to guardrail and 21.4 percent due to other objects).

Beyond 30 ft from the traveled way, the fixed object coverage factors for the 4:1 and 6:1 Clear Zone sections are indistinguishable, while the fixed object coverage factor for Nonclear Zones sections is significantly higher.

On freeways, there generally are fewer fixed objects than on two-lane highways, although the results of comparisons between the 4:1 and 6:1 Clear Zone policies are similar. The roadside design policies vary more widely in fixed object coverage for four-lane divided nonfreeways, although these data represent a smaller sample than for two-lane highways and freeways.

Table C-7 is presented to illustrate the typical differences in roadside fixed objects between the design policies for two-lane highways and for freeways. The frequency of fixed objects is tabulated for each design policy. The table should help readers to visualize both the actual character of the roadside for each design policy and the meaning of the fixed object coverage factor.

The conclusion of the field survey analysis of fixed objects is that the frequency of fixed objects varies between roadside design policies in a predictable manner. The 4:1 and 6:1 Clear Zone sections were found to be similar in fixed object coverage within the 30-ft clear zone, although the 4:1 sections had more guardrail. However, some fixed objects were found within the clear area in both cases. The Nonclear Zone sections have substantially more fixed objects than either the 4:1 or 6:1 Clear Zone sections at 20 ft and beyond.

Table C-7. Typical distribution of roadside fixed objects for one side of a one-mile roadway section.

Type of Fixed Object	Distance from Traveled Way 0-20 ft	20-30 ft	30-50 ft
6:1 Clear Zone -- Freeway (Coverage Factor @ 30 ft = 6.5%)			
Length of Guardrail (ft)	150	0	0
Length of Bridge Rail (ft)	100	0	0
Length of Continuous Objects (ft)[a]	0	0	0
Number of Point Objects	1	2	1
4:1 Clear Zone -- Freeway (Coverage Factor @ 30 ft = 11%)			
Length of Guardrail (ft)	100	0	0
Length of Bridge Rail (ft)	50	0	0
Length of Continuous Objects (ft)	0	0	200
Number of Point Objects	1	1	2
6:1 Clear Zone -- Two-Lane Highway (Coverage Factor @ 30 ft = 10%)			
Length of Guardrail (ft)	50	0	0
Length of Bridge Rail (ft)	80	0	0
Length of Continuous Objects (ft)	0	200	300
Number of Point Objects	2	3	8
4:1 Clear Zone -- Two-Lane Highway (Coverage Factor @ 30 ft = 17%)			
Length of Guardrail (ft)	420	0	0
Length of Bridge Rail (ft)	30	0	0
Length of Continuous Objects (ft)	0	150	400
Number of Point Objects	4	9	11
Nonclear Zone -- Two Lane Highway (Coverage Factor @ 30 ft = 24%)			
Length of Guardrail (ft)	80	0	0
Length of Bridge Rail (ft)	80	0	0
Length of Continuous Objects (ft)	0	800	700
Number of Point Objects	11	10	24

[a] Includes only continuous objects other than guardrail or bridge rail.

Roadway Geometrics

Differences in roadway geometrics between highway sections with different roadside policies were considered because it was expected that sections with better roadside design represent more recent construction and could also have better roadway geometrics. This phenomenon, if present, could become a source of bias in the subsequent accident analysis because an effect of roadway geometrics on accident rate could be mistaken for an effect of roadside design policy. Field survey data were gathered on the dimensions of four roadway cross-sectional elements at each measurement point: lane width, outside shoulder width, inside (median) shoulder width, and median width. In addition, the presence or absence of a horizontal curve at each measurement point was noted. The analysis of these data is discussed below. However, it was not feasible within the time and cost constraints of the field survey to collect data on the longitudinal extent of roadway geometric features along entire study sections. Such roadway geometric elements as the distribution of degree of horizontal curvature, the distribution of roadway grade, the length of crest vertical curves, and the sight distance remain potential sources of bias, although the authors are of the opinion that such biases are not large.

On two-lane highways, the sections with different roadside design policies do not differ in the proportion of sites on tangents, as opposed to horizontal curves. The mean lane width also does not vary with the roadside design policy; each policy has a roughly equal mixture of 11-ft and 12-ft lanes, with an average lane width of approximately 11.5 ft. However, the Clear Zone and Nonclear Zone sections do differ in shoulder width. The Clear Zone sections tend to have wider shoulders than the Nonclear Zone sections, while the 6:1 and 4:1 Clear Zone sections do not themselves differ significantly in shoulder width.

No difference was found between roadside design policies for freeways in the proportion of tangent roadway sections or lane widths. In fact, only one freeway section with lanes less than 12 ft wide was found. There was also no significant difference in median width between the roadside design policies. Small, but significant, differences between roadside design policies were found for both outside shoulder width and inside shoulder width on freeways.

Similarly, for four-lane nonfreeways, the only statistically significant difference in roadway geometrics between roadside design policies is for outside shoulder width. There was no significant difference for proportion of tangent sections, lane width, or inside shoulder width. The median width data for four-lane nonfreeways was not meaningful because, for a number of sections, the roadways in opposite directions of travel were built at different times under different roadside design policies. Not only was it impossible to classify medians for such sections as associated with one roadside design policy or another, but such medians also tended to be much wider than normal.

The conclusion of the roadway geometric analysis was that, of the variables studied, only shoulder width varies significantly between the roadside design policies. It was decided that any possible effect of shoulder width on accident rate should be controlled for in the accident analysis that follows, before the effect of roadside design policy on accident experience is assessed. The highway sections appear comparable between roadside design policies in lane width and median width.

APPENDIX D

ANALYSIS OF ACCIDENT DATA

This appendix documents the statistical analysis of accident data that was performed to evaluate differences in accident experience between roadside design policies. Included in the discussion are the objectives of the analysis, the rationale for the variables used in the analysis, the rationale for the statistical techniques used in the analysis, the results of the statistical analysis, and the interpretation of those results.

ANALYSIS OBJECTIVES

The statistical analysis of accident data conducted in this study had three objectives. These were:

1. To determine whether roadside design policy has a statistically significant effect on traffic accident experience.

2. To determine the magnitude of the effect of roadside design policy on accident experience, if the effect is statistically significant.

3. To express the roadside design policy effect in a form most useful for application by highway agencies in design decisions.

ANALYSIS APPROACH

The statistical analysis approach was developed in a series of three steps: (1) select measure(s) of effectiveness (dependent variables) for the analysis; (2) select independent variables for the analysis; and (3) select a statistical technique to determine whether the roadside design policy effect is statistically significant. Each of these steps is discussed individually below.

Measures of Effectiveness

The primary measure of effectiveness (or dependent variable) selected to evaluate roadside design policies is the single-vehicle run-off-road accident rate. The single-vehicle run-off-road accident rate for a one-year period, expressed as accidents per million vehicle-miles, was defined in the conventional manner:

$$AR = \frac{(N) \quad (10^6)}{(ADT)\ (D)\ (L)}$$

where AR = Single-vehicle run-off-road accident rate, accidents per million vehicle-miles;

N = Number of single-vehicle run-off-road accidents;

ADT = Average daily traffic volume, vpd;

D = Duration of study period in days, in this case, 365 days or 1 year; and

L = length of study section, miles.

Throughout this study, reference to the accident rate implies the single-vehicle run-off-road accident rate. An important feature of this measure of effectiveness is that all accidents used in its determination involve a vehicle that leaves the roadway. It would be questionable to presume any relationship between roadside design policy and accidents where no vehicle left the roadway. Therefore, the measure of effectiveness for an evaluation of roadside design policy should be a measure of run-off-road accidents only.

The primary measure of effectiveness does not include all run-off-road accidents, but only those involving a single vehicle. A desirable aspect of restricting the evaluation to single-vehicle run-off-road accidents is that the severity (or lack of severity) of a single-vehicle run-off-road accident can be attributed in large degree to the roadside design. Naturally, some other factors, such as the angle of departure from the roadway and the driver's reaction, do have an influence, as well.

On the other hand, multiple-vehicle run-off-road accidents are both less frequent than single-vehicle run-off-road accidents and less susceptible to amelioration by roadside design improvements. An evaluation of nonintersection accidents in Illinois found that only 15 percent as many multiple-vehicle run-off-road accidents as single-vehicle run-off-road accidents occur on two-lane highways and only 29 percent as many on freeways. Multiple-vehicle run-off-road accidents are less susceptible to improvement because each accident would still involve a collision between vehicles even if the roadside design were perfect. Finally, multiple-vehicle run-off-road accidents, more than single-vehicle run-off-road accidents, tend to be concentrated at specific geometric features such as intersections; consideration of intersections was excluded from the scope of this study. For these reasons, it was concluded that the single-vehicle run-off-road accident rate was the best measure of effectiveness to evaluate roadside design policies.

One of the studies discussed in Appendix A found that multiple-vehicle accident rates were higher on sections with improved roadside design policy (16). At sites with low traffic volume, much of this increase in multiple-vehicle accidents occurred at intersections. The authors hypothesized that this increase might be due to driver confusion when confronted with a wide expanse of cleared right-of-way. This hypothesis has not been tested in the current study because the project scope specifically excludes consideration of accident experience at intersections. However, the variation of accident rate between roadside design policies for other accident types, including single-vehicle nonrun-off-road accidents, multiple-vehicle nonintersection accidents, and total accidents, is examined in the final section of this appendix.

The primary measure of effectiveness has been expressed as an accident rate because the study sections vary in length and average daily traffic volume. The accident rate expresses the accident experience in a form proportional to the risk of an accident to an individual vehicle traveling a specified (1 mile) length of highway.

It was our original intention to subdivide the single-vehicle run-off-road accident rate into measures of fixed-object collision accidents and run-off-road noncollision accidents. However, the proportions of these two components of the single-vehicle run-off-road accident rate varied so widely from state to state as to call into question the ability of accident records to supply data at this level of detail. For example, on 4:1 Clear Zone sections on freeways the proportion of single-vehicle run-off-road accidents involving fixed object collisions ranged from 57 percent in Minnesota to 15 percent in Missouri. The authors do not believe that such disparities result from any actual differences in roadside design between the states, and is more likely to result from differences in definitions and lack of reliability in the accident reporting system. For this reason, it was decided not to use the available data on fixed-object and run-off-road noncollision accident rates.

The study also included an evaluation of accident severity measures, including both the accident severity distribution (proportion of fatal, injury, and property-damage-only accidents) and the single-vehicle run-off-road accident rate for fatal and injury accidents only. It is appropriate at this point to explain why measures of both accident rate and accident severity are being used in a roadside safety study, inasmuch as roadside safety improvements clearly cannot prevent drivers from running off the roadway but can only reduce the severity for those who do. An understanding of this apparent paradox requires a definition of the terms encroachment and accident, as used in practice.

Drivers who run off the road are said to encroach on the roadside, and such events are referred to as "roadside encroachments." Clearly, encroachments occur because of lack of driver attention or because of some condition on the roadway or because of some combination of these--and not because of the roadside design. Thus, roadside design is strictly a severity-increasing rather than a causative factor in roadside encroachments. However, no reliable records of the severity of encroachment exist that could provide the basis for an evaluation of roadside design policies on specific roadways.

On the other hand, a run-off-road accident, from the point of view of a safety researcher, is a roadside encroachment whose consequences are severe enough to be reported. Typically, accidents that involve a fatality, an injury, or property damage above a specified dollar amount are required by law to be reported. In this sense, therefore, the roadside design can "cause" a run-off-road accident by causing it to be severe enough to be reported. For this reason, an evaluation of run-off-road accident experience related to roadside design policy must consider both the rate at which accidents occur and the severity distribution of the accidents that do occur.

Unfortunately, the nature of accident reporting systems further complicates the use of accident records in roadside safety evaluations. Not only does the threshold level of property damage for a reportable accident vary from state to state, but many property-damage-only accidents that exceed that threshold are not reported. The reliability of accident reporting systems can vary from state to state and even from jurisdiction to jurisdiction within a state. The reporting reliability for fatal and injury accidents is usually much higher than for property-damage-only accidents, suggesting that the accident rate based on fatal and injury accidents only may be a more reliable measure of effectiveness.

Independent Variables

The independent variables for the accident analysis are those variables that may have an influence on the measure of effectiveness (or dependent variable) -- single-vehicle run-off-road accident rate. In accordance with the analysis objectives, the primary independent variable for the analysis is roadside design policy. Three different levels of roadside design policy are to be evaluated and any differences in accident experience between the policies identified. The three roadside design policies -- 6:1 Clear Zone, 4:1 Clear Zone and Nonclear Zone -- have been introduced in Chapter Two, and the specific geometric features associated with each policy have been documented from the field survey in Appendix C.

Several other independent variables were considered because they may also influence the single-vehicle run-off-road accident rate. These additional variables include state, average daily traffic volume (ADT), and shoulder width.

State was considered as an independent variable because statistically significant state-to-state differences in single-vehicle run-off-road accident rate were found for four of five highway type roadside design policy combinations tested (all except 4:1 Clear Zone sections for two-lane highways). It might be tempting to explain these differences by variations in the reliability of the accident reporting systems of the three states. However, three of the four significant differences persisted even when the analysis was restricted to fatal and injury accidents only. This analysis convinced us that (1) although the observed state-to-state differences could be partly due to unreliable accident reporting, they also represent, in part, true differences in accident experience between the states; and (2) the influence of these state-to-state differences must be accounted for or corrected before assessing the statistical significance of the roadside design policy effect.

It was documented in Table B-1 that, even within one highway type, the highway sections for different roadside design policies also differ in ADT. For two-lane highways, for example, the average ADT is 2,031 for 6:1 Clear Zone sections, 2,778 for 4:1 Clear Zone sections, and 2,745 for Nonclear Zone sections. For freeways, the average ADT is 8,401 for 6:1 Clear Zone sections and 10,066 for 4:1 Clear Zone sections. Because the run-off-road accident rate is known to vary with ADT in some situations, it is important that this effect be accounted for before assessing the effect of roadside design policy.

One concern raised during the study was the influence of roadway geometrics on accident rate. For example, some of the observed differences between 6:1 Clear Zone sections and sections with other roadside design policies could be due to improved roadway geometrics on the 6:1 Clear Zone sections that make it less likely for vehicles to run off the road. The field survey reported in Appendix C examined the differences between roadside design policies in roadway geometrics including lane width, shoulder width, median width, and proportion of tangents and horizontal curves. Of these variables, only shoulder width was found to differ significantly between the roadside design policies. Therefore, shoulder width was used as an independent variable whose effect was accounted for before assessing the effect of roadside design policy.

Statistical Analysis Approach

The simplest and most direct method of evaluating the statistical significance of a factor with more than two levels, such as roadside design policy, is one-way analysis of variance. If the factor is found to be statistically significant, Duncan's multiple range test can then be used to determine which differences between the individual roadside design policies are statistically significant.

Although this approach was used in the initial analyses, it did not respond to one important goal of the analysis -- to assess the significance of roadside design policy only after accounting for the effects of other independent variables such as state, ADT, and shoulder width. Another analysis approach is used to accomplish this goal -- analysis of covariance. Analysis of covariance is a statistical technique used to assess the effects of both independent variables with several discrete levels (known as factors) and independent variables with values on a continuous scale (known as covariates). The independent variables roadside design policy and state are discrete variables most naturally treated as factors (in this case with three levels each); and ADT and shoulder width are continuous variables most naturally treated as covariates. Two dependent variables were used in separate analysis of covariance: single-vehicle run-off-road accident rate and fatal and injury single-vehicle run-off-road accident rate.

The specific form of analysis of covariance that was used was a hierarchical analysis of covariance, in which the effects of the independent variables are accounted for in sequence, so that a factor or covariate is statistically significant only if it explains a significant portion of the variance remaining after the variables considered previously have been accounted for. The relationship between hierarchical analysis of covariance and the classic approach to analysis of covariance is analogous to the relationship between multiple regression and stepwise regression. The independent variables were considered in a fixed order in the analysis (state, ADT, shoulder width, roadside design policy) so that the effect of the first three variables would be considered prior to the effect of roadside design policy. This approach prevents an effect of state, ADT, or shoulder width from being mistaken for an effect of roadside design policy.

Separate analyses of covariance were conducted for each of three highway types included in the study: two-lane highways, four-lane freeways, and four-lane divided nonfreeways. All three levels of roadside design policy were considered for each highway type, except that for freeways no data were available for the Nonclear Zone design policy.

In an analysis of variance or covariance with a balanced design, the best measure of effectiveness for each roadside design policy is simply the average (or arithmetic mean) accident rate for that policy. The experiment designs used in this study were not balanced, however, because the sample sizes in the cells defined by the experimental factors (state and roadside design policies) were not equal and the covariates (ADT and shoulder width) did not have the same mean in every cell. In such an unbalanced design, the best measure of effectiveness for each roadside design policy is the least square mean for that policy. The least square mean compensates for the differences between the cells in sample sizes and covariate means. The least square mean is, in effect, the mean accident rate that would result if every cell had the same sample size and the same mean for each covariate. The differences in accident rate between roadside design policies can be represented by the differences in the least square means.

Comparisons of the accident severity distribution were made using the Kolmogorov-Smirnov test (a nonparametric test for distribution shifts) and the Z-test for difference of proportions (based on the standard normal approximation to the binomial distribution) (6).

ANALYSIS RESULTS

The results of the accident data analysis are presented below. First, the results of several analyses of variance and covariance are presented to demonstrate that roadside design policy does have a statistically significant effect on accident rate. Then, the mean and adjusted (least square mean) accident rates are presented to show the magnitude of the differences in accident rate between policies. The effect of roadside design policy on accident severity is discussed, and, finally, the relationship of ADT on accident rate in the study data is illustrated.

Analysis of Variance and Covariance Results

This section presents the results of a series of analyses of variance and covariance that were performed on the run-off-road accident rate and the fatal and injury run-off-road accident rate. These analyses were performed by computer using the General Linear Model procedure of the Statistical Analysis System (SAS) (24). All conclusions presented here regarding statistical significance are at the 95 percent confidence level unless otherwise stated.

Table D-1 gives the results of three one-way analyses of variance, one for each highway type. In these analyses, the dependent variable is single-vehicle run-off-road accident rate and the independent variable is roadside design policy. The analyses show that the effect of roadside design policy on single-vehicle run-off-road accident rate is statistically significant for each of the three highway types. The proportion of the variation (R^2) in single-vehicle run-off-road accident rate explained by roadside design policy ranges from 0.039 for two-lane highways to 0.138 for four-lane divided nonfreeways. (It is not surprising that the latter highway type had the highest value of R^2, because it is based on data from only one state, whereas the other analyses are based on data from three states.)

Table D-1. Analysis of variance of roadside design policy for single-vehicle run-off-road accident rate.

Source of Variation		Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (At 95% Confidence Level)
TWO-LANE HIGHWAYS (N=2,024)						
POLICY	(Factor)	38.168	2	19.084	41.38	SIG
Explained		38.168	2	19.084	41.38	SIG
Error		931.969	2,021	0.461		(R^2=0.039)
TOTAL		970.137	2,023			
FOUR-LANE FREEWAYS (N=1,045)						
POLICY	(Factor)	2.150	1	2.150	51.26	SIG
Explained		2.150	1	2.150	51.26	SIG
Error		43.736	1,043	0.042		(R^2=0.047)
TOTAL		45.886	1,044			
FOUR-LANE DIVIDED NONFREEWAYS (N=580)						
POLICY	(Factor)	10.488	2	5.244	46.08	SIG
Explained		10.488	2	5.244	46.08	SIG
Error		65.665	577	0.114		(R^2=0.138)
TOTAL		76.153	579			

N = Sample size
SIG = Statistically significant

A further analysis was performed to avoid mistaking an effect of state, ADT, or shoulder width for an effect of roadside design policy. (The shoulder width used here was the width of the outside or righthand shoulder, rather than the inside or median shoulder, on the highway sections.) Table D-2 presents three analyses of covariance where the other independent variables were considered. These analyses indicate that the effect of roadside design policy on single-vehicle run-off-road accident rates is still statistically significant, even after consideration of the effects of state, ADT, and shoulder width. All four independent variables in the analysis of covariance for two-lane highways were statistically significant. It should be noted that the sample size for the analysis of covariance on two-lane highways in Table D-2 is slightly smaller than for the analysis of variance in Table D-1, because shoulder width data were missing for a few sections. The shoulder width covariate was eliminated from the analysis of covariance for freeways because it was not statistically significant. The state factor was not included in the analysis of four-lane divided nonfreeways because all of these data were from one state, and the ADT and shoulder width covariates were eliminated because they were not statistically significant. Thus, only the roadside design policy factor remains for four-lane divided nonfreeways and the analysis in Table D-2 is identical to the analysis in Table D-1. Both the two-lane and the freeway analyses contain a term for the interaction between state and roadside design policy; the state-policy interaction was statistically significant for the two-lane highways, but it was not statistically significant for the freeways.

Table D-2. Analysis of covariance of roadside design policy and other variables for single-vehicle run-off-road accident rate.

Source of Variation		Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (At 95% Confidence Level)
TWO-LANE HIGHWAYS (N=1,958)						
STATE	(Factor)	32.603	2	16.302	36.59	SIG
ADT	(Covariate)	2.865	1	2.865	6.43	SIG
OSW	(Covariate)	18.426	1	18.426	41.36	SIG
POLICY	(Factor)	18.150	2	9.075	20.37	SIG
STATE-POLICY	(Interaction)	9.557	4	2.389	5.36	SIG
Explained		81.601	10	8.160	18.31	SIG
Error		867.470	1,947	0.446		(R^2=0.086)
TOTAL		949.071	1,957			
FOUR-LANE FREEWAYS (N=1,045)						
STATE	(Factor)	3.250	2	1.625	42.40	SIG
ADT	(Covariate)	0.380	1	0.380	9.92	SIG
POLICY	(Factor)	2.434	1	2.434	63.50	SIG
STATE-POLICY	(Interaction)	0.032	2	0.016	0.42	NS
Explained		6.097	6	1.016	26.51	SIG
Error		39.789	1,038	0.038		(R^2=0.133)
TOTAL		45.886	1,044			
FOUR-LANE DIVIDED NONFREEWAYS (N=580)						
POLICY	(Factor)	10.488	2	5.244	46.08	SIG
Explained		10.488	2	5.244	46.08	SIG
Error		65.665	577	0.114		(R^2=0.138)
TOTAL		76.153	579			

N = Sample size
ADT = Average daily traffic volume
OSW = Outside shoulder width
SIG = Statistically significant
NS = Not statistically significant

The analyses previously described were repeated using the run-off-road accident rate for fatal and injury accidents as the dependent variable. The fatal and injury accident rate would normally be expected to be more reliable than the total accident rate because of the exclusion of property-damage-only accidents which are subject to variations in reporting levels. Tables D-3 and D-4 are analogous to Tables D-1 and D-2, respectively.

Table D-3. Analysis of variance of roadside design policy for fatal and injury single-vehicle run-off-road accident rate.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (At 95% Confidence Level)
TWO-LANE HIGHWAYS (N=2,024)					
POLICY (Factor)	7.096	2	3.953	16.86	SIG
Explained	7.906	2	3.953	16.86	SIG
Error	473.808	2,021	0.234		(R^2=0.016)
TOTAL	481.714	2,023			
FOUR-LANE FREEWAYS (N=1,045)					
POLICY (Factor)	0.192	1	0.192	15.65	SIG
Explained	0.192	1	0.192	15.65	SIG
Error	12.775	1,043	0.012		(R^2=0.014)
TOTAL	12.967	1,044			
FOUR-LANE DIVIDED NONFREEWAYS (N=580)					
POLICY (Factor)	2.868	2	1.434	44.95	SIG
Explained	2.868	2	1.434	44.95	SIG
Error	18.404	577	0.032		(R^2=0.134)
TOTAL	21.272	579			

N = Sample size
SIG = Statistically significant

Table D-4. Analysis of covariance of roadside design policy and other variables for fatal and injury single-vehicle run-off-road accident rate.

Source of Variation		Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (At 95% Confidence Level)
TWO-LANE HIGHWAYS (N=1,958)						
STATE	(Factor)	3.815	2	1.908	8.11	SIG
ADT	(Covariate)	1.442	1	1.442	6.13	SIG
OSW	(Covariate)	3.175	1	3.175	13.50	SIG
POLICY	(Factor)	5.475	2	2.738	11.64	SIG
STATE-POLICY	(Interaction)	2.212	4	0.553	2.35	NS[a]
Explained		16.119	10	1.612	6.85	SIG
Error		457.979	1,947	0.235		(R^2=0.034)
TOTAL		474.098	1,957			
FOUR-LANE FREEWAYS (N=1,045)						
STATE	(Factor)	0.604	2	0.302	25.98	SIG
POLICY	(Factor)	0.261	1	0.261	22.41	SIG
STATE-POLICY	(Factor)	0.026	2	0.013	1.13	NS
Explained		0.981	5	0.178	15.33	SIG
Error		12.076	1,039	0.012		(R^2=0.067)
TOTAL		12.967	1,044			
FOUR-LANE DIVIDED NONFREEWAYS (N=580)						
POLICY	(Factor)	2.868	2	1.434	44.95	SIG
Explained		2.868	2	1.434	44.95	SIG
Error		18.404	577	0.032		(R^2=0.134)
TOTAL		21.272	579			

N = Sample size
ADT = Average daily traffic volume
OSW = Outside shoulder width
SIG = Statistically significant
NS = Not statistically significant

[a] Statistically significant at 90% confidence level.

The analyses of variance in Table D-3 show roadside design policy to have a statistically significant effect on the fatal and injury run-off-road accident rate for all three highway types. The roadside design policy effect for the fatal and injury run-off-road accident rate, while still statistically significant, explains less of the variation than for the total run-off-road accident rate. As in Table D-1, the strongest relationship between roadside design policy and accident rate in Table D-3 was found for the four-lane divided nonfreeways, all of which are located in one state. The proportion of the variation (R^2) in fatal and injury single-vehicle run-off-road accident rate explained by roadside design policy ranges from 0.014 for freeways to 0.134 for four-lane divided nonfreeways.

Table D-4 presents the analysis of covariance results for fatal and injury run-off-road accident rate, which are analogous to the analysis of covariance results for the total run-off-road accident rate presented in Table D-2. As in these earlier analyses of covariance, the roadside design policy effect remains statistically significant after consideration of the state, ADT, and shoulder-width variables. With only two exceptions, the same independent variables and interactions that were statistically significant for the total run-off-road accident rate are also statistically significant for the fatal and injury run-off-road accident rate. First, the ADT factor was omitted from the analysis of freeways in Table D-4 because its effect on fatal and injury accident rate was not statistically significant. The other exception is the state-policy interaction for two-lane highways, which is also not statistically significant (see Table D-4).

The state-policy interaction in Tables D-2 and D-4 indicates whether the effect of roadside design policy on accident rate varies from state to state. If the interaction effect is significant, it implies that the accident rate for a given roadside design policy depends on the state. If the interaction effect is not significant, the roadside design policies can be assumed to have the same accident rate in every state. The analysis results reported above show that the state-policy interaction is clearly not statistically significant for freeways. The situation for two-lane highways is more complicated: the interaction effect is statistically significant for the total run-off-road accident, but is (barely) not statistically significant for the fatal and injury accident rate. Because the analysis of fatal and injury accident rates is assumed to be more reliable, and for reasons of simplicity, the authors have chosen to treat the state-policy interaction for two-lane highways as not statistically significant and to assume that the mean run-off-road accident rate for each highway type and roadside design policy is representative of all three states. However, one could also justify using a separate estimate in each state for the mean accident rates of each roadside design policy on two-lane highways. The magnitudes of the mean accident rates, both state-by-state and combined, are discussed in the next section.

The conclusion drawn from the analyses of variance and covariance is that roadside design policy has a statistically significant effect both on run-off-road accident rate and on fatal and injury run-off-road accident rate. Statistical significance implies that the effect of roadside design policy on accident rate is large enough that it is unlikely to have occurred because of random variation alone. However, statistical significance does not necessarily imply that the effect of roadside design policy on accident rate is large enough to be important in a practical sense. Practical conclusions must be based on the magnitude of the observed differences in accident rate between roadside design policies (see next section) and on the cost-effectiveness implications of those differences. All the statistical analysis can do is to provide confidence that the observed differences, however large or small, are real.

Mean and Adjusted Mean Accident Rates

This section compares the mean and adjusted (or least square mean) accident rates for the three highway types and the three roadside design policies. The most elementary measure of effectiveness for roadside design policy is a simple comparison of arithmetic mean accident rates. On freeways, for example, the mean run-off-road accident rate is 0.235 accidents per million vehicle-miles for 6:1 Clear Zone sections and is 0.329 accidents per million vehicle-miles for 4:1 Clear Zone sections. The difference in these mean rates, 0.094 accidents per million vehicle-miles, is a measure of effectiveness for improving a 4:1 Clear Zone design to a 6:1 Clear Zone design. After adjustment for the effects of state and ADT on accident rate, the least square mean accident rates obtained were 0.182 accidents per million vehicle-miles for 6:1 Clear Zone sections and 0.289 accidents per million vehicle-miles for 4:1 Clear Zone sections. The corresponding difference in mean accident rates is 0.107 accidents per million vehicle-miles. In most cases, the difference between roadside design policies in least square mean accident rate was slightly larger than the difference in arithmetic mean accident rate, although the increase was never very large.

Tables D-5 and D-6 present a summary of the arithmetic and least square means for each highway type and roadside design policy for the individual and combined states. The means for run-off-road accident rate are given in Table D-5 and those for fatal and injury run-off-road accident rate are given in Table D-6. The least square means are preferable to the arithmetic means as a measure of effectiveness, and the least square means for the combined states are the single best measures of effectiveness for roadside design policy. Statistical comparisons performed using the least square means procedure of the SAS computer package confirm that, for each highway type, the least square mean accident rates for all of the roadside design policies are significantly different from one another.

Tables D-5 and D-6 also show the measures of effectiveness obtained from the data for the individual states. The state data illustrate that, although the magnitudes of the accident rates themselves vary markedly from state to state, with one exception, the differences in mean accident rate between roadside design policies are quite consistent from state to state. The one exception is the comparison between 4:1 Clear Zone and Nonclear Zone sections for two-lane highways, which

Table D-5. Comparison of accident rates between roadside design policies (run-off-road accidents per million vehicle-miles).

Highway Type	Data Set	Statistic	Roadside Design Policy: 6:1 CZ	4:1 CZ	NCZ	Differences Between Roadside Design Policies: 6:1 vs. 4:1	4:1 vs. NCZ
Two-Lane	Illinois	Arithmetic mean	0.385	0.543	1.180	0.158	0.637
	Minnesota	Arithmetic mean	0.141	0.237	0.471	0.096	0.234
	Missouri	Arithmetic mean	0.238	0.389	0.505	0.151	0.116
	All states	Arithmetic mean	0.243	0.379	0.639	0.136	0.260
	Illinois	Least square mean	0.415	0.580	1.189	0.165	0.609
	Minnesota	Least square mean	0.123	0.234	0.325	0.111	0.091
	Missouri	Least square mean	0.223	0.393	0.526	0.170	0.133
	All states	Least square mean	0.254	0.403	0.680	0.149	0.277
Freeway	Illinois	Arithmetic mean	0.270	0.377	--	0.107	--
	Minnesota	Arithmetic mean	0.133	0.225	--	0.092	--
	Missouri	Arithmetic mean	0.136	0.267	--	0.131	--
	All states	Arithmetic mean	0.235	0.329	--	0.094	--
	Illinois	Least square mean	0.272	0.375	--	0.103	--
	Minnesota	Least square mean	0.135	0.224	--	0.089	--
	Missouri	Least square mean	0.138	0.267	--	0.129	--
	All states	Least square mean	0.182	0.289	--	0.107	--
Four-Lane Divided (Nonfreeway)	Missouri	Arithmetic mean	0.155	0.319	0.607	0.164	0.288
	Missouri	Least square mean	0.155	0.319	0.607	0.164	0.288

6:1 CZ = 6:1 Clear Zone design policy
4:1 CZ = 4:1 Clear Zone design policy
NCZ = Nonclear Zone design policy

Table D-6. Comparison of accident rates between roadside design policies (fatal and injury run-off-road accidents per million vehicle-miles).

Highway Type	Data Set	Statistic	Roadside Design Policy 6:1 CZ	4:1 CZ	NCZ	Differences Between Roadside Design Policies 6:1 vs. 4:1	4:1 vs. NCZ
Two-Lane	Illinois	Arithmetic mean	0.126	0.215	0.495	0.089	0.280
	Minnesota	Arithmetic mean	0.067	0.113	0.221	0.046	0.108
	Missouri	Arithmetic mean	0.121	0.207	0.246	0.086	0.039
	All states	Arithmetic mean	0.113	0.198	0.291	0.085	0.093
	Illinois	Least square mean	0.140	0.232	0.527	0.092	0.295
	Minnesota	Least square mean	0.046	0.109	0.159	0.063	0.050
	Missouri	Least square mean	0.108	0.208	0.272	0.010	0.064
	All states	Least square mean	0.098	0.183	0.320	0.085	0.137
Freeway	Illinois	Arithmetic mean	0.103	0.135	--	0.032	--
	Minnesota	Arithmetic mean	0.046	0.057	--	0.011	--
	Missouri	Arithmetic mean	0.055	0.105	--	0.050	--
	All states	Arithmetic mean	0.089	0.117	--	0.028	--
	Illinois	Least square mean	0.103	0.135	--	0.032	--
	Minnesota	Least square mean	0.046	0.057	--	0.011	--
	Missouri	Least square mean	0.055	0.105	--	0.050	--
	All states	Least square mean	0.068	0.100	--	0.032	--
Four-Lane Divided (Nonfreeway)	Missouri	Arithmetic mean	0.057	0.129	0.298	0.072	0.169
	Missouri	Least square mean	0.057	0.129	0.298	0.072	0.169

6:1 CZ = 6:1 Clear Zone design policy
4:1 CZ = 4:1 Clear Zone design policy
NCZ = Nonclear Zone design policy

is larger in Illinois than in the other two states.

Table D-7. Adjusted mean accident rates by highway type and roadside design policy.

Highway Type	Roadside Design Policy 6:1 CZ	4:1 CZ	NCZ	Differences Between Roadside Design Policies 6:1 vs. 4:1 Δ	Significance[a]	4:1 vs. NCZ Δ	Significance[a]
RUN-OFF-ROAD ACCIDENTS PER MILLION VEH-MILES							
Two-Lane	0.254	0.403	0.680	0.149	SIG	0.277	SIG
Freeway	0.182	0.289	--	0.107	SIG	--	--
Four-Lane Divided (Nonfreeway)	0.155	0.319	0.607	0.164	SIG	0.288	SIG
FATAL AND INJURY RUN-OFF-ROAD ACCIDENTS PER MILLION VEH-MILES							
Two-Lane	0.098	0.183	0.320	0.085	SIG	0.137	SIG
Freeway	0.068	0.100	--	0.032	SIG	--	--
Four-Lane Divided (Non-Freeway)	0.057	0.129	0.298	0.072	SIG	0.169	SIG

[a] Statistically significant at 95% confidence level.

The key measures of effectiveness from the accident analysis are summarized in Table D-7. This table shows the least square means for the individual highway types and roadside design policies and for the differences between policies. Table D-7 shows that the differences in accident rate between the roadside design policies are statistically significant and that the roadside design policies vary quite markedly in accident rate, relative to one another; for example, the fatal and injury accident rate for a 6:1 Clear Zone section on a two-lane highway is about half the rate for a 4:1 Clear Zone section, which is in turn about half the rate for a Nonclear Zone section. Nevertheless, the differences in accident rate between roadside design policies are quite small in absolute magnitude; for example, the largest difference between roadside design policies found in Table D-7 is 0.288 accidents per million vehicle-miles for four-lane divided nonfreeways, which corresponds to 0.46 accidents per mile per year. The assessment of whether the observed differences in accident rate are large enough to justify additional expenditures to incorporate a clear zone in a highway design requires a cost-effectiveness analysis. Design examples illustrating such cost-effectiveness analyses will be found in Appendix F.

Tests for Accident Severity Effects

The analysis described above has established that the run-off-road accident rate decreases as the roadside design policy improves. Further statistical tests were conducted to determine whether the roadside design policies also differ in the severity distribution for reported accidents. Accident severity is generally classified in three categories: fatal accidents, injury accidents, and property-damage-only accidents. If there is a shift in the distribution between these accident severity levels from one roadside design policy to another, this shift should be considered in any cost-effectiveness analysis of design policies.

Table D-8 presents the severity distribution for run-off-road accidents by highway type and roadside design policy. The table entries represent the combined data for Illinois, Minnesota, and Missouri.

Table D-8. Accident severity distribution for single-vehicle run-off-road accidents.

Highway Type	Roadside Design Policy	Fatal Accidents No.	Fatal Accidents %	Injury Accidents No.	Injury Accidents %	Property-Damage Only Accidents No.	Property-Damage Only Accidents %	Total Accidents No.	Total Accidents %
Two-Lane	6:1 CZ	12	2.5	201	41.1	276	56.4	489	100.0
	4:1 CZ	48	3.0	720	44.5	850	52.5	1,618	100.0
	NCZ	22	1.4	684	43.0	886	55.6	1,592	100.0
Four-Lane Freeway	6:1 CZ	32	1.6	705	35.7	1,237	62.7	1,974	100.0
	4:1 CZ	71	1.5	1,638	34.8	2,999	63.7	4,708	100.0
Four-Lane Divided (Nonfreeway)	6:1 CZ	4	1.5	109	41.4	150	57.0	163	100.0
	4:1 CZ	15	1.8	348	42.9	448	55.2	811	100.0
	NCZ	2	1.0	95	49.0	97	50.0	194	100.0

The differences in accident severity distribution between roadside design policies shown in Table D-8 are small and there is no consistent pattern of lower accident severity on improved roadside design policies. Statistical tests were conducted to compare the accident severity distributions for pairs of roadside design policies within individual highway types. Three different forms of the accident severity distribution were tested: one form using three severity levels (fatal vs. injury vs. property-damage-only), and two other forms using just two levels (fatal vs. injury; and fatal and injury vs. property-damage-only). The three-level comparisons were performed using the Kolmogorov-Smirnov test for distribution shifts (6). The two-level comparisons were performed using the Z-test for differences in proportions (19).

The results of the statistical tests involving accident severity distribution are given in Table D-9. Of the 21 tests performed, only one was statistically significant. Furthermore, the comparison that was statistically significant was in the opposite sense to that expected; the proportion of fatal and injury accidents involving fatalities was larger for 4:1 Clear Zone sections than for Nonclear Zone sections on two-lane highways. This result to the contrary notwithstanding, it was concluded that there is no difference between roadside design policies in the severity distribution of reported accidents.

Further support for this conclusion was obtained from an analysis of covariance, similar to those presented in Tables D-2 and D-4, using the severity ratio (ratio of fatal and injury accident rate to total accident rate) as the dependent variable. Table D-10 presents the results of this analysis. No statistically significant effect of roadside design policy on severity ratio was found for either two-lane highways or four-lane divided nonfreeways. A statistically significant effect of roadside design policy on severity ratio was found at the 90 percent confidence level for freeways; however, examination of the least mean square severity ratios for freeways found a lower severity ratio for the 4:1 Clear Zone design policy than for the 6:1 Clean Zone design policy. These results are quite consistent with the analysis of the accident severity distribution described earlier.

None of the analyses reported above reveals any consistent trend toward roadside design policy improvements decreasing fatal and injury accident rate to a greater extent than property-damage-only accidents. The reader should not misinterpret this finding to mean that roadside design policy improvements do not decrease the frequency of severe accidents; the finding means only that such improvements are equally effective in reducing both fatal and injury accidents

Table D-9. Statistical tests of accident severity distributions for run-off-road accidents.

Highway Type	Roadside Design Policy Comparison	3 Levels (Fatal Injury/PDO)[a]	2 Levels (Fatal Injury)[b]	2 Levels (Fatal and Injury/PDO)[b]
Two Lane	6:1 CZ vs. 4:1 CZ	NS	NS	NS
	4:1 CZ vs. NCZ	NS	SIG[c]	NS
	6:1 CZ vs. NCZ	NS	NS	NS
Freeway	6:1 CZ vs. 4:1 CZ	NS	NS	NS
Four-Lane Divided (Nonfreeway)	6:1 CZ vs. 4:1 CZ	NS	NS	NS
	4:1 CZ vs. NCZ	NS	NS	NS
	6:1 CZ vs. NCZ	NS	NS	NS

[a] Using Kolmogorov-Smirnov test for distribution shift.

[b] Using Z-test for difference of proportions.

[c] Statistical significance at 95% confidence level.

Table D-10. Analysis of covariance of roadside design policy and other variables for ratio of fatal and injury accident rate to total accident rate.

Source of Variation		Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (at 95% Confidence Level)
		TWO-LANE HIGHWAYS (N=1,181)				
State	(Factor)	0.906	2	0.453	3.14	SIG
Policy	(Factor)	0.005	2	0.002	0.02	NS
State-Policy	(Interaction)	0.573	4	0.286	0.99	NS
Explained		1.483	8	0.185	1.28	NS
Error		169.128	1,172	0.144		(R^2 = 0.009)
Total		170.610	1,180			
		FREEWAYS (N=986)				
State	(Factor)	0.783	2	0.392	5.55	SIG
Policy	(Factor)	0.209	1	0.209	2.97	NS[a]
State-Policy	(Interaction)	0.108	2	0.054	0.76	NS
Explained		1.100	5	0.220	3.12	SIG
Error		69.089	980	0.070		(R^2 = 0.015)
Total		70.189	985			
		FOUR-LANE DIVIDED NONFREEWAYS (N=389)				
ADT	(Covariate)	0.662	1	0.662	4.95	SIG
Policy	(Factor)	0.422	2	0.211	1.58	NS
Explained		1.084	3	0.361	2.70	SIG
Error		51.518	385	0.133		(R^2 = 0.021)
Total		52.602	388			

[a] Statistically significant at 90% confidence level.

and property-damage-only accidents.

Relationship of ADT and Single-Vehicle Run-Off-Road Accident Rate

The planned use of a cost-effectiveness approach to compare roadside design policies makes it especially important to quantify the relationship between run-off-road accident rate and ADT. The analysis of covariance results reported earlier have shown that ADT can have a statistically significant influence on accident rate; therefore, the magnitude and direction of this influence should be determined. (It should be noted that for two-lane highways both the ADT and shoulder width covariates were statistically significant. This sensitivity to shoulder width has been controlled for, but has not been investigated in the same depth as ADT.) Furthermore, the ADT is also used to convert accident rate into accident frequency per mile per year, an essential step in cost-effectiveness analysis.

An analysis of covariance model generally represents the relationship between a covariate and the dependent variable (in this case, the accident rate and ADT relationship) as a straight line. As an extension of the analysis of covariance procedure, a statistical test can be employed to determine whether the slope of the linear accident rate and ADT relationship differs between the roadside design policies or whether a single common slope can be used for all roadside design policies. This determination requires a different analysis of covariance model than was used earlier, because the ADT covariate must be entered into the model after, rather than before, the roadside design policy factor. The comparison of slopes is performed by an F-test described by Ostle (19, p. 204) and is performed if, and only if, there is a significant linear relationship between accident rate and ADT. The specific procedure used to perform the slope comparisons using the SAS computer package was that described by Milliken and Johnson (14, Chapter XI).

For two-lane highways, the slopes of the run-off-road accident rate and ADT regression lines for the three roadside policies are -0.038, -0.050, and -0.027 accidents per million vehicle-miles per 1,000 vpd for 6:1 Clear Zone, 4:1 Clear Zone, and Nonclear Zone sections, respectively. These three individual linear relationships between accident rate and ADT were each statistically significant (i.e., the slope of each regression is significantly different from zero).

An F-test to compare these slopes indicates that they do not differ significantly ($F(2,2018) = 0.596$), indicating that the common slope of -0.041 accidents per million vehicle-miles per 1,000 vpd can be used for all three roadside design policies.

The negative slope of this relationship indicates that single-vehicle run-off-road accident rate decreases with increasing ADT. This same trend has been observed in other studies, where the total accident rate for two-lane highways has been found to decrease with increasing traffic volume, particularly at low traffic volume levels where single-vehicle accidents predominate (25). This relationship can be expressed as:

$$AR = -0.041 \; ADT + b_o$$

where AR = Single-vehicle run-off-road accident rate, accidents per million vehicle-miles;

ADT = Average daily traffic volume, 1,000 vpd; and,

b_o = A constant that depends on the roadside design policy (b_o = 0.361 for 6:1 Clear Zone sections, 0.510 for 4:1 Clear Zone sections, and 0.787 for Nonclear Zone sections).

A similar analysis for fatal and injury run-off-road accident rate found that a common slope of -0.026 accidents per million vehicle-miles per 1,000 vpd should be used ($F(2,2018) = 1.06$). This relationship can be expressed as:

$$AR_{FI} = -0.026 \; ADT + b_o$$

where AR_{FI} = Fatal and injury single-vehicle run-off-road accident rate, accidents per million vehicle-miles;

ADT = Average daily traffic volume, 1,000 vpd; and,

b_o = A constant that depends on the roadside design policy (b_o = 0.166 for 6:1 Clear Zone sections, 0.251 for 4:1 Clear Zone sections, and 0.388 for Nonclear Zone sections).

For freeways, accident rate and ADT regression lines for the 6:1 and 4:1 Clear Zone policies were not statistically significant. This finding means that the best estimate of the slope of the accident rate and ADT relationship for freeways is zero. The same result was obtained for the relationship between fatal and injury accident rate and ADT for freeways. The slope of the accident rate and ADT relationships for four-lane divided nonfreeways were also found to be not significantly different from zero. These results are in contrast to the results presented for freeways in Tables D-2 and D-4, where the ADT and roadside design policy variables were considered in a different order.

ILLUSTRATION OF ANALYSIS RESULTS

The analysis results developed in this appendix are presented graphically in this section. A series of figures illustrates the relationship between accident experience and ADT for the range of highway types and roadside design policies studied. Because it is often difficult to interpret the meaning of an accident rate, the accident experience has been expressed in these figures as accident frequency per mile per year. The accident frequency per mile per year is computed as:

$$APMPY = \frac{AR(ADT)(365)}{10^6}$$

where APMPY = Number of accidents per mile per year;

AR = Accident rate, accidents per million vehicle-miles; and

ADT = Average daily traffic volume, vpd.

All of these figures represent single-vehicle run-off-road accidents per mile per year on both sides of the road and in the medians of divided highways.

Figure D-1 shows the relationship between run-off-road accidents per mile per year and ADT for three roadside design policies on two-lane highways. The magnitude of the differences in accident experience between roadside design policies is also illustrated. Figure D-2 shows a similar relationship for fatal and injury accidents on two-lane highways. These relationships are based directly on the equations presented in the discussion of accident rate and ADT relationships. The range of ADT for two-lane highways represented in the project data base is approximately 750 to 5,000 vpd; the relationships in Figures D-1 and D-2 should not be extrapolated beyond this range because they quickly lose their validity.

Figure D-3 shows the relationship between run-off-road accidents per mile per year and ADT on four-lane freeways. Figure D-4 shows the corresponding relationship for fatal and injury run-off-road accidents. These relationships are based on the accident rates in Table D-7 and should not be extrapolated beyond the ADT range from 2,000 to 20,000.

Finally, Figures D-5 and D-6 show the relationship between accidents per mile per year and ADT on four-lane divided nonfreeways for total run-off-road accidents and fatal and injury run-off-road accidents, respectively. These figures are based directly on the accident rates in Table D-7 and should not be extrapolated beyond the ADT range from 3,000 to 10,000.

ANALYSIS OF ACCIDENT TYPES OTHER THAN SINGLE-VEHICLE RUN-OFF-ROAD ACCIDENTS

This section presents a brief review of the accident experience for all accident types. The types of accidents that are discussed in this section, in addition to single-vehicle run-off-road accidents are, single-vehicle nonrun-off-road accidents, multiple-vehicle nonintersection-related accidents, and total accidents.

Tables D-11 and D-12 present mean accident rates by accident type and roadside design policy. The combined accident rate for all severity levels is presented in Table D-11 and the accident rate for fatal and injury accidents only in Table D-12. The accident rates in these tables are least square means that have been adjusted for the effects of state, ADT, and shoulder width (whenever these effects are statistically significant), in the same manner as the mean accident rates in Table D-7 were adjusted.

Throughout the study, there had been a concern that differences in roadway geometrics between the roadside design policies could produce an effect that could be mistaken for an effect of roadside design policy. The only roadway geometric feature whose effect was adjusted for in the analysis was shoulder width, although state and ADT could be a

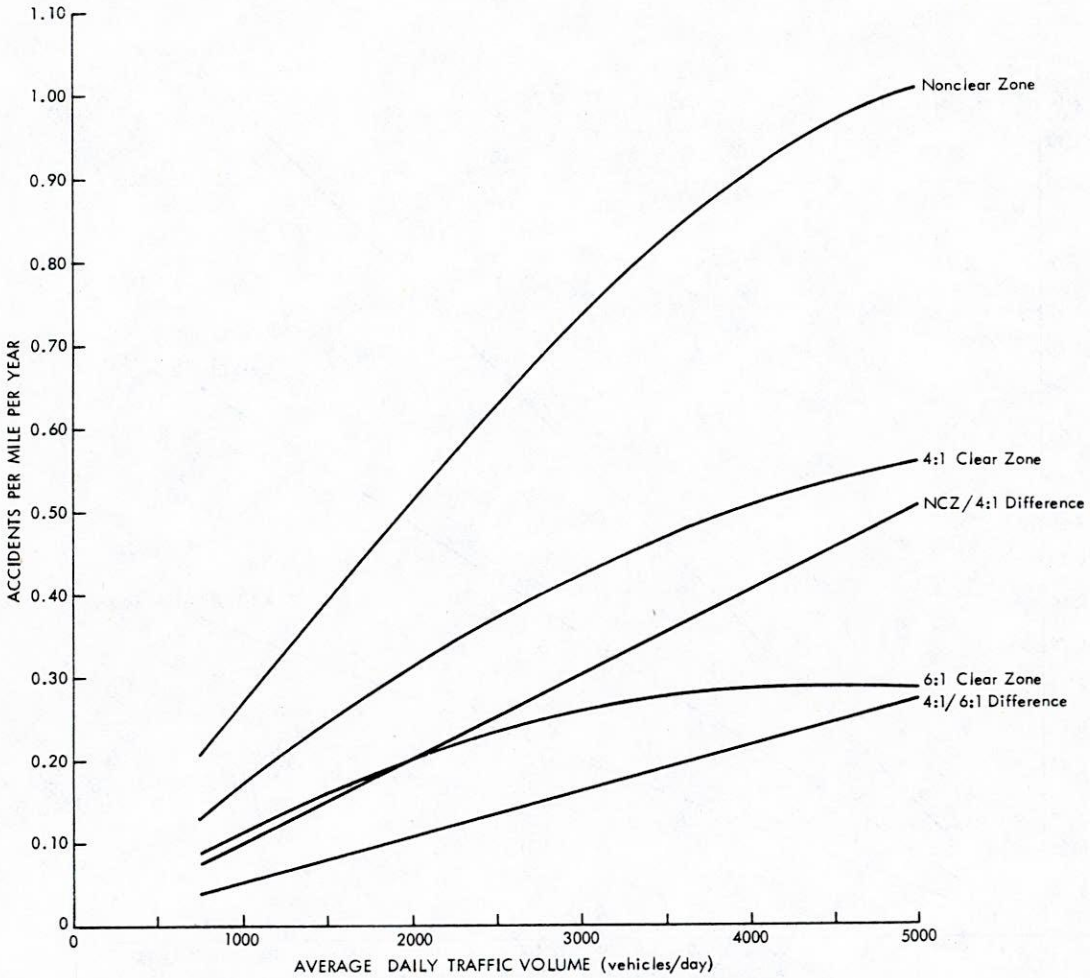


Figure D-1. Relationship between single-vehicle run-off-road accidents per mile per year and ADT for two-lane highways.

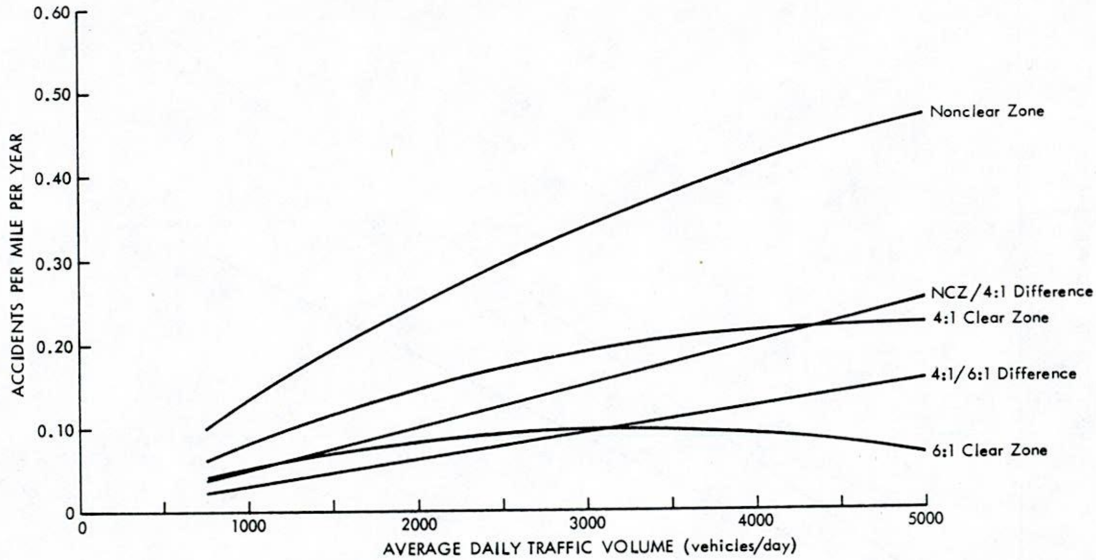


Figure D-2. Relationship between fatal and injury single-vehicle run-off-road accidents per mile per year and ADT for two-lane highways.

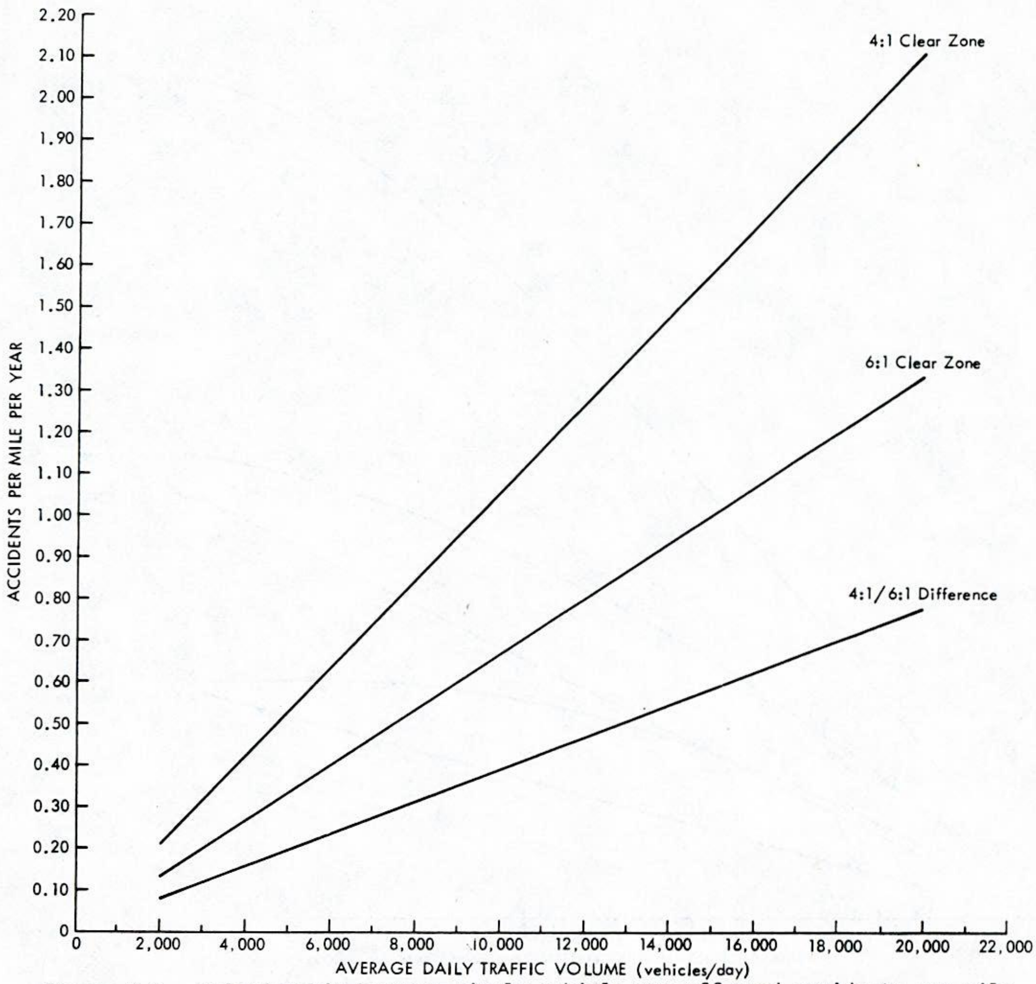


Figure D-3. Relationship between single-vehicle run-off-road accidents per mile per year and ADT for freeways.

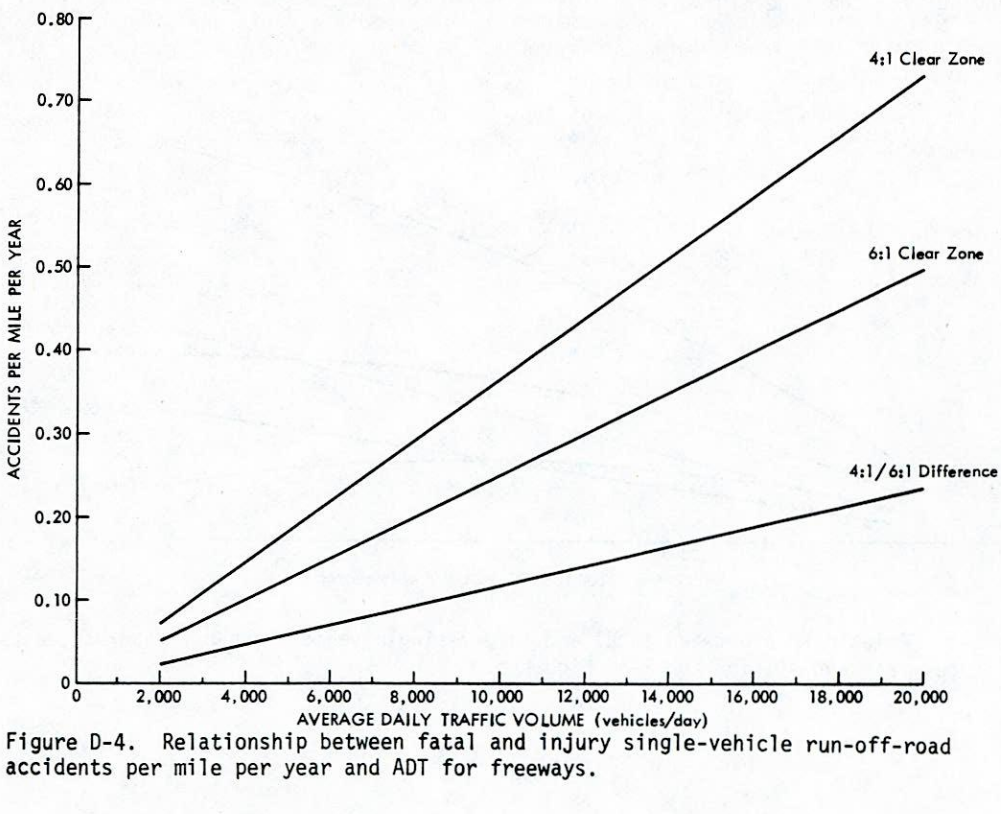


Figure D-4. Relationship between fatal and injury single-vehicle run-off-road accidents per mile per year and ADT for freeways.

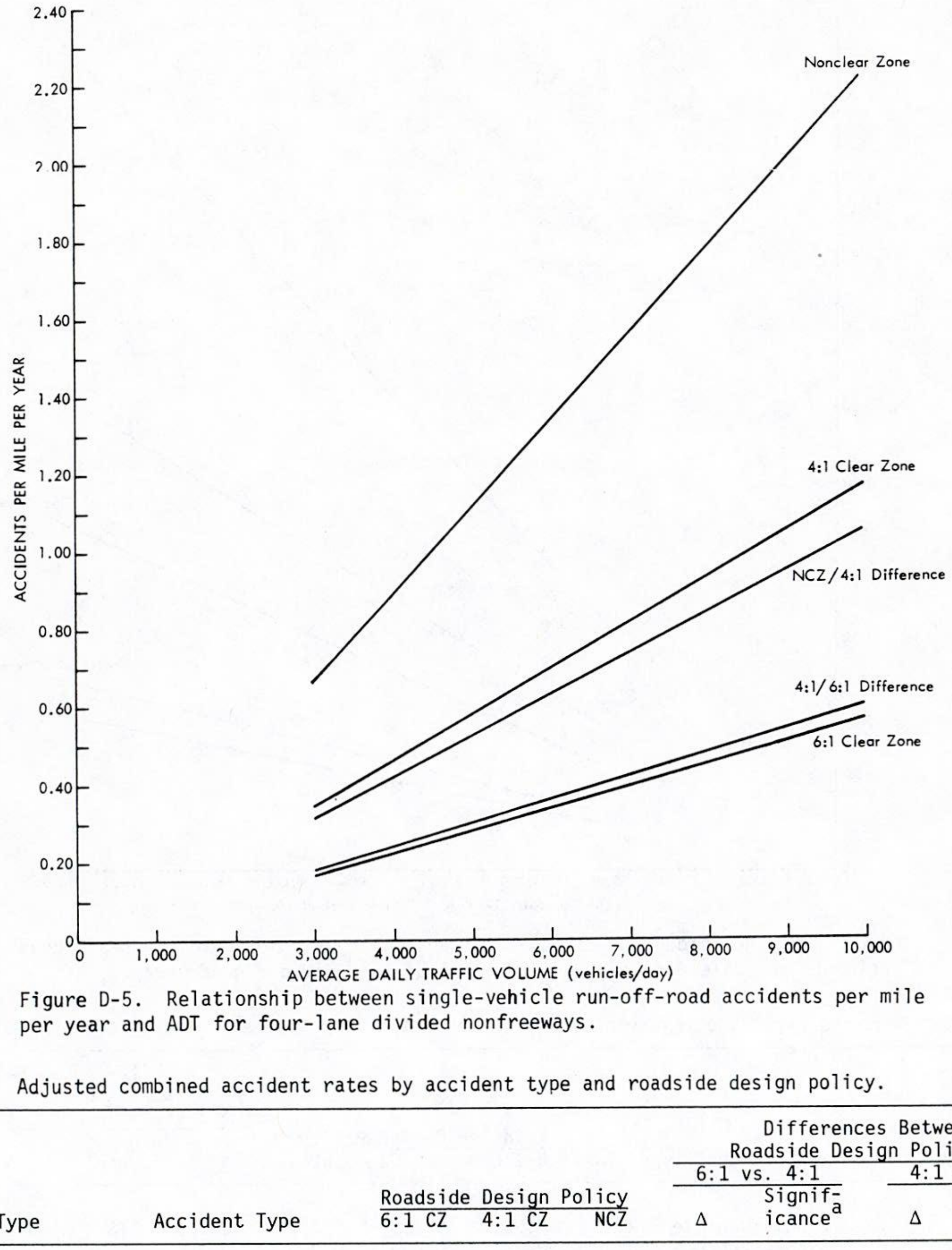


Figure D-5. Relationship between single-vehicle run-off-road accidents per mile per year and ADT for four-lane divided nonfreeways.

Table D-11. Adjusted combined accident rates by accident type and roadside design policy.

		Roadside Design Policy			Differences Between Roadside Design Policies			
					6:1 vs. 4:1		4:1 vs. NCZ	
Highway Type	Accident Type	6:1 CZ	4:1 CZ	NCZ	Δ	Significance[a]	Δ	Significance[a]
Two-Lane	Single-Vehicle ROR	0.254	0.403	0.680	0.149	SIG	0.277	SIG
	Single-Vehicle non-ROR	0.227	0.318	0.259	0.091	SIG	-0.059	SIG
	Multiple-Vehicle	0.323	0.478	0.506	0.155	SIG	0.028	NS
	Total	0.804	1.199	1.445	0.395	--	0.246	--
Freeway	Single-Vehicle ROR	0.182	0.289	--	0.107	SIG	--	--
	Single-Vehicle non-ROR	0.107	0.135	--	0.028	SIG	--	--
	Multiple-Vehicle	0.176	0.205	--	0.029	SIG	--	--
	Total	0.465	0.629	--	0.164	--	--	--
Four-Lane Divided (Nonfreeway)	Single-Vehicle ROR	0.155	0.319	0.607	0.164	SIG	0.288	SIG
	Single-Vehicle non-ROR	0.112	0.140	0.165	0.028	NS[b]	0.025	NS
	Multiple-Vehicle	0.143	0.185	0.317	0.042	NS[b]	0.132	SIG
	Total	0.410	0.644	1.089	0.234	--	0.445	--

[a] Statistical significance at 95% confidence level, unless otherwise stated.

[b] Statistically significant at 90% confidence level.

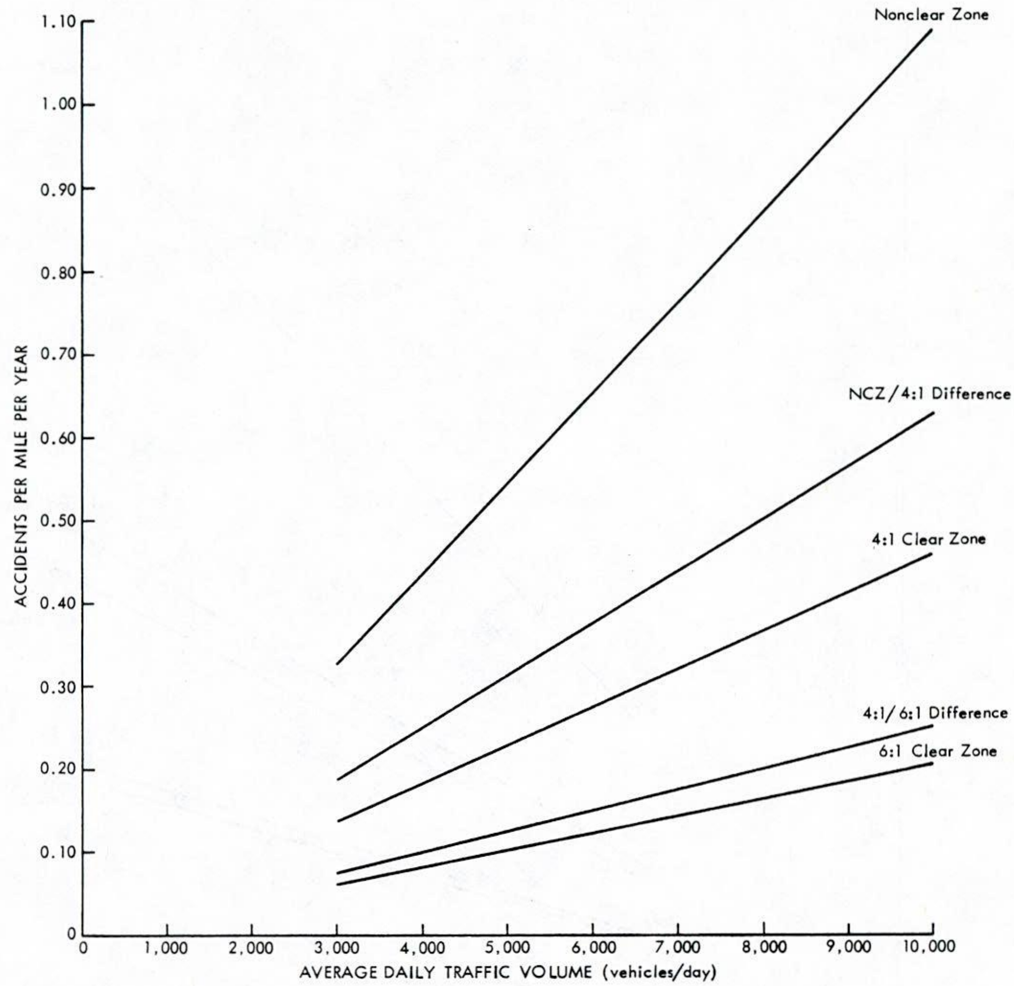


Figure D-6. Relationship between fatal and injury single-vehicle run-off-road accidents per mile per year and ADT for four-lane divided nonfreeways.

Table D-12. Adjusted fatal and injury accident rates by accident type and roadside design policy.

Highway Type	Accident Type	Roadside Design Policy 6:1 CZ	4:1 CZ	NCZ	Differences Between Roadside Design Policies: 6:1 vs. 4:1 Δ	6:1 vs. 4:1 Significance[a]	4:1 vs. NCZ Δ	4:1 vs. NCZ Significance[a]
Two-Lane	Single-Vehicle ROR	0.098	0.183	0.320	0.085	SIG	0.137	SIG
	Single-Vehicle non-ROR	0.036	0.059	0.063	0.023	NS[b]	0.004	NS[b]
	Multiple-Vehicle	0.121	0.130	0.186	0.009	NS	0.056	NS[b]
	Total	0.255	0.372	0.569	0.117	--	0.197	--
Freeway	Single-Vehicle ROR	0.068	0.100	--	0.032	SIG	--	--
	Single-Vehicle non-ROR	0.016	0.020	--	0.004	NS	--	--
	Multiple-Vehicle	0.064	0.069	--	0.005	NS	--	--
	Total	0.148	0.189	--	0.041	--	--	--
Four-Lane Divided (Nonfreeway)	Single-Vehicle ROR	0.057	0.129	0.298	0.072	SIG	0.169	SIG
	Single-Vehicle non-ROR	0.011	0.015	0.006	0.004	NS	-0.009	NS
	Multiple-Vehicle	0.052	0.051	0.099	-0.001	NS	0.048	NS
	Total	0.120	0.195	0.403	0.075	--	0.208	--

[a] Statistical significance at 95% confidence level, unless otherwise stated.

[b] Statistically significant at 90% confidence level.

surrogate for other geometric and terrain features to some extent. The accident rates in Table D-11 and, especially, Table D-12, provide some evidence to relieve this concern. Although there were some statistically significant differences for the combined accident rates for all severity levels, no statistically significant differences in fatal and injury accident rate were found at the 95 percent confidence level for either single-vehicle nonrun-off-road accidents or multiple-vehicle accidents.

APPENDIX E

ESTIMATION OF ROADSIDE ACCIDENT RATES

Although the data base developed in this study is limited to highway sections with three basic roadside design policies, a much broader comparison of roadway configuration is possible if a predictive model could be applied. This appendix (1) compares the accident rates found in the project data base with those predicted by the NCHRP Report 148 roadside hazard model, (2) describes a method for adjusting the model results, and (3) predicts run-off-road accident rates for several roadside configurations that could not be addressed directly with the available data.

THE NCHRP REPORT 148 MODEL

A roadside hazard model, developed by Glennon in NCHRP Report 148 (9), provides a basic analysis technique for comparison of roadside improvements. This model, in a slightly less objective form, is also presented in the AASHTO Barrier Guide (2).

The model depends on the concept that an injury-producing roadside impact occurs as a sequence of four conditional events. First, the vehicle must be within the discrete increment of roadway associated with a potential collision with the roadside obstacle. Then, a roadside encroachment must occur. Next, the lateral displacement of the vehicle must be great enough for collision with the roadside obstacle. And, finally, the collision must be of sufficient magnitude to produce an injury.

This sequence of events suggests a conceptual approach for evaluating the degree of hazard for roadside situations. Such an approach considers the vehicular exposure, the expected vehicular encroachment rate, the expected distribution of encroachment angles, the expected distribution of lateral displacements of encroaching vehicles, and the severity, size, and lateral placement of the roadside obstacle. Figure E-1 is a schematic illustration of the increment, L, of highway length associated with a particular roadside obstacle. The hazard envelope is defined by the locus of the right-front corner of the colliding vehicle.

The description of the foregoing variables suggests that a mathematical relationship is required to truly evaluate the hazard index of a particular roadside situation. For a given angle of encroachment, Θ, the explicit hazard equation given in NCHRP Report 148 is as follows:

$$H = \frac{E_f S}{5{,}280}\left[\ell\int_{s}^{\infty} f(y)dy + \int_{\ell}^{\ell+d\csc\theta}\int_{s+(x-\ell)\cos\theta\sin\theta}^{\infty} f(y)dydx + \int_{\ell+d\csc\theta}^{\ell+d\csc\theta+w\cot\theta}\int_{s+d\cos\theta+(x-\ell-d\sec\theta)\tan\theta}^{\infty} f(y)dydx\right]$$

where
- H = Hazard index, number of fatal and nonfatal injury accidents per year;
- E_f = Encroachment frequency, number of encroachments per mile per year;
- S = Severity index, proportion of fatal and nonfatal injury accidents;
- ℓ = Longitudinal length of the obstacle, feet;
- w = Lateral width of the obstacle, feet;
- s = Lateral placement of the obstacle, feet;
- d = Width of the vehicle, feet;
- θ = Angle of encroachment, degrees;
- x = Longitudinal distance from the farthest downstream encroachment point to the encroachment point of reference, feet; and
- $f(y)$ = Probability density function of lateral displacements of encroaching vehicle.

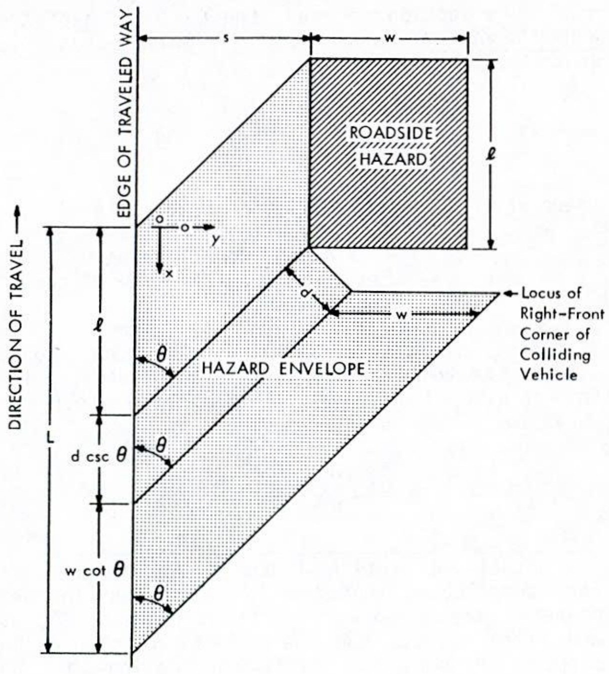


Figure E-1. Schematic illustration of roadside obstacle and its relationship to an encroaching vehicle.

Each integral expression in the brackets of the hazard equation multiplied by $E_f/5,280$ yields the number of fatal and nonfatal injury accidents per year expected for each subdivision of the hazard envelope. Thus, the first expression in the brackets represents the contribution of the exposure length, ℓ, and considers the probability of a vehicle lateral displacement greater than s. The second expression is the contribution of the exposure length d csc Θ to the hazard index. The third expression is the contribution of the exposure length w cot Θ. The double integrals account for the varying lateral displacements of a vehicle required for collision.

The model as presented in NCHRP Report 148 applies only to freeway situations because it uses the roadside encroachment parameters developed by Hutchinson and Kennedy (13). More recently, Glennon and Wilton (11) have expanded the applicability of the roadside hazard model. Although this further research was limited to developing estimates of the necessary inputs and modifications to the original hazard model developed in NCHRP Report 148, it is usable for predicting the effectiveness of roadside safety improvements on all classes of highways. The new formulation contributes additional information about the nature of vehicle encroachments and the severity indices of roadside hazards for all classes of highways other than freeways, including: urban arterial streets, rural two-lane highways, and rural multilane highways.

APPLICATION OF THE NCHRP REPORT 148 MODEL TO ROADSIDE DESIGN POLICIES

When predicting the accident experience for one side of a section of road, the basic form of the NCHRP Report 148 model can be simplified as follows:

$$H = \frac{E_f S}{5,280} \ [\ell \cdot P(y \geq s)]$$

where $P(y \geq s)$ = Probability that the lateral displacement, y, of the vehicle will exceed some lateral distance, s, from the edge of the traveled way.

If the roadside terrain had one constant slope, starting at the edge of traveled way and extending to infinity, this equation could be further reduced to:

$$H = \frac{E_f S \ell}{5,280}$$

The actual application of the model, however, is more complicated than the foregoing equation because of the combined effects of roadside slopes and fixed objects and the effects of changes in slope. An example of this application will be presented later.

As shown earlier in this report, the best estimate of the fatal and injury run-off-road accident rate for the various roadside design policies is as follows:

Highway Type	Roadside Design Policy	Fatal and Injury Run-Off-Road Accident Rate (Acc/MVM)
Freeway	6:1 Clear Zone	0.068
Freeway	4:1 Clear Zone	0.100
Two-lane	6:1 Clear Zone	0.098
Two-lane	4:1 Clear Zone	0.183
Two-lane	Nonclear Zone	0.320

In order to compare the predictions of the NCHRP Report 148 model with these results a detailed description of the roadside slopes and fixed objects representing each policy is required. Such descriptions developed from the field survey data are given in Tables E-1 through E-5 for the five combinations of highway type and roadside design policy. As seen from these tables, none of the clear zone policies is perfectly applied. Some fixed objects remain within the 30-ft clear area and the nominal maximum slope is exceeded up to 20 percent of the time on freeways and more often on two-lane highways. Although the highways where the 6:1 Clear Zone policy was applied are dominated by 6:1 slopes, a fair proportion of less desirable slopes is present. Likewise, when the 4:1 Clear Zone policy was applied to freeways, slopes of 4:1 or better were dominant. For two-lane highways where the 4:1 Clear Zone policy was applied, however, the dominant slopes are 3:1 and 4:1. The Nonclear Zone sections on two-lane highways exhibited the least desirable roadside design with a 21 percent coverage of fixed objects at 20 ft and dominant slopes of 2:1 and 3:1.

ACCIDENT RATE COMPARISON USING THE NCHRP REPORT 148 MODEL

With the distributions of roadside features shown in the last section, it is possible to compare the actual roadside accident rates with those predicted by the NCHRP Report 148 model (using inputs shown both in that report and in the Glennon and Wilton report). And, if there are some variances, the NCHRP Report 148 model can be calibrated for the purpose of looking at other roadside configurations.

Table E-1. Distribution of roadside features for 6:1 Clear Zone sections on freeways.

CROSS-SECTION FEATURES

General Cross-Section	Shoulder Width (ft)	Cut Slopes: Foreslope	Cut Slopes: Backslope	Fill Slopes: Within 30 ft	Fill Slopes: Beyond 30 ft	Median Foreslope	Percent of Mileage
Guardrail and Bridge Rail	11	--	--	--	--	--	5.00
Cut	11	6:1	4:1	--	--	6:1	6.02
Cut	11	5:1	4:1	--	--	6:1	0.98
Fill	11	--	--	6:1	4:1	6:1	68.64
Fill	11	--	--	5:1	4:1	6:1	14.96
Fill	11	--	--	4:1	3:1	6:1	4.40
							100.00

FIXED OBJECT COVERAGE
(Not including Guardrail and Bridge Rail)

Lateral Placement (ft)	Coverage Factor (%)[a]
12-20	0
21-30	1
> 30	3

[a] Fixed-object coverage factor for outside of roadway; no fixed objects other than guardrail in median.

Table E-2. Distribution of roadside features for 4:1 Clear Zone sections on freeways.

CROSS-SECTION FEATURES

General Cross-Section	Shoulder Width (ft)	Cut Slopes Fore-slope	Cut Slopes Back-slope	Fill Slopes Within 30 ft	Fill Slopes Beyond 30 ft	Median Foreslope	Percent of Mileage
Guardrail and Bridge Rail	10.5	--	--	--	--	--	8.00
Cut	10.5	6:1	4:1	--	--	5:1	3.30
Cut	10.5	5:1	4:1	--	--	5:1	9.90
Cut	10.5	4:1	4:1	--	--	5:1	6.16
Cut	10.5	3:1	3:1	--	--	5:1	2.64
Fill	10.5	--	--	6:1	4:1	5:1	9.10
Fill	10.5	--	--	5:1	4:1	5:1	20.30
Fill	10.5	--	--	4:1	3:1	5:1	28.70
Fill	10.5	--	--	3:1	3:1	5:1	9.10
Fill	10.5	--	--	2:1	2:1	5:1	2.80
							100.00

FIXED OBJECT COVERAGE
(Not Including Guardrail and Bridge Rail)

Lateral Placement (ft)	Coverage Factor (%)[a]
12-20	2
21-30	1
> 30	5

[a] Fixed-object coverage factor for outside of roadway; no fixed objects other than guardrail in median.

Table E-3. Distribution of roadside features for 6:1 Clear Zone sections on two-lane highways.

CROSS-SECTION FEATURES

General Cross-Section	Shoulder Width (ft)	Cut Slopes Fore-slope	Cut Slopes Back-slope	Fill Slopes Within 30 ft	Fill Slopes Beyond 30 ft	Percent of Mileage
Guardrail and Bridge Rail	10	--	--	--	--	3.00
Cut	10	6:1	4:1	--	--	25.20
Cut	10	5:1	4:1	--	--	5.60
Cut	10	4:1	4:1	--	--	1.40
Cut	10	3:1	3:1	--	--	1.05
Cut	10	2:1	2:1	--	--	1.75
Fill	10	--	--	6:1	4:1	44.02
Fill	10	--	--	5:1	4:1	9.92
Fill	10	--	--	4:1	3:1	3.10
Fill	10	--	--	3:1	3:1	2.48
Fill	10	--	--	2:1	2:1	2.48
						100.00

FIXED OBJECT COVERAGE
(Not Including Guardrail and Bridge Rail)

Lateral Placement (ft)	Coverage Factor (%)
12-20	0
21-30	7
> 30	9

The best way to show the application of the NCHRP Report 148 model is by using an example calculation. The following calculation is for 6:1 fill slopes on a 4:1 Clear Zone section on a freeway (Table E-2):

$$H = \frac{.00092(10066)}{2}\,[(.20)(.21)(.98)+(.55)(.21)(.02)$$
$$+(.20)(.38)(.99)+(.55)(.38)(.01)$$
$$+(.40)(.31)(.95)+(.55)(.31)(.05)]\,.091$$
$$+\ \frac{(.00092)(10066)}{2}\,[(.30)(.90)]\,.091$$

H = 0.1998 fatal and injury accidents per mile per year.

In this calculation, the first expression is the hazard of the roadside on the outside of the roadway and the second expression is the hazard associated with the median. The first part of each expression is the product of the slope (.00092) of the encroachment rate and ADT relationship and the ADT. This term is divided by 2 to obtain the encroachment rate for one-half (outside or median) of the highway. The slope for the encroachment rate and ADT relationship is given in the Glennon and Wilton report for all types of highway. The last part of each expression is the proportion of each mile that has 6:1 outside fill slopes (from Table E-2).

The outside roadside hazard calculation has six components within the brackets applying to three lateral increments of the roadside. The first lateral increment is 12 to 20 ft with a 6:1 fill slope and 2 percent fixed object coverage. For freeways 21 percent of roadside encroachments have a lateral displacement within this increment and will experience a severity index of 0.20

Table E-4. Distribution of roadside features for 4:1 Clear Zone sections on two-lane highways.

CROSS-SECTION FEATURES

General Cross-Section	Shoulder Width (ft)	Cut Slopes Fore-slope	Cut Slopes Back-slope	Fill Slopes Within 30 ft	Fill Slopes Beyond 30 ft	Percent of Mileage
Guardrail and Bridge Rail	10	--	--	--	--	8.00
Cut	10	6:1	4:1	--	--	7.05
Cut	10	5:1	4:1	--	--	8.46
Cut	10	4:1	4:1	--	--	16.45
Cut	10	3:1	3:1	--	--	14.57
Cut	10	2:1	2:1	--	--	0.47
Fill	10	--	--	6:1	4:1	2.25
Fill	10	--	--	5:1	4:1	6.30
Fill	10	--	--	4:1	3:1	13.50
Fill	10	--	--	3:1	3:1	19.80
Fill	10	--	--	2:1	2:1	3.15
						100.00

FIXED OBJECT COVERAGE
(Not Including Guardrail and Bridge Rail)

Lateral Placement (ft)	Coverage Factor (%)
12-20	4
21-30	5
> 30	8

Table E-5. Distribution of roadside features for Nonclear Zone sections on two-lane highways.

CROSS-SECTION FEATURES

General Cross-Section	Shoulder Width (ft)	Cut Slopes Fore-slope	Cut Slopes Back-slope	Fill Slopes Within 30 ft	Fill Slopes Beyond 30 ft	Percent of Mileage
Guardrail and Bridge Rail	8	--	--	--	--	3.00
Cut	8	6:1	4:1	--	--	5.28
Cut	8	5:1	4:1	--	--	3.08
Cut	8	4:1	4:1	--	--	9.68
Cut	8	3:1	3:1	--	--	18.48
Cut	8	2:1	2:1	--	--	7.48
Fill	8	--	--	6:1	4:1	2.12
Fill	8	--	--	5:1	4:1	9.01
Fill	8	--	--	4:1	3:1	12.19
Fill	8	--	--	3:1	3:1	13.78
Fill	8	--	--	2:1	2:1	15.90
						100.00

FIXED OBJECT COVERAGE
(Not Including Guardrail and Bridge Rail)

Lateral Placement (ft)	Coverage Factor (%)
10-20	4
21-30	17
> 30	17

(proportion of fatal and injury accidents) for the slope and a severity index of 0.55 for the fixed objects. The second lateral increment is 21 to 30 ft and will contain 38 percent of the lateral displacements on a 6:1 fill slope with 1 percent fixed object coverage. The third lateral increment is 31 ft and greater and will contain 31 percent of the lateral displacements with a 4:1 fill slope and 5 percent fixed object coverage. The median roadside hazard calculation allows simply for the severity (.30) of 5:1 fill slopes experienced by all encroachments (90 percent) beyond 12 ft laterally. The total hazard for the 9.1 percent of 4:1 Clear Zone sections on freeways that have 6:1 fill slopes was determined to be 0.1998 fatal and injury accidents per mile per year.

The total calculated hazard for the 4:1 Clear Zone sections on freeways was 2.934 fatal and injury accidents per mile per year. This accident frequency was converted to an accident rate by dividing it by the total annual exposure in vehicle-miles, based on the average ADT of 10,066 vpd for freeway 4:1 Clear Zone and the section length of 1 mile. This calculation yields a computed rate of 0.799 fatal and injury accidents per million vehicle-miles.

Table E-6 shows a comparison of the measured rates with those calculated using the NCHRP Report 148 model for each roadside design policy. As seen from Table E-6, the NCHRP Report 148 model, using input data developed in the Hutchinson and Kennedy and Glennon and Wilton studies, greatly overestimates the fatal and injury run-off-road accident rate found from the project data base. Furthermore, the overestimation of accident rate is greater for the better roadside design policies. There are at least two potential explanations for this overestimation of accident rate, as follows:

1. The mean and variance of the speed distribution during the study period (1975-1980) were probably lower than mean and variance of the speeds prevailing in the Hutchinson and Kennedy, NCHRP Report 148, and Glennon and Wilton studies. This might lead to lower encroachment rates and lower severity indices.

2. The Hutchinson and Kennedy study may have measured some controlled encroachments, leading to an overestimation of the rate of roadside encroachments that could potentially produce an accident. The preliminary results of a current Federal Highway Administration study of encroachments on a high-volume urban freeway suggest that the encroachment rates measured by Hutchinson and Kennedy are high.

Because the results obtained with the NCHRP Report 148 model do not agree with the actual accident data obtained in this study, it does not appear desirable to use the model directly to predict accident rates for roadside designs for which data were collected in the study. However, the ratio between the predicted and observed results in Table E-6 can be used as a correction factor to adjust results obtained with the NCHRP Report 148 model to be comparable to the observed accident rates. It is important to note that this correction factor increases as the roadside design policy improves for both freeways and two-lane highways. The use of such a correction factor appears justified because it is the input data to the model (especially the encroachment rates), rather than the logical structure of the model itself, that is in doubt.

Table E-6. Comparison of observed and predicted accident rates for various roadside design policies.

Highway Type	Roadside Design Policy	Observed Rate (Fatal and Injury Accidents per Million Vehicle-Miles)	Predicted Rate (Fatal and Injury Accidents per Million Vehicle-Miles)	Correction Factor (Ratio of Predicted to Observed Rate)
Freeway	6:1 Clear Zone	0.068	0.568	8.35
Freeway	4:1 Clear Zone	0.100	0.799	7.99
Two-Lane	6:1 Clear Zone	0.098	0.449	4.58
Two-Lane	4:1 Clear Zone	0.183	0.614	3.36
Two-Lane	Nonclear Zone	0.320	0.754	2.36

ACCIDENT RATE ESTIMATION USING THE NCHRP REPORT 148 MODEL

Several roadside designs were of interest but were either not present in the three states where accident data were collected or were not present in sufficient length to obtain reliable accident rates. The NCHRP Report 148 model, together with the correction factors presented in Table E-6, were used to estimate the accident rates for such designs. The roadside designs whose accident rates are estimated in this section include freeways with a Nonclear Zone roadside design policy, freeways, and two-lane highways with 20-ft clear zones and freeways and two-lane highways with more uniformly applied 6:1 Clear Zone and 4:1 Clear Zone roadside design policies.

Estimation of Run-Off-Road Accident Rate for Freeways Without Clear Zones

Freeways without a clear recovery zone were not included in the accident study portion of this

Table E-7. Distribution of roadside features assumed for Nonclear Zone sections on freeways.

CROSS-SECTION FEATURES

General Cross-Section	Shoulder Width (ft)	Cut Slopes Fore-slope	Cut Slopes Back-slope	Fill Slopes Within 30 ft	Fill Slopes Beyond 30 ft	Median Foreslope	Percent of Mileage
Guardrail and Bridge Rail	8	--	--	--	--	--	3.00
Cut	8	6:1	4:1	--	--	3.5:1	2.52
Cut	8	5:1	4:1	--	--	3.5:1	1.47
Cut	8	4:1	4:1	--	--	3.5:1	4.62
Cut	8	3:1	3:1	--	--	3.5:1	8.82
Cut	8	2:1	2:1	--	--	3.5:1	3.57
Fill	8	--	--	6:1	4:1	3.5:1	3.04
Fill	8	--	--	5:1	4:1	3.5:1	12.92
Fill	8	--	--	4:1	3:1	3.5:1	17.48
Fill	8	--	--	3:1	3:1	3.5:1	19.76
Fill	8	--	--	2:1	2:1	3.5:1	22.80
							100.00

FIXED OBJECT COVERAGE
(Not including Guardrail and Bridge Rail)

Lateral Placement (ft)	Coverage Factor (%)[a]
10-20	4
21-30	17
> 30	17

[a] Fixed-object coverage factor for outside of roadway; no fixed objects other than guardrail in median.

research. However, an estimation of the run-off-road accident rate for this kind of roadway is of interest to the study. To obtain this estimate, the NCHRP Report 148 model was applied to a hypothesized roadside design for a freeway Nonclear Zone, shown in Table E-7. This roadside design is essentially equivalent to the roadside design for Nonclear Zone sections on two-lane highways (presented in Table E-5) except that the overall proportions of cut and fill were the same as for 4:1 Clear Zone sections on freeways. When the NCHRP Report 148 model was applied, using a correction factor of 7.63 (extrapolated from the correction factors for 4:1 and 6:1 Clear Zones on freeways in Table E-6), the resulting accident rate was 0.149 fatal and injury accidents per million vehicle-miles. Since fatal and injury accidents constitute 36.6 percent of all run-off-road accidents on freeways, the total accident rate is estimated as 0.407 accidents per million vehicle-miles. This estimated accident rate for Nonclear Zone sections on freeways is about 50 percent higher than the observed rate for 4:1 Clear Zone sections on freeways and over twice that observed for 6:1 Clear Zone sections on freeways.

Estimation of Run-Off-Road Accident Rate for Highways with 20-Ft Clear Zones

One objective of the study was to determine the effect of clear zone width on run-off-road accident rates. However, this objective could not be attained through collection and analysis of accident data on existing highways, because a 20-ft clear zone policy has never been implemented on a wide scale. The NCHRP Report 148 model was applied, in the same manner as described above, to estimate the run-off-road accident rates for sections where a clear zone is present but extends only 20 ft from the traveled way. Such estimates were prepared for both 6:1 and 4:1 Clear Zone policies on both freeways and two-lane highways. The distributions of roadside features for these estimates are the same as those given in Tables E-1 through E-4 except that the foreslope break point was located at 20 ft, rather than 30 ft, from the traveled way and the fixed-object coverage factors were moved 10 ft closer to the roadway. The estimated accident rates for these 20-ft clear zones in comparison to the observed rates for 30-ft clear zones are as follows:

Highway Type	Roadside Design Policy	Fatal and Injury Accident Rate (Accidents per Million Vehicle-Miles) 20-ft Clear Zone	30-ft Clear Zone
Freeway	6:1 Clear Zone	0.078	0.068
Freeway	4:1 Clear Zone	0.106	0.100
Two-Lane	6:1 Clear Zone	0.105	0.098
Two-Lane	4:1 Clear Zone	0.191	0.183

These results show that the estimated accident rates for 20-ft clear zone policies are approximately 10 percent higher than the observed accident rate for 30-ft clear zone policies.

Estimation of Run-Off-Road Accident Rates for a More Uniform Application of Clear Zone Policies

It was established in the field survey portion of this study that the 6:1 and 4:1 Clear Zone sections contain some steeper slopes and some fixed objects within the 30-ft clear recovery area. The NCHRP Report 148 model was used to determine what the single-vehicle run-off-road accident rate would be if a more uniform roadside design policy had been applied. For this purpose, the distributions of roadside features in Tables E-1 through E-4 were changed to include no slopes steeper than the nominal slope (6:1 or 4:1, as appropriate) and no fixed objects other than guardrail or bridge rail within 30 ft of the traveled way. The model correction factors were also adjusted to reflect the improvement in roadside design policy. The following results were obtained:

Highway Type	Roadside Design Policy	Maximum Foreslope	Correction Factor	Estimated Fatal and Injury Accident Rate (Accidents per Million Vehicle-Miles)
Freeway	6:1 Clear Zone	6:1	8.50	0.064
Freeway	4:1 Clear Zone	4:1	8.20	0.095
Two-Lane	6:1 Clear Zone	6:1	5.00	0.069
Two-Lane	4:1 Clear Zone	4:1	4.00	0.139

In comparing these accident rates with those of the actual policy applications, a difference of only about 5 percent is apparent for freeways, but a difference of about 25 percent was found for two-lane highways. Thus, there are accident reduction benefits that could be obtained from roadside improvements even on highways that nominally have 30-ft clear zones. However, the cost-effectiveness of such improvements must be examined on a site-by-site basis.

APPENDIX F

DESIGN EXAMPLES

This appendix presents four examples of the cost-effectiveness of improving roadside designs. These examples include:

1. Improvement from Nonclear Zone policy to a 4:1 Clear Zone policy on freeways.

2. Improvement from 4:1 Clear Zone policy to 6:1 Clear Zone policy on freeways.

3. Improvement from Nonclear Zone policy to 4:1 Clear Zone policy on two-lane highways.

4. Improvement from 4:1 Clear Zone policy to 6:1 Clear Zone policy on two-lane highways.

These examples could represent a reconstruction project for an existing highway or a change in the roadside design policy for a newly planned highway. The purpose of the examples is to illustrate a procedure that could be applied to select the most appropriate roadside design policy for individual roadway sections or to establish appropriate roadside design policies for specific highway types or functional classes. As the examples are intended to be illustrative only, none of the specific results presented in this appendix should be misconstrued as representing a generally applicable design policy. Accident rates, construction costs, and terrain vary widely from state to state and from highway section to highway section within states. Such variations should be accounted for in establishing roadside design policies.

For each example, we have estimated the additional cost of constructing a one-mile section of highway from one roadside design policy to another and the savings in accident costs that would result. Accident cost estimates compiled by both the National Highway Traffic Safety Administration and the National Safety Council have been used. The ratio between the present worth of accident reduction benefits and construction costs has been expressed as a function of ADT and the "breakeven" ADT at which the improvement becomes cost-effective has been determined.

These examples are not presented to suggest that roadside design improvements are always cost-effective above a given ADT and are never cost-effective below it. Reconstruction costs may vary greatly from project to project because of differences in terrain, roadside obstacles, surrounding development, and other factors. In particular, construction costs are likely to be higher than normal on complex reconstruction projects. The accident reduction effectiveness may also vary from site to site. The examples are presented only to illustrate the cost-effectiveness implications of applying the average accident reduction effectiveness measures to a typical roadside design. Users of the recommended cost-effectiveness methodology should recognize that the cost-effectiveness of roadside design improvements is sensitive to the values used for construction costs, accident costs, interest rates, and service lives and should select values that are consistent with the experience and policies of their agencies, as well as accepted engineering literature.

The following discussion first identifies the elements used in the cost-effectiveness analyses to estimate construction costs and accident cost savings. Then, the four design examples and their results are presented individually.

COST-EFFECTIVENESS METHODOLOGY

This section presents the methodology used to determine the cost-effectiveness of improving roadside design policy for the design examples. This methodology is applied to evaluated generalized design situations in these examples, but could also be applied to evaluate roadside design improvements at a specific site. First, the benefit-cost ratio used as a measure of cost-effectiveness is defined and then each element used in the benefit-cost determination is discussed.

Benefit-Cost Ratio

The benefit-cost ratio used as an indicator of cost-effectiveness in the design examples is the ratio of the present worth of annual accident cost savings to the present worth of the improvement construction cost minus its residual value. This benefit-cost ratio is defined formally as:

$$B/C = \frac{(\Delta AR \times ADT \times D \times 10^{-6}) \times AC \times (SPW - i\% - n)}{CC - RV \times (PW - i\% - n)}$$

where:

B/C = Benefit-cost ratio for roadside improvement;

ΔAR = Reduction in accident rate due to roadside improvement, accidents per million vehicle-miles;

ADT = Average daily traffic volume, vpd;

D = Number of days per year = 365;

AC = Cost savings per accident reduced, dollars;

CC = Improvement construction cost, dollars;

RV = Residual value of improvement at end of analysis period, dollars;

(SPW - i% - n) = Uniform series present worth factor for n years at an interest rate of i%; and

(PW - i% - n) = Single amount present worth factor for n years at an interest rate of i%.

The first term in the numerator of the benefit-cost expression ($\Delta AR \times ADT \times D \times 10^{-6}$) represents the annual number of accidents reduced by the roadside design improvement. This term represents the annual number of accidents reduced on both sides of the highway and in the median of divided highways. The ADT used to calculate the annual number of accidents reduced should be the average ADT over the analysis period, which can be approximated by the projected ADT at the mid-point of the analysis period. No benefits other than accident reduction are included in the benefit-cost ratio. However, possible additional benefits are discussed in a later section.

If the benefit-cost ratio for an improvement exceeds 1.0, the improvement is considered to be cost-effective and economically justified. If the benefit-cost ratio is less than 1.0, the improvement is not cost-effective and an alternative investment of the available funds should be sought. In the four design examples, the benefit-cost ratio has been expressed as a (linear) function of ADT.

The ADT for which the benefit-cost ratio is exactly equal to 1.0 is referred to as the "breakeven" ADT and it provides an indication, on the average, of the traffic volume level at which roadside design improvements become cost-effective. The "breakeven" ADT has been computed, for illustrative purposes, in generalizing the design examples presented in this appendix. However, the computation of the "breakeven" ADT is not essential when evaluating roadside design policies for an individual highway section with known ADT.

Accident Cost Reduction Elements

Three elements used in the computation of the accident cost savings from improvement of roadside design policies are discussed here. These are the accident rate reduction, the cost savings per accident reduced, and the uniform series present worth factor.

Accident Rate Reduction

The reduction in accident rate resulting from the improvement of roadside design policy is taken directly from Table D-7 for three of the four examples. The exception is the comparison involving Nonclear Zone sections on freeways. No data were available to determine the accident rate for such sections, but an estimate based on the NCHRP Report 148 model was developed in Appendix E; the fourth and final design example was based on this estimate.

For both two-lane highways and freeways, the differences in accident rate between roadside design policies found in this study were not influenced by ADT. Thus, for all four cost-effectiveness examples, the numerator of the benefit-cost expression is a linear function of ADT.

Accident Cost Savings

Cost data for traffic accident involvements are published by two sources: the National Highway Traffic Safety Administration (NHTSA) (17) and the National Safety Council (NSC) (18). The NHTSA cost data were first published for 1972 and have been updated for 1975. The NSC cost data are updated annually, most recently for 1980. These two sets of accident cost estimates differ markedly, because different cost elements and definitions have been used for each. The NHTSA costs are higher than the NSC costs for fatalities, but lower for injuries and property-damage-only involvements. There is no agreement within the highway community about which source of cost data is most reliable for cost-effectiveness analyses. For this reason, both sets of cost estimates have been used in the analyses to indicate a range of possible outcomes.

Table F-1 illustrates the computations to determine the average cost of a traffic accident from the costs for fatalities, injuries, and property-damage-only involvements. Estimates of the average number of fatalities per fatal accident, injuries per fatal accident, and injuries per injury accident were obtained for both two-lane highways and freeways from the accident data for Illinois. These data were used to compute the cost per accident for fatal accidents, injury accidents, and property-damage-only accidents. These accident costs were updated to 1981 so that they can be compared fairly to estimated 1981 construction costs; the cost update factor used for this purpose was the ratio of the Consumer Price Index (CPI) for January 1981 to the CPI for January of the year for which the published accident cost data were established. Finally, the updated costs for fatal, injury, and property-damage-only accidents were combined into an average cost per accident for each highway type, using as weights the accident severity distribution from Table D-8. (The use of an average cost per accident for each highway type is because the statistical analysis found no effect of roadside design policy on the accident severity distribution. If such an effect had been found, the accident cost reduction estimates would have been determined separately for each severity level.) The resulting accident cost estimates were $9,266 (NSC) and $14,502 (NHTSA) for two-lane highways, as compared to $7,748 (NSC) and $10,977 (NHTSA) for freeways.

Table F-1. Estimated accident costs by highway type.

Highway Type:	Two-Lane Highways		Four-Lane Freeways	
Source of Accident Cost Data:	NSC[a]	NHTSA[b]	NSC	NHTSA
Cost Per Fatality	$170,000	$287,175	$170,000	$287,175
Cost Per Injury	6,700	3,185	6,700	3,185
Cost Per PDO Involvement	980	520	980	520
Fatalities Per Fatal Accident[c]	1.04	1.04	1.05	1.05
Injuries Per Fatal Accident[c]	0.48	0.48	1.38	1.38
Injuries Per Injury Accident[c]	1.30	1.30	1.48	1.48
PDO Involvement Per PDO Accident	1.00	1.00	1.00	1.00
Cost Per Fatal Accident	$180,016	$300,191	$187,746	$305,929
Cost Per Injury Accident	8,710	4,141	9,916	4,714
Cost Per PDO Accident	980	520	980	520
Date of Cost Estimate	1980	1975	1980	1975
CPI[d] of Date of Cost Estimate	233.3	156.1	233.3	156.1
CPI on 1/1/81	260.7	260.7	260.7	260.7
Cost Update Factor	1.12	1.67	1.12	1.67
Updated Cost Per Fatal Accident	$201,618	$501,319	$210,276	$510,901
Updated Cost Per Injury Accident	9,755	6,915	11,106	7,872
Updated Cost Per PDO Accident	1,098	868	1,098	868
Percent Fatal Accidents	2.2%	2.2%	1.5%	1.5%
Percent Injury Accidents	43.4%	43.4%	35.1%	35.1%
Percent PDO Accidents	54.4%	54.4%	63.4%	63.4%
Average Cost Per Accident	$ 9,266	$ 15,402	$ 7,748	$ 10,977

[a] National Safety Council accident costs (1980).

[b] National Highway Traffic Safety Administration accident cost (1975).

[c] Estimated from project accident data for Illinois.

[d] Consumer Price Index.

Uniform Series Present Worth Factor

The principles of economic analysis require that comparisons between costs and benefits of an improvement project be made at the same point in time. In accordance with the recommendation of the AASHTO publication, "A Manual on User Benefit Analysis of Highway and Bus Transit Improvements," (1) all costs and benefits have been reduced to their present worth (i.e., their value at the time when the improvement is constructed).

The appropriate factor to reduce the accident reduction benefits, represented as a uniform series of annual cash flows over the entire analysis period, to their present worth is called the uniform series present worth factor. This factor is:

$$(SPW - i\% - n) = \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

where: (SPW - i% - n) = Uniform series present worth factor;

i = Minimum attractive rate of return (or discount rate) represented as a decimal = i%/100; and

n = Duration of analysis period, years.

The minimum attractive rate of return (or discount rate) represents the time value of money. This rate should equal the return on alternative long-term investments that must be foregone if the improvement is constructed. We followed the recommendation of the AASHTO User Benefit Analysis Manual that the analysis be conducted on a constant-dollar basis (i.e., excluding the effects of inflation) with a 4 percent minimum attractive rate of return (i = 0.04). Four percent is an estimate of the real long-term cost of capital, over and above the inflation rate. If a higher minimum attractive rate of return--representing current market interest rates--had been used, it would also be necessary to increase the accident cost each year to keep pace with inflation.

The analysis period of 20 years was also chosen in accordance with the AASHTO User Benefit Analysis Manual. Although some cost elements such as earthwork and right-of-way generally have service lives longer than 20 years, it is difficult to predict accident rates or traffic volumes beyond this period. The cost elements with service lives longer than 20 years have been handled by assigning them a residual value at the end of the analysis period.

The uniform series present worth factor for 20 years at a minimum attractive rate of return of 4 percent is 13.59.

Other Benefits

No benefits from roadside design improvements other than accident reduction benefits have been included in the design examples. A study by the Minnesota DOT (15) noted that the use of 6:1 roadside slopes may have benefits other than accident reduction including improved erosion control and snow and ice control. No data are available to quantify these benefits, and it is assumed that their magnitude will vary between climates and geographical areas. In other cases, the use of clear recovery zones may involve increased maintenance costs. It is recommended that if such benefits and costs can be quantified in the future, they should be included in cost-effectiveness analyses of roadside design at specific sites.

Construction Cost Elements

Four elements used in the estimation of construction cost are discussed in this section. These are: the unit construction costs, the construction quantities, the residual value of the improvement, and the single amount present worth factor.

Unit Construction Costs

Unit construction costs have been estimated for earthwork, right-of-way, culverts, breakaway signs, tree removal, and utility pole relocation. These costs are based primarily on data obtained from the California Department of Transportation, the Illinois Department of Transportation, and the Missouri Highway and Transportation Department and have been adjusted, where appropriate, to represent 1981 costs. The individual unit costs and their sources are identified below.

Earthwork cost data were obtained from Illinois and Missouri. Illinois generally experiences a cost of $3.00/yd^3 for excavation of cut and placement of the earth in a fill embankment. When fill exceeds cut and borrow material must be obtained, a cost of $5.00/yd^3 for placement of fill embankment is typical in Illinois. Missouri generally experiences lower earthwork costs than Illinois. A cost of $2.18/yd^3 is typical in Missouri for both excavation embankment and borrow embankment, although an additional right-of-way or easement cost would be incurred to obtain the use of the borrow pit. The average of the Illinois and Missouri costs for excavation and embankment is $2.60/yd^3. The estimated average cost per cubic yard for borrow embankment is $3.90/yd^3.

A typical cost for acquisition of right-of-way in rural areas was reported to be $0.068/ft^2 in Illinois and $0.08/ft^2 in Missouri. An average cost of $0.075/ft^2 was used for right-of-way cost acquisition.

The cost of pipe culvert was reported to be $80/linear foot in Illinois. Missouri reports costs for box culverts ranging from $125 to $1,100/ft depending on the culvert size and depth of fill over the culvert. It was decided to assume that the roadside improvement projects in these design examples involved only pipe culverts at $80/foot. Users are cautioned that construction costs will increase and roadside design improvements will be less cost-effective if the project requires wider box culverts.

The cost for installation of breakaway signs, removal of trees, and relocation of utility poles was based on the costs used in a recent California Department of Transportation study (22) of fixed object accidents. The reported cost of installing a breakway sign in 1975-1977 was $120 per sign, which was substantially less than the ($500) cost of relocating the sign 30 ft from the traveled way. For this study, the installation cost of a breakaway sign was updated to a 1981 cost of $190 per sign to account for inflation.

The California study found that the cost of removing trees depended on both the number of trees removed and the marketability of the timber, in the following manner:

Number of Trees Removed	Cost of Tree Removal ($)	
	Ornamental	Marketable
0-100	$400	$100
> 100	50	10

For purposes of this study, it was decided to assume that more than 100 trees were being removed, but that the timber had no commercial value. The $50 cost for tree removal was updated to $75 for 1981 to account for inflation.

The cost of relocating a utility pole was estimated by California at $1,500 including the acquisition of right-of-way. It was decided that the inclusion of right-of-way in this cost was appropriate because the right-of-way needed to relocate utility poles would be located beyond that required for the roadside slopes. The updated 1981 cost for relocating a utility pole is $2,350 per pole.

Construction Quantities

Quantities for construction cost items were derived for each design example from assumptions regarding the typical cross section for fills, typical cross section for cuts, distribution of cuts and fills, and distribution of roadside fixed objects for each highway type and roadside design policy. These assumptions were based to the maximum possible extent on the field survey results reported in Appendix C, except for Nonclear Zone sections on freeways which were not studied in the field. The geometrics of the assumed cut and fill cross sections are given in Table F-2. These cross sections provide a reasonable representation, on the average, of roadside designs that vary widely in the field.

Table F-2. Geometrics of typical cross-section used to determine construction quantities.

Geometric Element	Two-Lane Highways			Freeways		
	6:1 CZ	4:1 CZ	NCZ	6:1 CZ	4:1 CZ	NCZ
Percent of Length in Cut	40%	40%	40%	14%	14%	14%
Percent of Length on Fill	55%	55%	55%	80%	80%	80%
Percent of Length with Guardrail or Bridge Rail	5%	5%	5%	6%	6%	6%
Slope of Fill Foreslope (within 30 ft of traveled way)	6:1	4:1	3:1	6:1	4:1	3:1
Slope of Fill Foreslope (beyond 30 ft of traveled way)	4:1	3:1	3:1	4:1	3:1	3:1
Fill Embankment Height (ft)	5.5	5.5	5.5	6.0	6.0	6.0
Slope of Cut Foreslope	6:1	4:1	3:1	6:1	4:1	3:1
Depth of Ditch (ft)	3.0	3.0	3.0	3.0	3.0	3.0
Slope of Cut Backslope	4:1	3.5:1	3:1	4:1	3.5:1	3:1
Cut Backslope Height (ft)	6.0	6.0	6.0	13.0	13.0	13.0
Median Width (ft)	-	-	-	70.0	70.0	70.0
Slope of Median Foreslope	-	-	-	6:1	4:1	3:1
Median Foreslope Height	-	-	-	3.0	3.0	3.0
Outside Shoulder Width (ft)	8.0	8.0	8.0	10.0	10.0	10.0
Inside (median) Shoulder Width (ft)	-	-	-	4.0	4.0	4.0

The proportion of cut and fill sections and the cut and fill embankment heights were held constant across roadside design policies for each highway type. In a realistic design situation, these quantities would not vary greatly between alternative roadside design policies for the same horizontal and vertical alignment, unless the natural terrain had a consistent slope transverse to the roadway. For each highway type, the proportion of cut and fill sections and the cut and fill embankment heights are based on the average values for these quantities from the field survey across all roadside design policies. A small proportion of each section (5 percent for two-lane highways and 6 percent for freeways) was assumed to have guardrail or bridge rail; the roadside geometrics for these areas behind the guardrail or bridge rail were not varied from one roadside design policy to another.

The slopes of the cut and fill foreslopes and the cut backslopes were varied in a systematic manner between the roadside design policies. The cut and fill foreslopes within 30 ft of the traveled way were 6:1 for 6:1 Clear Zone sections, 4:1 for the 4:1 Clear Zone sections, and 3:1 for the Nonclear Zone sections. Steeper slopes were used for the Clear Zone sections on cut backslopes and on fill foreslopes beyond 30 ft from the traveled way.

For freeway medians, the same foreslope was used as for the right side of the roadway. The height of this foreslope was assumed to be 3 ft. Beyond this foreslope, the median was assumed to be flat (typical cross sections for the center of depressed medians often have a slight slope such as 20:1).

These typical cross sections were used to estimate construction quantities, including additional earthwork, longer culverts, and wider rights-of-way, required to upgrade one roadside design to another along a 1-mile section. Earthwork quantities, expressed in cubic yards, were computed separately for cut and fill as the product of the additional cross-sectional area and the length of cut or fill in the 1-mile section. Additional culvert length was required for flattening slopes; it was assumed that one culvert for each 2,000 ft of fill section required lengthening. Right-of-way acquisition was estimated separately for cut and fill based on the product of the added width of cross section and the length of cut or fill in the one-mile section. For example, it was estimated that upgrading a one-mile section of two-lane highway from a 4:1 Clear Zone to a 6:1 Clear Zone design requires 5,784 yd^3 of fill, 5,632 yd^3 of cut, 21.3 ft of additional culvert, and 80,590 ft^2 of additional right-of-way. The construction quantity estimates used for the other design examples will be found in the discussion of the individual examples.

For cost-estimating purposes, it was assumed that there were no fixed objects to be removed on the 4:1 Clear Zone sections. The fixed object distribution used for Nonclear Zone sections on two-lane highways was that found in the field survey. Because no data were available for Nonclear Zone sections on freeways, the same coverage factor as for two-lane highways was used. Point objects within 10 ft of the traveled way and a portion of the objects within 20 ft of the traveled way were assumed to be signs that could be converted to breakaway design. The remaining objects within 30 ft from the traveled way were assumed to be trees or utility poles; design example 4 gives separate consideration to Nonclear Zone sections on two-lane highways, both with and without utility poles. The removal of fixed objects located more than 30 ft from the traveled way was not evaluated.

No construction costs were included for the removal of continuous objects located within 30 ft of the traveled way of Nonclear Zone sections. Other than guardrail and bridge rail, the main continuous objects found on the roadside were fences and rock cuts. It is assumed that the cost of removing a fence would be included in the right-of-way acquisition cost and that the cost of enlarging a rock cut would be so large as to be prohibitive.

Residual Value

The recommendations of the AASHTO User Benefit Analysis Manual concerning the residual value of the improvement at the end of the 20-year analysis period were followed. Earthwork and right-of-way acquisition are capital items that are major components of the improvement construction cost in the design examples and have service lives substantially longer than 20 years (typically, 40 to 50 years). This longer service life can be accounted for properly if the improvement project is assigned a residual value at the end of the analysis period. In this case, the residual value of the improvement has been computed as 100 percent of the right-of-way cost and 50 percent of the earthwork cost.

Single Amount Present Worth Factor

Before the residual value is subtracted from the construction cost, it must be reduced to its present worth. The appropriate factor for this calculation is the single amount present worth factor, defined as:

$$(PW - i\% - n) = \frac{1}{(1 + i)^n}$$

where: (PW - i% - n) = Single amount present worth factor;

i = Minimum attractive rate of return (or discount rate) represented as a decimal = i%/100; and

n = Duration of analysis period, years.

This present worth factor is entirely analogous to the uniform series present worth factor discussed earlier except that it is applied to determine the present worth of a single amount on a specified future data rather than a series of annual amounts over a specified period.

The single amount present worth factor for 20 years at a 4 percent minimum attractive rate of return is 0.4564.

DESIGN EXAMPLE 1 -- NONCLEAR ZONE VS. 4:1 CLEAR ZONE FOR FREEWAYS

The first design example considers the upgrading of a freeway section without a roadside clear recovery area to a 4:1 Clear Zone design. This example is largely hypothetical, because the run-off-road accident rate for the Nonclear Zone design on freeways was not determined from accident data, but was estimated in Appendix E using the roadside hazard model of NCHRP Report 148.

The assumed roadside design for the freeway Nonclear Zone sections is based on the roadside design for two-lane Nonclear Zone sections. The fatal and injury run-off-road accident rate estimated in Appendix E for a freeway Nonclear Zone is 0.149 accidents per million vehicle-miles. The percentage of fatal and injury involvement in single-vehicle run-off-road accidents on freeways is 36.6 percent. Based on this accident severity distribution, the estimated total run-off-road accident rate for a freeway Nonclear Zone is 0.407 accidents per million vehicle-miles, in contrast to the rate of 0.289 accidents per million vehicle-miles for a freeway 4:1 Clear Zone. The difference between these rates, which is the estimated effectiveness measure for the improvement, is 0.118 accidents per million vehicle-miles. If the estimated accident rate from Appendix E for a more uniform application of the 4:1 Clear Zone policy on freeways had been used, rather than the actual accident rate from Appendix D, the estimated benefits for this example would be 10 percent higher.

The construction costs for earthwork, right-of-way acquisition, and culverts to upgrade a Nonclear Zone freeway section to a 4:1 Clear Zone freeway section were estimated from the cross-section geometrics presented in Table F-2. The cost for removing fixed objects on freeways was assumed to be relatively low, equivalent to the cost for installing a breakaway sign or removing a tree. Higher cost improvements, such as removing utility poles, were not considered appropriate for this example because it would be unlikely to find utility poles on the roadside of a freeway. The total estimated construction cost for improving a freeway Nonclear Zone to a 4:1 Clear Zone is $31,265 per mile.

Table F-3 illustrates the economic evaluation of this improvement. The breakeven point between a Nonclear Zone design and a 4:1 Clear Zone design on a freeway is 5,410 vpd, based on the NSC accident costs, and 3,820 vpd based on the NHTSA accident costs. The corresponding benefit-cost ratios as a function of ADT are shown in Figure F-1. The horizontal line in the figure corresponds to a benefit-cost ratio of 1.0, the point at which the benefits and costs are equal.

Very few rural freeways have traffic volumes below the level of 3,800 to 5,400 vpd. Thus, the 4:1 Clear Zone design policy is usually justified economically for rural freeways. However, the reader is cautioned in this example, as in the others, that the cost and effectiveness measures can vary from site to site.

DESIGN EXAMPLE 2 -- 4:1 CLEAR ZONE VS. 6:1 CLEAR ZONE FOR FREEWAYS

The second design example considers the upgrading of a freeway section from a 4:1 Clear Zone to a 6:1 Clear Zone design policy. This example is applicable to an existing highway that has a 4:1 Clear Zone or an existing or planned highway where it has already been determined that a 4:1 Clear Zone is economically justified.

The construction costs considered for this example are the cost for additional earthwork, right-of-way acquisition, and culvert extension. The improvement generally required flattening cut and fill foreslopes from 4:1 to 6:1; the specific

Table F-3. Economic evaluation for Design Example 1--Nonclear Zone vs. 4:1 Clear Zone for freeways.

Construction Cost and Residual Value Per Mile

		Construction Cost	Residual Value
Earthwork (balanced cut and fill)	4,449 yd^3 @ \$2.60/yd^3 =	\$11,567	\$ 5,784
Earthwork (borrow for fill embankment)	2,435 yd^3 @ \$3.90/yd^3 =	9,497	4,748
Right-of-Way Acquisition	56,235 ft^2 @ \$0.075/ft^2 =	4,221	4,221
Culvert	21.0 ft @ \$80/ft =	1,680	0
Breakaway Signs	10 @ \$190 each =	1,900	0
Tree Removal or Equivalent	32 @ \$75 each =	2,400	0
Utility Pole Relocation		0	0
		\$31,265	\$14,753

Benefit-Cost Comparison

	NSC Accident Costs			NHTSA Accident Costs		
	ADT=5,000	ADT=10,000	ADT=15,000	ADT=5,000	ADT=10,000	ADT=15,000
Accident Rate Reduction (accidents per 10^6 vehicle-miles)	0.118	0.118	0.118	0.118	0.118	0.118
Average Daily Traffic Volume (vpd)	5,000	10,000	15,000	5,000	10,000	15,000
Duration of Period (days)	365	365	365	365	365	365
Length of Section (miles)	1.00	1.00	1.00	1.00	1.00	1.00
Annual Number of Accidents Reduced	0.215	0.431	0.646	0.215	0.431	0.646
Accident Cost (dollars)	7,748	7,748	7,748	10,977	10,977	10,977
Uniform Series Present Worth Factor	13.59	13.59	13.59	13.59	13.59	13.59
Total Benefits (dollars)	22,638	45,382	68,021	32,073	64,295	96,369
Construction Cost (dollars)	31,265	31,265	31,265	31,265	31,265	31,265
Residual Value (dollars)	14,753	14,753	14,753	14,753	14,753	14,753
Single Amount Present Worth Factor	0.4564	0.4564	0.4564	0.4564	0.4564	0.4564
Total Costs (dollars)	24,532	24,532	24,532	24,532	24,532	24,532
Benefit-Cost Ratio (B/C)	0.92	1.85	2.77	1.31	2.62	3.93
	Breakeven ADT (B/C=1.0) = 5,410			Breakeven ADT (B/C=1.0) = 3,820		

cross-section geometrics used to derive the construction cost estimates are given in Table F-2. The estimated construction cost for this design example is \$47,148 per mile.

The estimated accident rate reduction for this improvement is 0.107 accidents per million vehicle-miles, based on the analysis results presented in Appendix D. If, instead, an accident rate reduction estimate from Appendix E based on the more uniform application of the 6:1 and 4:1 Clear Zone design policies to freeways had been used, the estimated benefits for this example would have been 3 percent lower.

The benefit-cost comparison for the improvement is given in Table F-4. The benefit-cost ratio, based on NSC accident costs, ranges from 0.58 for an ADT of 5,000 vpd to 1.74 for an ADT of 15,000 vpd; the benefits and costs are equal at an ADT of 8,650 vpd. If the NHTSA accident costs are used, the benefit-cost ratio ranges from 0.82 at an ADT of 5,000 vpd to 2.46 at an ADT of 15,000 vpd; the benefits and costs are equal at an ADT of 6,100 vpd.

The variation of the benefit-cost ratio with ADT is shown in Figure F-2. The results of this evaluation suggest that, on the average, the use of a 6:1 Clear Zone design policy is justified for rural freeways with traffic volumes above the range of 6,100 to 8,650 vpd. Below that traffic volume level, the use of a 4:1 Clear Zone design would be more cost-effective.

DESIGN EXAMPLE 3 -- NONCLEAR ZONE VS. 4:1 CLEAR ZONE FOR TWO-LANE HIGHWAYS

The third design example considers the improvement of a two-lane highway section without a clear zone to a 4:1 Clear Zone design. The construction cost elements considered for this improvement are earthwork, right-of-way acquisition, culvert extension, installation of breakaway signs, and removal or relocation of trees and utility poles. Because the costs of tree removal and utility pole relocation differ markedly, two cases were considered. In the first case, only signs and trees are present on the roadside within 30 ft of the traveled way. In the second case, a line of 21 utility poles at 250-ft spacing on one side of the road must be relocated beyond 30 ft from the traveled way and the number of trees to be removed is reduced correspondingly to produce, on the average, the same distribution of roadside fixed objects as in the first case. The same earthwork, right-of-way, and culvert costs were used for both cases. This improvement generally flattened cut and fill foreslopes from 3:1 to 4:1; the specific

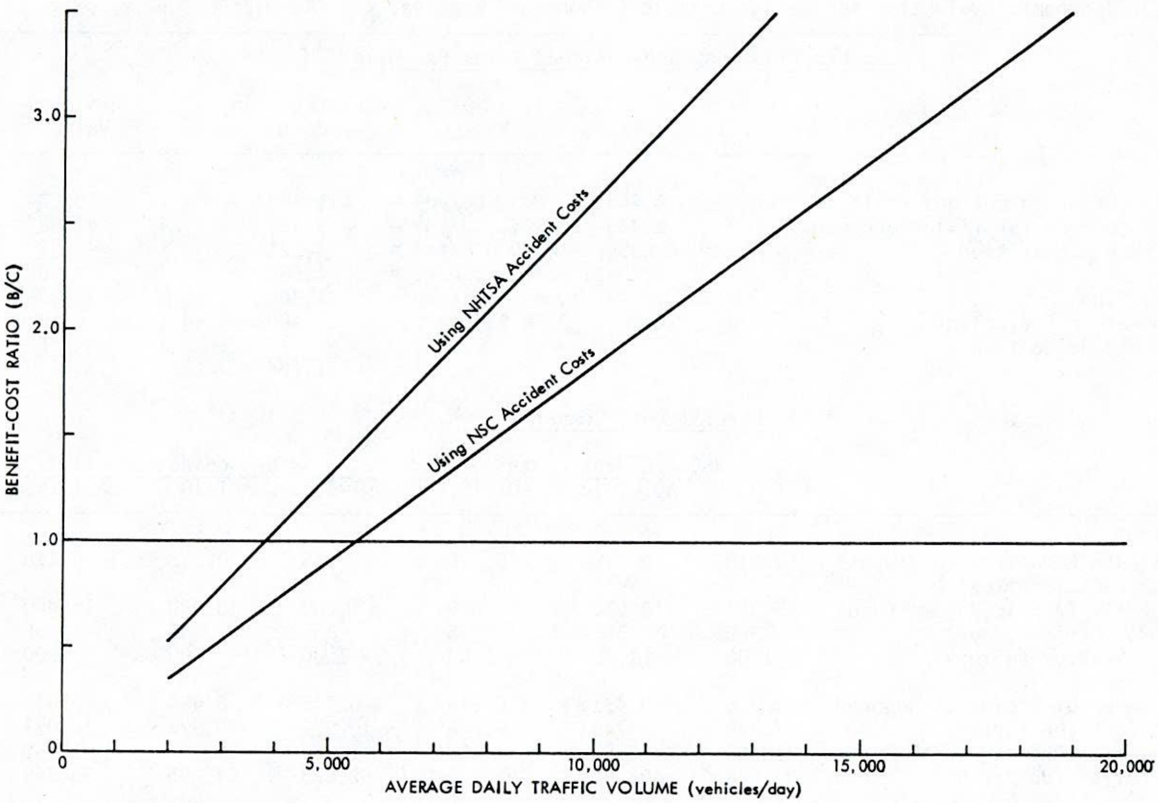


Figure F-1. Benefit-cost ratio as a function of ADT for improving freeways from Nonclear Zone to 4:1 Clear Zone policy.

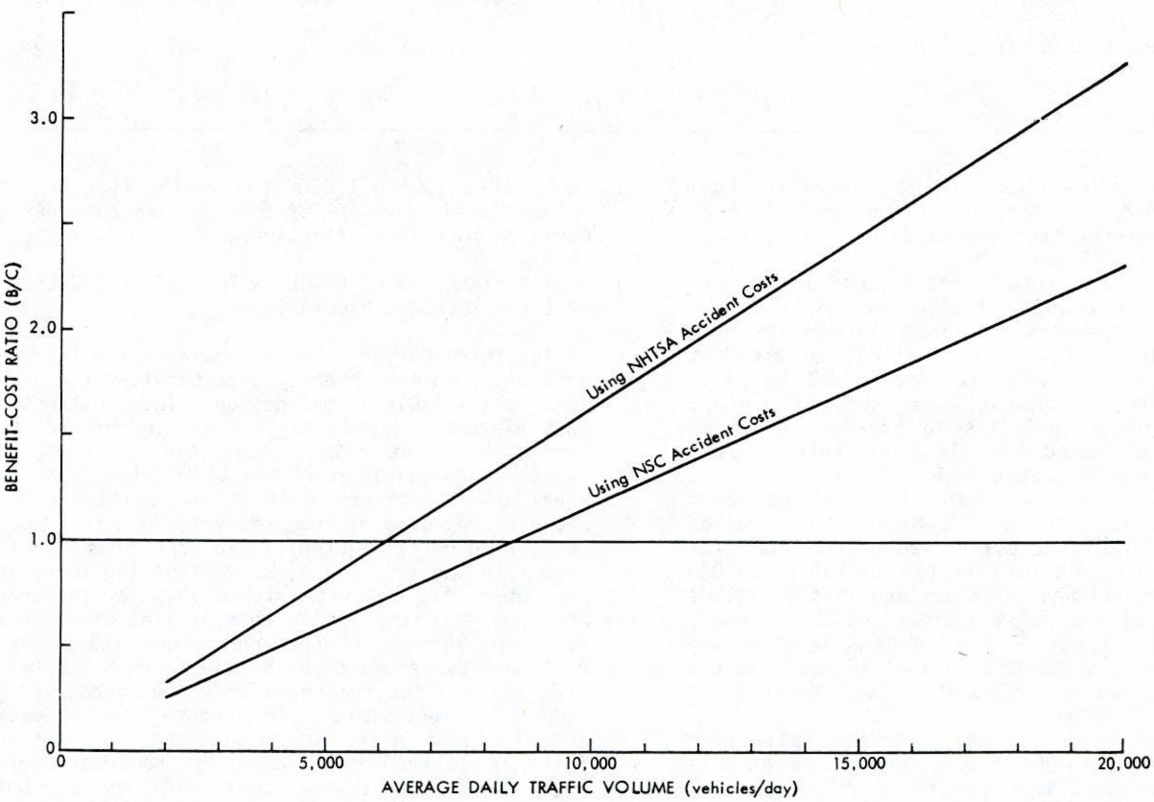


Figure F-2. Benefit-cost ratio as a function of ADT for improving freeways from 4:1 Clear Zone to 6:1 Clear Zone policy.

Table F-4. Economic evaluation for Design Example 2--4:1 Clear Zone vs. 6:1 Clear Zone for freeways.

Construction Cost and Residual Value Per Mile

		Construction Cost	Residual Value
Earthwork (balanced cut and fill)	6,584 yd^3 @ \$2.60/yd^3 =	\$17,118	\$ 8,559
Earthwork (borrow for fill embankment)	5,427 yd^3 @ \$3.90/yd^3 =	21,165	10,583
Right-of-Way Acquisition	83,530 ft^2 @ \$0.075/ft^2 =	6,265	6,265
Culvert	32.5 ft @ \$80/ft =	2,600	0
Breakaway Signs		0	0
Tree Removal or Equivalent		0	0
Utility Pole Relocation		0	0
		\$47,148	\$25,407

Benefit-Cost Comparison

	NSC Accident Costs			NHTSA Accident Costs		
	ADT=5,000	ADT=10,000	ADT=15,000	ADT=5,000	ADT=10,000	ADT=15,000
Accident Rate Reduction (accidents per 10^6 vehicle-miles)	0.107	0.107	0.107	0.107	0.107	0.107
Average Daily Traffic Volume (vpd)	5,000	10,000	15,000	5,000	10,000	10,000
Duration of Period (days)	365	365	365	365	365	365
Length of Section (miles)	1.00	1.00	1.00	1.00	1.00	1.00
Annual Number of Accidents Reduced	0.195	0.391	0.586	0.195	0.391	0.586
Accident Cost (dollars)	7,748	7,748	7,748	10,977	10,977	10,977
Uniform Series Present Worth Factor	13.59	13.59	13.59	13.59	13.59	13.59
Total Benefits (dollars)	20,533	41,170	61,703	29,090	58,328	87,418
Construction Cost (dollars)	47,148	47,148	47,148	47,148	47,148	47,148
Residual Value (dollars)	25,407	25,407	25,407	25,407	25,407	25,407
Single Amount Present Worth Factor	0.4564	0.4564	0.4564	0.4564	0.4564	0.4564
Total Costs (dollars)	35,552	35,552	35,552	35,552	35,552	35,552
Benefit-Cost Ratio (B/C)	0.58	1.16	1.74	0.82	1.64	2.46
	Breakeven ADT (B/C=1.0) = 8,650			Breakeven ADT (B/C=1.0) = 6,100		

geometrics used to derive these cost estimates are given in Table F-2.

The estimate of the additional construction cost for providing a 4:1 Clear Zone on a two-lane highway is \$19,029 per mile without the relocation of utility poles and \$66,804 per mile including the relocation of utility poles. The site-specific conditions on a particular roadway could require a construction cost anywhere between the estimates or even exceeding the latter estimate.

The accident rate reduction estimate for this example was 0.277 accidents per million vehicle-miles, based on the statistical analysis results reported in Table D-7. The same accident rate reduction estimate was used for both cases, because the severity of accidents involving trees and utility poles is generally similar. For example, Glennon (9) found the severity of accidents involving utility poles to be similar to trees of comparable size. If the accident rate estimate for 4:1 Clear Zone sections on two-lane highways were based on the estimate for a more uniform application of that policy from Appendix E, rather than the actual policy estimate from Appendix D, a 32 percent increase in the estimated benefits would result.

Table F-5 presents the results of the benefit-cost comparison for the first case, or "low-cost" improvement, involving flattening slopes and treatment of signs and trees. The results of this analysis show that the provision of 4:1 Clear Zones can be justified at relatively low traffic volume levels. The "breakeven" ADT, where the costs and benefits are equal, is 750 vpd based on the NHTSA accident costs and 1,180 vpd based on the NSC accident costs.

Table F-6 presents the results of the benefit-cost comparison for the second case, or "high-cost" improvement, that involved relocation of utility poles. The combination of higher construction costs with the same effectiveness estimate results in a less cost-effective improvement. The "breakeven" ADT for the second case is 3,150 vpd based on the NHTSA accident costs and 4,930 vpd based on the NSC accident costs.

The benefit-cost ratio for this example is shown in Figure F-3 as a function of ADT for both cases and for both sets of accident cost estimate. The horizontal line in the figure corresponds to a benefit-cost ratio of 1.0, the point at which the benefits and costs are equal.

The reader should be cautious in drawing general conclusions from Figure F-3. The figure illustrates that the wide variation in the cost for providing a clear recovery area, as well as the traffic volume, has a strong influence on the

Table F-5. Economic evaluation for Design Example 3--Nonclear Zone vs. 4:1 Clear Zone for two-lane highways (first case).

Construction Cost and Residual Value Per Mile

		Construction Cost	Residual Value
Earthwork (balanced cut and fill)	3,520 yd³ @ $2.60/yd³ =	$ 9,152	$4,576
Earthwork (borrow for fill embankment)		0	0
Right-of-Way Acquisition	57,288 ft² @ $0.075/ft² =	4,297	4,297
Culvert	16.0 ft @ $80/ft =	1,280	0
Breakaway Signs	10 @ $190 each =	1,900	0
Tree Removal or Equivalent	32 @ $75 each =	2,400	0
Utility Pole Relocation		0	0
		$19,029	$8,873

Benefit-Cost Comparison

	NSC Accident Costs			NHTSA Accident Costs		
	ADT=750	ADT=2,000	ADT=5,000	ADT=750	ADT=2,000	ADT=5,000
Accident Rate Reduction (accidents per 10^6 vehicle-miles)	0.277	0.277	0.277	0.277	0.277	0.277
Average Daily Traffic Volume (vpd)	750	2,000	5,000	750	2,000	5,000
Duration of Period (days)	365	365	365	365	365	365
Length of Section (miles)	1.00	1.00	1.00	1.00	1.00	1.00
Annual Number of Accidents Reduced	0.076	0.202	0.506	0.076	0.202	0.506
Accident Cost (dollars)	9,266	9,266	9,266	14,502	14,502	14,502
Uniform Series Present Worth Factor	13.59	13.59	13.59	13.59	13.59	13.59
Total Benefits (dollars)	9,571	25,437	63,718	14,978	39,810	99,724
Construction Cost (dollars)	19,029	19,029	19,029	19,029	19,029	19,029
Residual Value (dollars)	8,873	8,873	8,873	8,873	8,873	8,873
Single Amount Present Worth Factor	0.4564	0.4564	0.4564	0.4564	0.4564	0.4564
Total Costs (dollars)	14,980	14,980	14,980	14,980	14,980	14,980
Benefit-Cost Ratio (B/C)	0.64	1.70	4.25	1.00	2.66	6.65
	Breakeven ADT (B/C=1.0) = 1,180			Breakeven ADT (B/C=1.0) = 750		

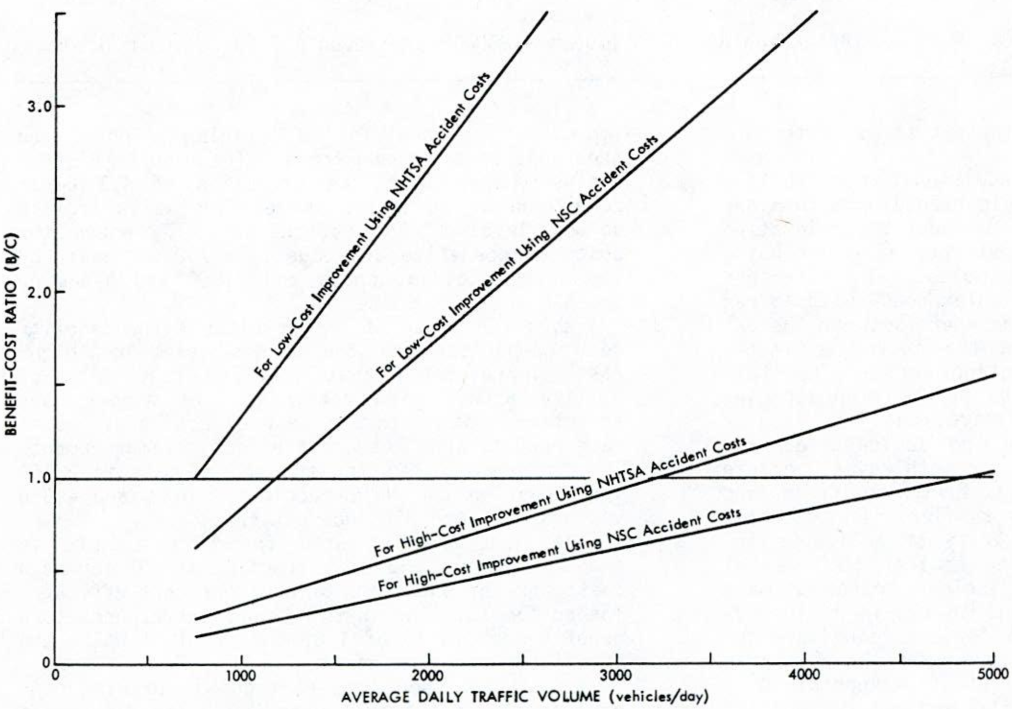


Figure F-3. Benefit-cost ratio as a function of ADT for improving two-lane highways from Nonclear Zone to 4:1 Clear Zone policy.

Table F-6. Economic evaluation for Design Example 3--Nonclear Zone vs. 4:1 Clear Zone for two-lane highways (second case).

Construction Cost and Residual Value Per Mile

		Construction Cost	Residual Value
Earthwork (balanced cut and fill)	3,520 yd³ @ \$2.60/yd³ =	\$ 9,152	\$4,576
Earthwork (borrow for fill embankment)		0	0
Right-of-Way Acquisition	57,288 ft² @ \$0.075/ft² =	4,297	4,297
Culvert	16.0 ft @ \$80/ft =	1,280	0
Breakaway Signs	10 @ \$190 each =	1,900	0
Tree Removal or Equivalent	11 @ \$75 each =	825	0
Utility Pole Relocation	21 @ \$2,350 each =	49,350	0
		\$66,804	\$8,873

Benefit-Cost Comparison

	NSC Accident Costs			NHTSA Accident Costs		
	ADT=750	ADT=2,000	ADT=5,000	ADT=750	ADT=2,000	ADT=5,000
Accident Rate Reduction (accidents per 10^6 vehicle-miles)	0.277	0.277	0.277	0.277	0.277	0.277
Average Daily Traffic Volume (vpd)	750	2,000	5,000	750	2,000	5,000
Duration of Period (days)	365	365	365	365	365	365
Length of Section (miles)	1.00	1.00	1.00	1.00	1.00	1.00
Annual Number of Accidents Reduced	0.076	0.202	0.506	0.076	0.202	0.506
Accident Cost (dollars)	9,266	9,266	9,266	14,502	14,502	14,502
Uniform Series Present Worth Factor	13.59	13.59	13.59	13.59	13.59	13.59
Total Benefits (dollars)	9,571	25,437	63,718	14,978	39,810	99,724
Construction Cost (dollars)	66,804	66,804	66,804	66,804	66,804	66,804
Residual Value (dollars)	8,873	8,873	8,873	8,873	8,873	8,873
Single Amount Present Worth Factor	0.4564	0.4564	0.4564	0.4564	0.4564	0.4564
Total Costs (dollars)	62,754	62,754	62,754	62,754	62,754	62,754
Benefit-Cost Ratio (B/C)	0.15	0.41	1.02	0.24	0.64	1.59
	Breakeven ADT (B/C=1.0) = 4,930			Breakeven ADT (B/C=1.0) = 3,150		

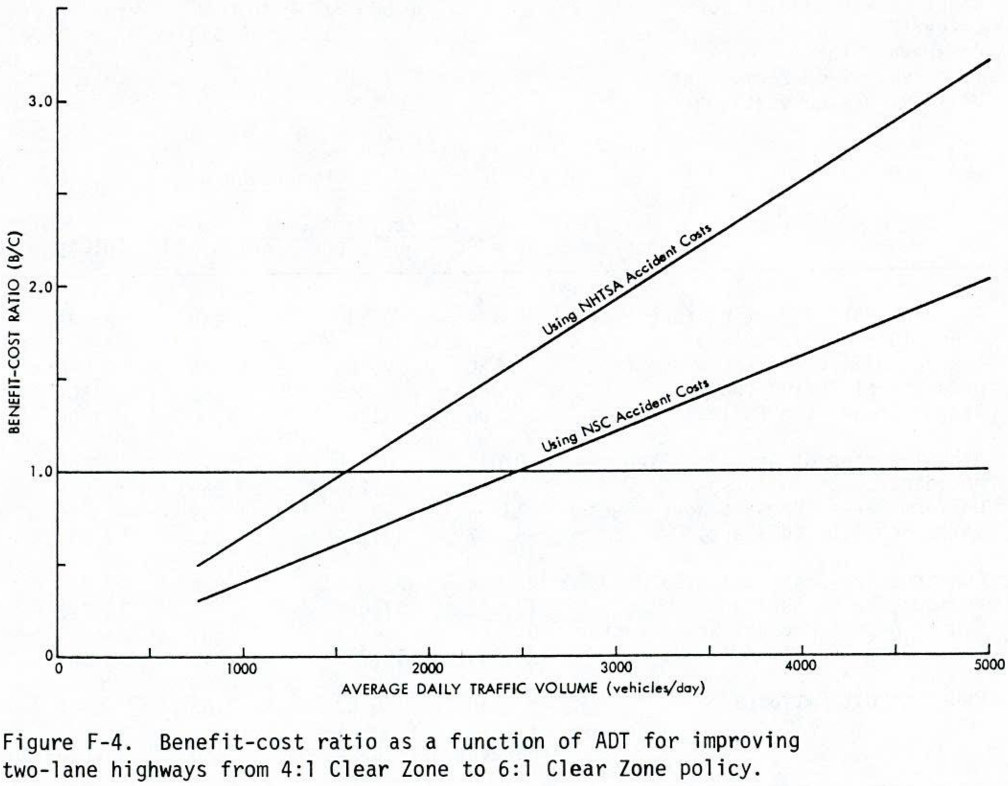


Figure F-4. Benefit-cost ratio as a function of ADT for improving two-lane highways from 4:1 Clear Zone to 6:1 Clear Zone policy.

cost-effectiveness of the 4:1 Clear Zone design policy. Where the construction cost is low, a clear recovery area with 4:1 slopes can be justified on two-lane highways as low as 750 to 1,200 vpd. However, where the required construction costs are high, clear recovery areas may not be justified even on highways with traffic volumes of 3,100 to 4,900 vpd.

DESIGN EXAMPLE 4 -- 4:1 CLEAR ZONE VS. 6:1 CLEAR ZONE FOR TWO-LANE HIGHWAYS

The fourth and final example considers the improvement of a two-lane highway section from a 4:1 Clear Zone design policy to a 6:1 Clear Zone design policy. This example is applicable to an existing highway that has a 4:1 Clear Zone or an existing or planned highway where it has already been determined that a 4:1 Clear Zone is economically justified.

The construction costs considered for this example are the costs for additional earthwork, right-of-way acquisition, and culvert extension. The improvement generally required flattening cut and fill foreslopes for 4:1 to 6:1; the specific cross-section geometrics used to derive the construction cost estimates are given in Table F-2. The estimated construction cost for this design example is $22,984 per mile.

The estimated accident rate reduction for this improvement is 0.149 accidents per million vehicle-miles, based on the statistical analysis results presented in Appendix D. If the accident rate reduction estimate had been based on the more uniform application of the 6:1 and 4:1 Clear Zone policies discussed in Appendix E, rather than the results obtained for the actual policy applications in Appendix D, the estimated benefits for this example would be 21 percent lower.

The benefit-cost comparison for the improvement is given in Table F-7. The benefit-cost ratio, based on NSC accident costs, ranges from 0.30 for an ADT of 750 vpd to 2.05 for an ADT of 5,000 vpd; the benefits and costs are equal at an ADT of 2,450 vpd. If the NHTSA accident costs are used, the benefit-cost ratio ranges from 0.47 at 750 vpd to 3.2 at 5,000 vpd, with the breakeven point at 1,560 vpd.

The variation of benefit-cost ratio with ADT is shown in Figure F-4. The results of this evaluation suggest that, on the average, the use of a 6:1 Clear Zone design policy is justified on two-lane highways for traffic volumes above the range of 1,600 to 2,500 vpd. Below that traffic volume level, the use of 4:1 Clear Zone design policy would be more cost-effective.

Table F-7. Economic evaluation for Design Example 4--4:1 Clear Zone vs. 6:1 Clear Zone for two-lane highways.

Construction Cost and Residual Value Per Mile

		Construction Cost	Residual Value
Earthwork (balanced cut and fill)	5,632 yd³ @ $2.60/yd³ =	$14,643	$ 7,322
Earthwork (borrow for fill embankment)	152 yd³ @ $3.90/yd³ =	593	296
Right-of-Way Acquisition	80,589 ft² @ $0.075/ft² =	6,044	6,044
Culvert	21.3 ft @ $80/ft =	1,704	0
Breakaway Signs		0	0
Tree Removal or Equivalent		0	0
Utility Pole Relocation		0	0
		$22,984	$13,622

Benefit-Cost Comparison

	NSC Accident Costs			NHTSA Accident Costs		
	ADT=750	ADT=2,000	ADT=5,000	ADT=750	ADT=2,000	ADT=5,000
Accident Rate Reduction (accidents per 10^6 vehicle-miles)	0.149	0.149	0.149	0.149	0.149	0.149
Average Daily Traffic Volume (vpd)	750	2,000	5,000	750	2,000	5,000
Duration of Period (days)	365	365	365	365	365	365
Length of Section (miles)	1.00	1.00	1.00	1.00	1.00	1.00
Annual Number of Accidents Reduced	0.040	0.109	0.272	0.040	0.109	0.272
Accident Cost (dollars)	9,266	9,266	9,266	14,502	14,502	14,502
Uniform Series Present Worth Factor	13.59	13.59	13.59	13.59	13.59	13.59
Total Benefits (dollars)	5,037	13,726	34,252	7,833	21,481	53,606
Construction Cost (dollars)	22,984	22,984	22,984	22,984	22,984	22,984
Residual Value (dollars)	13,622	13,622	13,622	13,622	13,622	13,622
Single Amount Present Worth Factor	0.4564	0.4564	0.4564	0.4564	0.4564	0.4564
Total Costs (dollars)	16,749	16,749	16,749	16,749	16,749	16,749
Benefit-Cost Ratio (B/C)	0.30	0.82	2.05	0.47	1.28	3.20
	Breakeven ADT (B/C=1.0) = 2,450			Breakeven ADT (B/C=1.0) = 1,560		

THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 250 committees, task forces, and panels composed of more than 3,100 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, and other organizations and individuals interested in the development of transportation.

The Transportation Research Board operates within the National Research Council. The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine.

The National Academy of Sciences was established in 1863 by Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology, required to advise the Federal Government upon request within its fields of competence. Under its corporate charter the Academy established the National Research Council in 1916, the National Academy of Engineering in 1964, and the Institute of Medicine in 1970.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 42970

IDAHO TRANS DEPT
P O BOX 7129
BOISE ID 83707

000015M025
DISTRICT ENGR DISTRICT 1