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Effectiveness of Clear Recovery Zones

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Clear recovery zones outside the highway shoulder provide an opportunity for vehicles that leave the roadway to come to a safe stop or to return to the roadway. The results of a research effort to determine the effectiveness of clear recovery zones in reducing the number and severity of run-off-the-road (ROR) accidents and to provide an approach for the cost-effective application of clear recovery zones are presented. Actual accident data were obtained and analyzed to compare three different roadside design policies: the 6:1 clear zone policy, the 4:1 clear zone policy, and the nonclear zone policy. Three highway types were also considered: two-lane highways, four-lane freeways, and four-lane divided nonfreeways. Road sections that had these highway types and roadside design policies were identified in Illinois, Minnesota, and Missouri. Analysis of the accident data for the study sections revealed that roadside design policy had a statistically significant relation to single-vehicle ROR accident rate for all of the highway types studied. The differences in the accident rate between roadside design policies were quantified for each highway type. An analysis of the severity of single-vehicle ROR accidents revealed that the severity distribution did not vary between the roadside design policies on any of the three highway types studied. Four design examples were developed in order to illustrate the cost-effectiveness implications of the safety effectiveness measures developed in the study. The examples compared the accident reduction benefits and typical construction costs for improving highways from one roadside design policy to another.

A clear recovery zone is a relatively flat roadside area that is free of unprotected fixed objects and other nontraversable hazards; it is 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 1960s 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 do not have a clear recovery zone at all. It has been suggested in recent design guidelines that there is a need for clear recovery areas wider than 30 ft when embankment slopes steeper than 6:1 are used.

Some of the major findings of NCHRP Project 17-5, which was conducted to help highway agencies with limited funds develop a rational basis for making cost-effective applications of clear recovery zones, are presented. The full study has been published in NCHRP Report 247 (1).

OBJECTIVES AND SCOPE

The objectives of the study were to determine the safety effectiveness of clear recovery zones of differing slopes and widths in reducing the number and severity of run-off-the-road (ROR) accidents and to describe a framework based on clear zone effectiveness that could be used in design practice to assure the 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, the study was intended to evaluate the safety effectiveness of providing clear recovery zones by flattening slopes 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 [average daily traffic (ADT) less than 750 vehicles/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 by comparing the accident experience of highway sections constructed under different roadside design policies. Three distinct roadside design policies have been used by U.S. highway agencies; they are 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.

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 (for example, shoulder width), 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 ROR accident rate for all levels of accident severity and the fatal and injury single-vehicle ROR accident rate. These measures of effectiveness were restricted to ROR accidents because it would be questionable to presume a relation between roadside design policy and accidents where no vehicle left the roadway. The measure of effectiveness was restricted to single-vehicle ROR accidents; multiple-vehicle ROR accidents were excluded because single-vehicle ROR accidents are more frequent on rural highways than multiple-vehicle ROR accidents and because the severity of single-vehicle ROR accidents can be attributed in large degree to roadside design. Single-vehicle ROR accidents that involve both the outside (right side) and the median (left side) of the roadway on divided highways were considered.

The independent variables for the analysis, besides roadside design policy, were state, ADT, and shoulder width. The basic technique used for the statistical evaluation was analysis of covariance.

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; they are described briefly in this section. The policies vary in both the embankment slopes used and the presence of fixed objects outside the highway shoulder. Typical cross sections for the three roadside design policies are shown in Figure 1. The data in the figure indicate 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 zone highway sections are too highly variable to be illustrated by one typical cross section.

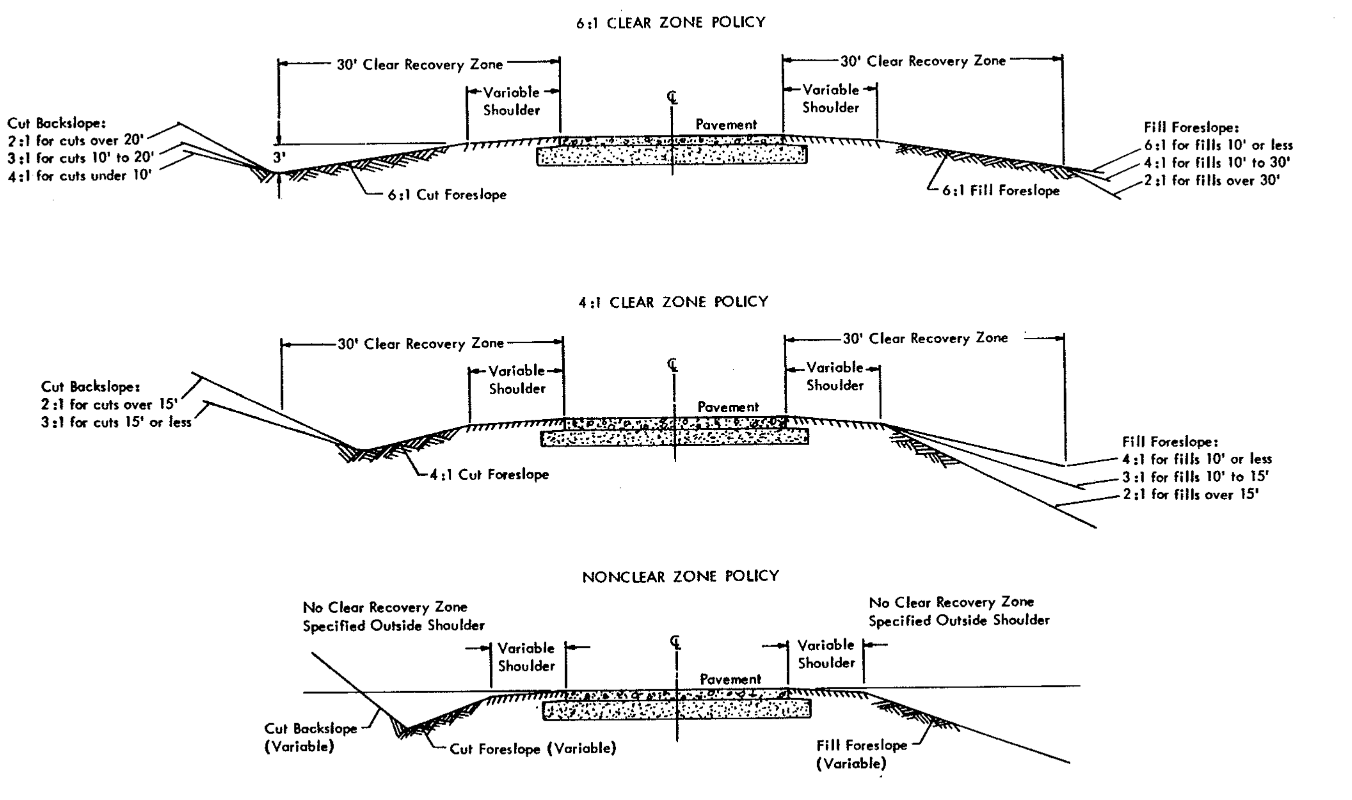
The 6:1 clear zone roadside design policy has been generally used in freeway construction and in some reconstruction projects on other types of highways since the late 1960s. Highways constructed under this policy generally have foreslopes of 6:1 or flatter within 30 ft of the traveled way. Embankment 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 in this study, for example).

The field survey indicated that the average embankment foreslope of 6:1 clear zone sections was 5.8:1 for two-lane highways, 6.9:1 for freeways, and 5.7:1 for four-lane divided nonfreeways. The slope on higher fill embankments 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 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, which is 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 represented the combined total for unprotected fixed objects, guardrail, and bridge rail.

The 4:1 clear zone roadside design policy was in general use by many highway agencies before the 6:1 clear zone policy was recommended by AASHTO, and it 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 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 this is 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

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



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 is apparent 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 these 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 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 24 percent for two-lane highways and 42 percent for four-lane divided nonfreeways.

PREVIOUS CLEAR ZONE EFFECTIVENESS STUDIES

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

MnDOT conducted a study of ROR accidents that occurred on rural, two-lane highways with 55-mph speed limits. (Note that these data are from a June 1980 unpublished report by MnDOT, "Comparison of Accident Rates Related to 4:1 and 6:1 Inslopes on 2-Lane Rural Trunk Highways.") The accident experience of roadways that had 6:1 foreslopes was compared with roadways that had 4:1 foreslopes. Both the 6:1 and 4:1 study sections had 30-ft clear zones and were chosen because they were comparable in lane width, shoulder width, and other geometric features. The study included 24 sections (215 miles of highway) that had 6:1 foreslopes and 23 sections (234 miles of highway) that had 4:1 foreslopes.

The Minnesota study indicated that the fatal, injury, property-damage-only (PDO), and total accident rates for the sections that had 4:1 foreslopes were all larger than the corresponding rates for the roadway sections that had 6:1 foreslopes. The total accident rates and the accident rates for corresponding severity levels were compared statistically between the 4:1 and 6:1 sections by using the t-test. (The Beherns-Fisher procedure was used 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 PDO accident rates for the two types of roadway sections.

Another study of roadside design policies was performed in Missouri in the mid-1970s. The results of this study are presented in an unpublished memorandum of the Missouri Highway and Transportation Department entitled, "Summary of Accident Experience on Sections of Road Constructed with 20-Foot 'Safety Zones'". 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 authors of the Missouri study did not find a statistically significant difference in the overall accident rate or severity between sections with and without safety zones for any of the highway types considered.

A 1974 University of Illinois study evaluated various improvements in roadside safety design policies that had been implemented by the Illinois Department of Transportation during the preceding years. (Note that the data for the Illinois study are from V.E. Dotson's 1974 unpublished Master of Science thesis, "An Evaluation of the Thirty-Foot Clear Zone," prepared for the University of Illinois, Urbana.) Study sections were selected on four Interstate routes in one Illinois highway district. The study sections included 211.19 miles of rural freeway. Of this mileage, 90.57 miles were constructed to the latest safety standards (i.e., 6:1 embankment slopes and a 30-ft clear recovery zone), whereas 89.15 miles were constructed with 4:1 embankment slopes and had not been upgraded since the adoption of the safety standards.

A comparison of accident experience between sections that had 6:1 and 4:1 embankment slopes was conducted by using the data for three of the four Interstate routes. A two-way analysis of variance that used slope and route factors indicated that neither factor was statistically significant. A similar analysis for multiple-vehicle accident rate revealed the same result.

The results of the three studies that compared 6:1 and 4:1 slopes are summarized in Table 1. The studies used varying statistical techniques. The Missouri study covered all types of highways, and no significant difference in accident rates was revealed for any type of highway. The University of Illinois study did not reveal a significant difference in accident rate for freeways. The Minnesota study revealed a statistically significant difference between 4:1 and 6:1 slopes on two-lane highways.

Despite such varying conclusions, it is significant to note that the relative differences in the single-vehicle accident rate are 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 anal-

Table 1. Summary of studies that compared 6:1 and 4:1 embankment slopes.

Study	Highway Type	Accident Measured Used	Accident Rate (accidents per million vehicle miles) 6:1	4:1	Statistical Test Used	Conclusions
Minnesota[a]	Two lane	ROR accident rate	0.154	0.266	t-test[b]	Both total and fatal and injury accident rate were significantly lower for 6:1 sections
Missouri[c]	Primary two lane	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	0.248	0.412		
	Freeway	Total accident rate	0.379	0.430		
		Multiple-vehicle accident rate	0.174	0.163		
		Single-vehicle accident rate	0.205	0.163		
University of Illinois[d]	Freeway	Single-vehicle ROR accident rate	0.333	0.421	Analysis of variance	No statistically significant change in single-vehicle ROR or multiple-accident rate

[a]Data from June 1980 unpublished report ("Comparison of Accident Rates Related to 4:1 and 6:1 Inslopes on 2-Lane Rural Trunk Highways") from MnDOT.
[b]This t-test used the Behrens-Fisher procedure for unequal variances.
[c]Data from unpublished memorandum ("Summary of Accident Experience on Sections of Road Constructed with 20-Foot 'Safety Zones'") from the Missouri State Highway Commission.
[d]Data from V.E. Dotsun's 1974 unpublished Master of Science thesis ("An Evaluation of the Thirty-Foot Clear Zone") prepared for the University of Illinois, Urbana.

ysis techniques, the observed effects might be statistically significant.

DEVELOPMENT OF PROJECT DATA BASE

The project data base includes study sections for three highway types (two-lane highways, four-lane freeways, and four-lane divided nonfreeways) and 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 highway without full control of access) were readily available in Missouri and, therefore, these data were also used. Excluded from the study were highways with urban development and highways with ADT volumes less than 750 vehicles/day. All of the sections had 55-mph speed limits and shoulders at least 4 ft wide. Lane widths were either 11 or 12 ft.

A data base that contained the accident history, traffic volumes, and geometrics of these highway sections was assembled. The basic data-collection approach pursued was to make maximum use of the data already available in Illinois, Minnesota, and Missouri, while obtaining more recent accident data and expanding the number of highway sections studied, the range of highway types included, and the length of the study period. The data obtained for highway sections in Missouri included many of the same highway sections from the previous Missouri study, but also incorporated nonclear zone sections. The data base in Illinois was expanded to include highway sections from throughout the state rather than from a single district. In Minnesota the highway sections from the state study of 6:1 and 4:1 sections on two-lane highways were supplemented with two-lane nonclear zone sections and sections on freeways.

The accident data obtained for the sections in Illinois and Missouri covered the 5-yr period from 1975 through 1979, inclusive. The accident data in Minnesota included the 4-yr period from 1977 through 1980. The project analyses used each year of data from each study section as a separate observation. 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.

The entire data base contained 836 study sections that covered 4,601 miles of highway with a total exposure of more than 41 billion vehicle miles of travel during the study period. These highway sections experienced 11,649 single-vehicle ROR accidents during a study period that averaged about 4.4 yr in duration. Detailed breakdowns of the mileage and accident experience for the study sections can be found in the project report (1).

ANALYSIS OF ACCIDENT DATA

The three objectives of the statistical analysis of accident data conducted in this study were to

1. Determine whether roadside design policy has a statistically significant effect on traffic accident experience,
2. Determine the magnitude of the effect of roadside design policy on accident experience when the effect is statistically significant, and
3. 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: (a) select measure(s) of effectiveness (dependent variables) for the analysis; (b) select independent variables for the analysis; and (c) select a statistical technique to determine whether the effect of roadside design policy is statistically significant.

Measures of Effectiveness

The primary measure of effectiveness (or dependent variable) selected to evaluate roadside design policies is the single-vehicle ROR accident rate. The single-vehicle ROR accident rate for a 1-yr period, expressed as accidents per million vehicle-miles, was defined in the conventional manner:

$$AR = [(N)(10^6)]/[(ADT)(D)(L)] \quad (1)$$

where

AR = single-vehicle ROR accident rate (accidents per million vehicle-miles);
N = number of single-vehicle ROR accidents;
ADT = average daily traffic volume (vehicles/day);
D = duration of study period (days) [in this study, 365 days or 1 yr]; and
L = length of study section (miles).

The study also included an evaluation of accident severity measures, including both the accident severity distribution (proportion of fatal, injury, and PDO accidents) and the single-vehicle ROR accident rate for fatal and injury accidents only.

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 ROR 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 were evaluated, and any differences in accident experience between the policies were identified.

Several other independent variables were considered because they may also influence the single-vehicle ROR accident rate; these included state, ADT, volume, and shoulder width.

State was considered an independent variable because statistically significant state-to-state differences in single-vehicle ROR accident rate were found for four of the five combinations of highway type and roadside design policy 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 indicated that (a) 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 (b) the influence of these state-to-state differences must be accounted for or corrected before assessing the statistical significance of the effect of roadside design policy.

Even within one highway type the highway sections for different roadside design policies also differ in ADT. For example, the average ADT for two-lane highways is 2,031 for 6:1 clear zone sections, 2,778 for 4:1 clear zone sections, and 2,745 for nonclear zone sections. Because the ROR 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. A field survey of the study sections 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 differed 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 that has more than two levels, such as roadside design policy, is the one-way analysis of variance. If the factor is 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--which 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 of 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 analyses of covariance: single-vehicle ROR accident rate and fatal and injury single-vehicle ROR accident rate.

The specific form of analysis of covariance 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 relation between hierarchical analysis of covariance and the classic approach to analysis of covariance is analogous to the relation 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 before 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.

In an analysis of variance or covariance that has a balanced design, the best measure of effectiveness for each roadside design policy is the average (or arithmetic mean) accident rate for that policy. The experimental designs used in this study were not balanced 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. The best measure of effectiveness for each roadside design policy in such an unbalanced design 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 distribution of the accident severity were made by 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) (2).

Analysis Results

The results of the accident data analysis are presented in the following sections. First, the results of several analyses of variance and covariance are presented in order to demonstrate that roadside design policy has a statistically significant effect on accident rate. Second, the mean and adjusted (least square mean) accident rates are presented in order to indicate the magnitude of the differences in accident rate between policies. Third, the effect of roadside design policy on accident severity is discussed. Finally, the relation of ADT on accident rate in the study data is illustrated.

Results of Analysis of Covariance

The results of a series of analyses of variance and covariance that were performed on the ROR accident rate and the fatal and injury ROR accident rate are presented in this section. These analyses were performed by computer by using the general linear model procedure of the statistical analysis system (SAS) (3). All conclusions presented here regarding statistical significance are at the 95 percent confidence level unless otherwise stated.

The data in Table 2 give three analyses of covariance of the single-vehicle ROR accident rate where the effects of roadside design policy and the other independent variables were considered. These analyses indicate that the effect of roadside design policy on single-vehicle ROR accident rates is 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. 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; the ADT and shoulder width covariates were eliminated because they were not statistically significant. Thus only the factor of roadside design policy remains in the analysis of covariance for four-lane divided nonfreeways. Both two-lane and freeway analyses contain a term for the interaction between state and roadside design policy; the state-policy interaction was statistically significant for two-lane highways, but it was not statistically significant for freeways.

This same analysis was repeated by using the ROR 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 PDO accidents, which are subject to variations in reporting levels. The data in Table 3 for fatal and injury single-vehicle ROR accident rates are entirely analogous to the data in Table 2 for total single-vehicle ROR accident rates. As in the earlier analysis of covariance, the effect of roadside design policy remains statistically significant after consideration of the variables state, ADT, and shoulder width. With only two exceptions, the same independent variables and interactions that were statistically significant for the total ROR accident rate are also statistically significant for the fatal and injury ROR accident rate. One exception is that the ADT factor was omitted from the analysis of freeways in Table 3 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 also was not statistically significant.

The state-policy interaction in Tables 2 and 3 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 poli-

Table 2. Analysis of covariance of roadside design policy and other variables for single-vehicle ROR accident rates.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (at 95 percent confidence level)
Two-lane highways (n = 1,958)					
State[a]	32.603	2	16.302	36.59	SIG
ADT[b]	2.865	1	2.865	6.43	SIG
Outside shoulder width[b]	18.426	1	18.426	41.36	SIG
Policy[a]	18.150	2	9.075	20.37	SIG
State-policy[c]	9.557	4	2.389	5.36	SIG
Explained	81.601	10	8.160	18.31	SIG[d]
Error	867.470	1,947	0.446		
Total	949.071	1,957			
Four-lane freeways (n = 1,045)					
State[a]	3.250	2	1.625	42.40	SIG
ATD[b]	0.380	1	0.380	9.90	SIG
Policy[a]	2.434	1	2.434	63.50	SIG
State-policy[c]	0.032	2	0.016	0.42	NS
Explained	6.097	6	1.016	26.51	SIG[e]
Error	39.789	1,038	0.038		
Total	45.886	1,044			
Four-lane divided nonfreeways (n = 580)					
Policy[a]	10.488	2	5.244	46.08	SIG
Explained	10.488	2	5.244	46.08	SIG[b]
Error	65.665	577	0.114		
Total	76.153	579			

Note: SIG = statistically significant and NS = not statistically significant.

[a]Factor. [b]Covariate. [c]Interaction. [d]$R^2 = 0.086$. [e]$R^2 = 0.133$. [f]$R^2 = 0.138$.

Table 3. Analysis of covariance of roadside design policy and other variables for fatal and injury single-vehicle ROR accident rate.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (at 95 percent confidence level)
Two-lane highways (n = 1,958)					
State[a]	3.815	2	1.908	8.11	SIG
ADT[b]	1.442	1	1.442	6.13	SIG
Outside shoulder width[b]	3.175	1	3.175	13.50	SIG
Policy[a]	5.475	2	2.738	11.64	SIG
State-policy[c]	2.212	4	0.553	2.35	NS[d]
Explained	16.119	10	1.612	6.85	SIG[e]
Error	457.979	1,947	0.235		
Total	474.098	1,957			
Four-lane freeways (n = 1,045)					
State[a]	0.604	2	0.302	25.98	SIG
Policy[a]	0.261	1	0.261	22.41	SIG
State-policy[a]	0.026	2	0.013	1.13	NS[f]
Explained	0.891	5	0.178	15.33	SIG
Error	12.076	1,039	0.012		
Total	12.967	1,044			
Four-lane divided non-freeway (n = 580)					
Policy[a]	2.868	2	1.434	44.95	SIG
Explained	2.868	2	1.434	44.95	SIG[g]
Error	18.404	577	0.032		
Total	21.272	579			

Note: SIG = statistically significant and NS = not statistically significant.
[a]Factor.
[b]Covariate.
[c]Interaction.
[d]Statistically significant at 90 percent confidence level.
[e]R^2 = 0.034.
[f]R^2 = 0.067.
[g]R^2 = 0.134.

cies can be assumed to have the same accident rate in every state. The analysis results indicate that the state-policy interaction is not statistically significant for freeways.

The situation for two-lane highways is more complicated. The interaction effect is statistically significant for the total ROR accident rate 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 because of reasons of simplicity), the state-policy interaction for two-lane highways has been treated as being not statistically significant and it is assumed that the mean ROR accident rate for each highway type and roadside design policy is representative of all three states. Nevertheless, the use of a separate estimate in each state for the mean accident rates of each roadside design policy on two-lane highways could be justified. 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 covariance is that roadside design policy has a statistically significant effect both on the total ROR accident rate and on the fatal and injury ROR 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. Nevertheless, statistical significance does not necessarily imply that the effect of roadside design policy on accident rate is large enough to be significant in a practical sense. Practical conclusions must be based on the magnitude of the observed differences in accident rate between roadside design policies and on the cost-effectiveness implications of those differences. The statistical analysis can only provide confidence that the observed differences, however large or small, are real.

Mean and Adjusted Mean Accident Rates

In this section the mean and adjusted (or least square mean) accident rates for the three highway types and the three roadside design policies are compared. The most elementary measure of effectiveness for roadside design policy is a simple comparison of average or arithmetic mean accident rates. For example, on freeways the mean ROR accident rate is 0.235 accident/million vehicle-miles for 6:1 clear zone sections and 0.329 accident/million vehicle-miles for 4:1 clear zone sections. The difference in these mean rates--0.094 accident/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 the accident rate, the least square mean accident rates are 0.182 accident/million vehicle-miles for 6:1 clear zone sections and 0.289 accident/million vehicle-miles for 4:1 clear zone sections. The corresponding difference in mean accident rates is 0.107 accident/million vehicle-miles. In most cases the difference between roadside design policies in the least square mean accident rate was slightly larger than the difference in the arithmetic mean accident rate, although the increase was never large.

The data in Table 4 summarize the arithmetic and least square mean accident rates for each highway type and roadside design policy for the individual and combined states. The arithmetic means in Table 4 are the averages of all of the available data without regard to state, ADT, or shoulder width. 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 by using the least square means procedure of the SAS computer package confirm that, for each highway

Table 4. Comparison of accident rates between roadside design policies.

Highway Type	Data Set	Statistic	Accident Rates by Roadside Design Policy[a] 6:1 Clear Zone	4:1 Clear Zone	Nonclear Zone	Differences in Accident Rates Between Roadside Design Policies[a] 6:1 versus 4:1	4:1 versus Nonclear Zone
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

[a]Accident rates are measured for single-vehicle ROR accidents per million vehicle miles.

Table 5. Adjusted mean accident rates by highway type and roadside design policy.

Highway Type	Accident Rate by Roadside Design Policy[a] 6:1 Clear Zone	4:1 Clear Zone	Nonclear Zone	Differences in Accident Rates Between Roadside Design Policies[a] 6:1 versus 4:1 Δ	Significance[b]	4:1 versus Nonclear Zone Δ	Significance[b]
ROR accidents							
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 ROR accidents							
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 nonfreeway	0.057	0.129	0.298	0.072	SIG	0.169	SIG

Note: SIG = statistically significant.

[a]Accident rates are measured in accidents per million vehicle miles.
[b]Statistically significant at the 95 percent confidence level.

type, the least square mean accident rates for all of the roadside design policies are significantly different. Results analogous to those given in Table 4 were also obtained for the fatal and injury ROR accident rate.

Also given in Table 4 are the measures of effectiveness obtained from the data for the individual states. The state data indicate that, although the magnitudes of the accident rates themselves vary markedly from state to state, the differences in mean accident rate between roadside design policies are consistent from state to state, with only one exception. The one exception is the comparison between 4:1 clear zone and nonclear zone sections for two-lane highways, which is larger in Illinois than in the other two states.

The key measures of effectiveness from the accident analysis are summarized in Table 5. The data in this table give the least square means for the individual highways types and roadside design policies and for the differences between policies. The data in Table 5 indicate that the differences in accident rate between the roadside design policies are statistically significant and that the roadside design policies vary markedly in accident rate when compared. 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 small in absolute magnitude. For example, the largest difference between roadside design policies as given in Table 5 is 0.288 accident/million vehicle-miles for four-lane divided nonfreeways, which corresponds to 0.46 accident/mile/yr.

Tests for Effects of Accident Severity

The analysis described in the preceding section established that the ROR 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, injury, and PDO accidents. If there is a shift in the distribution between these levels of accident severity from one roadside design policy to another, this shift should be considered in any cost-effectiveness analysis of design policies.

The severity distribution for ROR accidents are given in Table 6 by highway type and roadside design

Table 6. Accident severity distribution for single-vehicle ROR accidents.

Highway Type	Roadside Design Policy	Accidents Fatal No.	Fatal Percent	Injury No.	Injury Percent	PDO No.	PDO Percent	Total No.	Total Percent
Two lane	6:1 clear zone	12	2.5	201	41.1	276	56.4	489	100.0
	4:1 clear zone	48	3.0	720	44.5	850	52.5	1,618	100.0
	Nonclear zone	22	1.4	684	43.0	886	55.6	1,592	100.0
Four-lane freeway	6:1 clear zone	32	1.6	705	35.7	1,237	62.7	1,974	100.0
	4:1 clear zone	71	1.5	1,638	34.8	2,999	63.7	4,708	100.0
Four-lane divided nonfreeway	6:1 clear zone	4	1.5	109	41.5	150	57.0	263	100.0
	4:1 clear zone	15	1.8	348	42.9	448	55.3	811	100.0
	Nonclear zone	2	1.0	95	49.0	97	50.0	194	100.0

Table 7. Statistical tests of distributions in accident severity for ROR accidents.

Highway Type	Road Design Policy Comparison	3 Levels[a] (fatal versus injury versus PDO)	2 Levels[b] (fatal versus injury)	2 Levels[b] (fatal and injury versus PDO)
Two lane	6:1 clear zone versus 4:1 clear zone	NS	NS	NS
	4:1 clear zone versus nonclear zone	NS	SIG[c]	NS
	6:1 clear zone versus nonclear zone	NS	NS	NS
Four-lane freeway	6:1 clear zone versus 4:1 clear zone	NS	NS	NS
Four-lane divided nonfreeway	6:1 clear zone versus 4:1 clear zone	NS	NS	NS
	4:1 clear zone versus nonclear zone	NS	NS	NS
	6:1 clear zone versus nonclear zone	NS	NS	NS

Note: NS = not statistically significant and SIG = statistically significant.

[a]Used Kolmogorov-Smirnov test for distribution shift.
[b]Used Z-test for difference of proportions.
[c]Statistically significant at 95 percent confidence level.

policy. The table entries represent the combined data for Illinois, Minnesota, and Missouri.

The differences in the distribution in accident severity between roadside design policies, as indicated by the data in Table 6, are small, and there is no consistent pattern of lower accident severity on improved roadside design policies. Statistical tests were conducted to compare the distributions in accident severity for pairs of roadside design policies within individual highway types. Three different forms of the distribution in accident severity were tested: one form that used three severity levels (fatal versus injury versus PDO), and two other forms that used two levels (fatal versus injury; and fatal and injury versus PDO). The three-level comparisons were performed by using the Kolmogorov-Smirnov test for distribution shifts (2). The two-level comparisons were performed by using the Z-test for differences in proportions (4).

The results of the statistical tests involving the distribution in accident severity are given in Table 7. 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 nonwithstanding, it was concluded that there is no difference between roadside design policies in the severity distribution of reported accidents.

None of these analyses reveals any consistent trend toward improvements in roadside design policy decreasing the fatal and injury accident rate to a greater extent than PDO accidents. The reader should not misinterpret this finding to mean that improvements in roadside design policy 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 and PDO accidents.

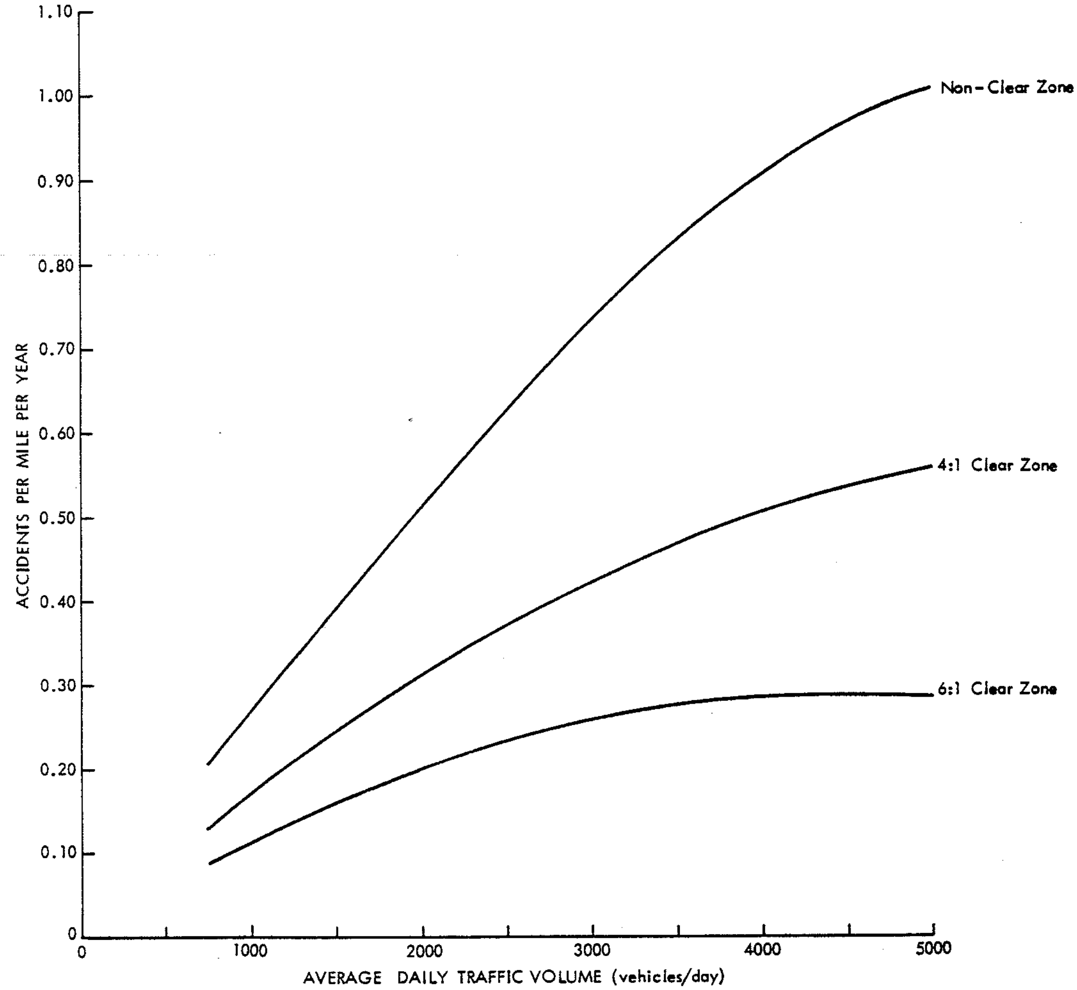
Relation of ADT and Single-Vehicle ROR Accident Rate

A further analysis was conducted to quantify the relation between ROR accident rate and ADT. The analysis of covariance results reported earlier have revealed that ADT can have a statistically significant influence on accident rate; therefore, the magnitude and direction of this influence was determined.

An analysis of covariance model generally represents the relation between a covariate and the dependent variable (in this case, the accident rate and ADT relation) as a straight line. As an extension of the analysis of covariance procedure, a statistical test can be used to determine whether the slope of the linear accident rate and ADT relation 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 model of analysis of covariance than the one used earlier because the ADT covariate must be entered into the model after, rather than before, the factor of roadside design policy. The comparison of slopes is performed by an F-test described by Ostle (4, p. 204) and is performed if, and only if, there is a significant linear relation between accident rate and ADT. The specific procedure used to perform the slope comparisons when using the SAS computer package was that described by G.A. Milliken and D.E. Johnson in Chapter XI of their unpublished paper "Analysis of Messy Data" prepared for an Institute of Professional Education seminar, Washington, D.C., June 1981 (298 pp.).

For two-lane highways, the slopes of the ROR accident rate and ADT regression lines for the three roadside policies are -0.038, -0.050, and -0.027 accident/million vehicle-miles per 1,000 vehicles/day for 6:1 clear zone, 4:1 clear zone, and nonclear zone sections, respectively. These three individual linear relations between accident rate and ADT were each statistically significant (i.e., the slope of

Figure 2. Relation between single-vehicle ROR accidents per mile per year and ADT for two-lane highways.



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], which indicates that the common slope of -0.041 accident/million vehicle-miles per 1,000 vehicles/day can be used for all three roadside design policies.

The negative slope of this relation indicates that the single-vehicle ROR 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 (5). This relation can be expressed as

$$AR = -0.041\ ADT + b_o \quad (2)$$

where

AR = single-vehicle ROR accident rate (accident/million vehicle-miles),

ADT = average daily traffic volume (1,000 vehicles/day) 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).

Figure 2 shows the variation of accidents per mile per year with ADT, based on the relation presented in Equation 2. The accident experience shown in Figure 2 has been expressed as an accident frequency per mile per year, rather than as an accident rate, in order to illustrate the magnitude of the average differences in roadside design policies; for this reason the relations shown in Figure 2 are nonlinear.

A similar analysis for fatal and injury ROR accident rate revealed that a common slope of -0.026 accident/million vehicle-miles per 1,000 vehicles/day should be used [F(2,2018) = 1.06]. This relation can be expressed as

$$AR_{FI} = -0.026\ ADT + b_o \quad (3)$$

where

AR_{FI} = fatal and injury single-vehicle ROR accident rate (accident/million vehicle-miles),

ADT = average daily traffic volume (1,000 vehicles/day), 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, the 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 relation for freeways is zero. The same result was obtained for the relation between fatal and injury accident rate and ADT for freeways. The slope of the accident rate and ADT relations for four-lane divided nonfreeways were also not significantly different from zero. These results are in contrast to the results given for freeways in Tables 2 and 3, where ADT and the variables for roadside design policy were considered in a different order.

Estimation of Accident Rates

Accident rates were estimated by using the model in NCHRP Report 148 (6) for several situations where accident data were not available. For example, there were no freeway sections in the study that had a nonclear zone design policy because most freeways either had a 30-ft clear recovery zone originally or have since been upgraded. The model in NCHRP Report 148 was used to estimate the single-vehicle ROR accident rate for a freeway that had a roadside design comparable to a two-lane nonclear zone section. This estimation process required an adjustment of the model (described in detail in the project report) because the accident rates predicted by the model for the types of highway sections evaluated in this study were much higher than those actually found in the project data and reported in Table 5. After adjustment of the model, the estimates obtained for nonclear zone sections on freeways were 0.149 accident/million vehicle-miles for the fatal and injury single-vehicle ROR accident rate and 0.407 accident/million vehicle-miles for the total single-vehicle ROR accident rate.

It was also determined that, by using the model in NCHRP Report 148 for both two-lane highways and freeways, highway sections with 20-ft clear zones would experience single-vehicle ROR accident rates approximately 10 percent higher than similar highway sections with 30-ft clear zones. It was determined that, if the 4:1 clear zone policy was more uniformly applied (where roadsides were completely clear of unprotected fixed objects and no slopes were steeper than 4:1), reductions in the accident rate of about 5 percent could be obtained on freeways and about 25 percent on two-lane highways. Similar results were obtained for a more uniform application of the 6:1 clear zone design policy on freeways and two-lane highways.

COST-EFFECTIVENESS IMPLICATIONS

Four design examples have been developed 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 ROR accident rates and construction costs may vary from site to site. These examples are intended only to compare the average reductions in the accident rate and the typical construction costs for improving highways with one roadside design policy to another. Highway agencies are encouraged to develop similar cost-effectiveness approaches based on accident rate and cost data appropriate for their locale.

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 B/C ratio equals or exceeds 1.0. The computation of the B/C ratio was based on an analysis period of 20 yr. Because the major capital items in each improvement (earthwork and right-of-way) generally have service lives longer than 20 yr, 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 given in Table 5 and an assumed value for the average ADT over the 20-yr analysis period. The discount rate used to obtain the present worth of future costs and benefits was 4 percent/yr. The 4 percent discount rate represents the real long-term cost of capital over the inflation rate. This rate allows the analysis to be conducted on a constant-dollar basis, with the effect of inflation excluded.

The differences between the roadside design policies in accident frequency per mile per year, and therefore in accident costs savings and the B/C ratio, increased with increasing traffic volume. Therefore, one method of illustrating the results of the benefit-cost analysis is to determine a break-even ADT; i.e., the traffic volume at which the present worth of the benefits of the accident reduction is exactly equal to the present worth of the construction cost of the improvement. The break-even ADT represents the minimum traffic volume at which a roadside design improvement on an average highway section would be cost effective. The break-even ADT has been computed, for illustrative purposes, in generalizing the design examples presented here. However, the computation of the break-even ADT is not essential when evaluating roadside design policies for an individual highway section with a known ADT. To determine the economic justification for roadside design improvements in such a case, it is necessary only to compute the B/C 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 (a) nonclear zone and 4:1 clear zone roadside design policies for freeways, (b) 4:1 clear zone and 6:1 clear zone roadside design policies for freeways, (c) nonclear zone and 4:1 clear zone roadside design policies for two-lane highways, and (d) 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 8, including the expected reduction in the accident rate, the cost savings per accident reduced, the construction cost of the improvement, and the break-even ADT. For each example, the break-even ADT was computed separately based on accident cost estimates developed by the National Safety Council (NSC) and the NHTSA.

The design examples for freeways indicate that the improvement from a nonclear zone to a 4:1 clear zone roadside design policy becomes cost effective in the ADT range of 3,820 to 5,410 vehicles/day. 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 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 of 6,100 to 8,650 vehicles/day. 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 indicate 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

Table 8. Summary of benefit-cost evaluation 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 ($/accident reduced)				
Based on NSC accident costs	7,748	7,748	9,266	9,266
Based on NHTSA accident costs	10,977	10,977	14,502	14,502
Improvement construction cost ($/mile)	31,265	47,148	19,029-66,804	22,984
Residual value of improvement after 20 yr ($/mile)	14,753	25,407	8,873	13,622
Breakeven ADT (vehicles/day) 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 NCHRP Report 247 (1).

roadside design is selected for each section of highway.

The results of the design examples for two-lane highways are not as clear as the results for freeways because the roadside designs found on two-lane highways and the costs of improvements in roadside design 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 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 of 750 to 4,930 vehicles/day. If a 4:1 clear zone design policy is 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 of 1,560 to 2,450 vehicles/day. There are situations on two-lane highways where either the 6:1 clear zone, the 4:1 clear zone, 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.

CONCLUSIONS

The major conclusion of this study is that there is a statistically significant relation between single-vehicle ROR accident rate and the roadside design policy used outside of the highway shoulder. The study findings provide estimates of the single-vehicle ROR 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 5. The variation of these measures of effectiveness with ADT can be examined by using Equations 2 and 3.

Four design examples demonstrate a cost-effectiveness comparison of the average accident reduction benefits and typical construction costs for improvements in roadside design policy. It is not suggested that decisions about roadside design policy can be based on these four examples. Nevertheless, the examples do indicate 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 in order to provide 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 improvements in roadside design policy, 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 improvements in roadside design should also be used. Nevertheless, it is recognized that agencies, for legal and administrative reasons, may want 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 in this paper, 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 or effectiveness.

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Discussion

Tom Mulinazzi*

I am impressed by the way Graham and Harwood document the findings of their research. I especially approve of one of their major recommendations--that roadside design policies should be flexible in order to provide a cost-effective roadside design for each highway section or highway project.

It is my belief that a large percentage of the single-vehicle encroachments off the roadway go unreported. This is shown in Figure 2. I do not believe that the 4:1 clear zone, the 6:1 clear zone, or the nonclear zone helps keep the vehicle on the traveled way. I do believe, however, that the use of the 6:1 clear zone permits many more single-vehicle encroachments to go unreported than on the 4:1 clear zone, and also more unreported encroachments on the 4:1 clear zone than on the nonclear zone. The 4:1 clear zone is steeper than the 6:1 clear zone, which would have a tendency to force vehicles to travel further from the traveled way on the 4:1 clear zone. The nonclear zone, by definition, has more fixed objects for an errant vehicle to hit. To repeat myself for emphasis, I do not believe that a 6:1 clear zone keeps vehicles on the traveled way; however, I do believe that the 6:1 clear zone allows more vehicles to reenter the roadway without having a reported accident.

In conclusion, I commend the authors for writing a well-documented paper and presenting some facts that should be useful for practicing highway engineers.

J.W. Hall**

Graham and Harwood have made a significant contribution by quantifying the level of effectiveness of clear recovery zones. Because their research provides the highway engineer with a technique for assessing roadside safety improvements, the interested reader is strongly encouraged to review the authors' work in NCHRP Report 247 (1). Because of its greater length, the full report more thoroughly documents the procedures and analyses used in this study.

The authors' research was funded by NCHRP, which imposes certain technical, financial, and time constraints on researchers. These constraints are clearly evidenced in their paper, which primarily focuses on the roadside while devoting only minimal attention to the roadway. The authors also incorporate previous reports and some secondary data sources to fill gaps that could not be examined in suitable detail because of the project's budgetary and temporal limitations. The reader who is cognizant of previous research involving ROR crashes will have little difficulty in recognizing how this research supplements the current state of the art; the more casual reader, however, could misinterpret some of the study results. The intent of this discussion, therefore, is to comment on several items that could cause confusion.

In Appendix D of NCHRP Report 247, the authors distinguish roadside encroachments from ROR crashes. The paper fails to make this distinction; consequently, the reader might erroneously conclude that improved roadside design will reduce the frequency with which vehicles leave the road. What has been learned from the project is that only those encroachments that meet the definition of an accident and that are reported decrease with improved roadside design. The researchers' difficulty in quantifying this decrease could be due in part to an underreporting of encroachments on safer roadsides where accident threshold damages are exceeded, but where the impacting vehicle is still drivable.

The project also conducted a rather casual qualitative evaluation of roadway curvature and no measurement of gradient at 130 randomly selected sites. A number of previous studies (7,8) have found a relation between these geometric features and the occurrence of ROR crashes (and presumably encroachments). The researchers were unable to distinguish roadside type on the basis of the proportion of sites with tangents for any of the three roadway types studied. Although this finding is mildly surprising, the reader should not interpret this to mean that alignment does not influence the occurrence of ROR accidents.

Because of project limitations the researchers were forced to rely on a restricted sample for this study. The researchers offer appropriate justification for their use of data from Illinois, Minnesota, and Missouri; indeed, the more than 11,000 accidents considered in this project appear adequate. Nevertheless, the authors fail to discuss the extent to which these states typify the situation in the remainder of the country. Without detracting from the findings in the study, it is noteworthy that, as a group, these three states exhibit accident characteristics that are somewhat different from those of other states.

Data from the Fatal Accident Record System (FARS) for 1980 reveal that these three states account for 8.26 percent of the fatal accidents studied in this research (rural, single-vehicle, ROR accidents on two- and four-lane highways), a figure slightly in excess of their 7.82 percent share of all fatal accidents. It is also noteworthy that a significantly lower percentage (46 percent) of these fatal accidents in the study states occur on curves than that reported for the remainder of the country (52 percent). It may also be relevant that less than 13 percent of the field sites studied in this research exhibited curvature; therefore, these may not be representative of the actual sites where these crashes are occurring. In addition, roadway alignment differences among these three states may partly account for the state-to-state differences in single-vehicle ROR crash rates observed by the researchers. Although it would be improper to draw far-reaching conclusions from the generalized alignment data provided by FARS, jurisdictions where adverse geometrics are more frequently associated with these types of crashes should recognize this difference when interpreting the results of this study.

The authors have clearly indicated that what they refer to as a 4:1 clear zone policy is actually a variable criteria that does not preclude slopes steeper than this value. Unfortunately, the policy is so variable that the average foreslope values cited are of questionable value. Actually, the inherent variations in roadside slopes with both longitudinal and lateral displacement make it exceedingly difficult to categorize this parameter, even for those sections of roadway supposedly built according to a specified policy. It is also not clear if the measurement techniques used by the researchers ignored slopes less than 5 ft.

The researchers used the model developed by Glen-

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non (6) to estimate accident rates for various roadside design policies. Predicted accident rates for freeways were 8 times the observed values. Although these differences are clearly troublesome, they are consistent with Glennon and Wilton's admonition (9) that the encroachment frequencies used in Glennon's earlier model are simply "order of magnitude" estimates. It has been suggested in recent research that the original encroachment data from Kennedy and Hutchinson have been applied far beyond their limits of applicability, thus producing unreliable results. In their paper the researchers have attempted to estimate accident rates for freeway sections with nonclear zone designs by adjusting predicted accident rates with a correction factor. Although the analysis appears to be conservative, the expected reduction in the accident rate for this type of roadway must be viewed with suspicion.

At the risk of engaging in a semantic debate, the researchers' use of the term "unprotected fixed object" must be criticized. Fixed objects do not need protection; people do. Since the mid-1960s highway engineers have recognized that one of their major responsibilities is to protect vehicle occupants from injury. A number of terms, including the possibly overworked "roadside obstacle," would be more suitable.

Although the focus of their paper is on clear recovery zones, the researchers incorporate the techniques of engineering economy to demonstrate the application of the findings of their study. They properly note some limitations of their examples and suggest that individual analyses be conducted at specific sites. They have chosen to use the 4 percent discount rate mentioned in the AASHTO Red Book (10) without noting that a number of researchers, including Kimboko and Henion (11), have raised objections to this approach. The use of a break-even analysis with a B/C ratio of 1.0 was appropriate for demonstration purposes in their paper, but the reader should be cautioned that such an analysis could yield incorrect results if it were applied in an attempt to determine the optimal expenditure of highway safety funds.

The researchers have provided an adequate assessment of the effectiveness of clear recovery zones. Although the study implies that the effectiveness derives primarily from roadside rather than roadway characteristics, evidence suggests that ROR crashes are not distributed uniformly or randomly along the roadway, and this concept is reinforced by the alignment differences between the FARS and random site data for the study states. Those people who use the findings from this study should recognize that the actual effectiveness of an improved roadside design policy will be greater at those locations where roadside encroachments are more likely to occur.

Authors' Closure

We thank Mulinazzi and Hall for taking the time to review and discuss our paper; we appreciate their comments.

Hall is quite preceptive to recognize that funded research must address the objectives defined by the sponsor and within constraints set by the sponsor. The objective of this study was to evaluate the safety effects of roadside design policies rather than to evaluate the safety effects of particular geometric features. The study was intended to address the following questions: Are clear recovery zones generally effective? and, What roadside design policies are most appropriate for application over relatively long sections of highway that traverse a variety of terrain features? The study was not intended to investigate the optimal roadside design at any specific location.

The evaluation was accomplished by using study sections that represent the variety of terrain, roadway geometrics, and roadside geometrics actually found in the field on highways constructed under each policy. The safety measures developed must be interpreted as averages over the mix of cut-and-fill sections and the distribution of embankment slopes, embankment heights, and fixed objects actually found for each policy in the field. The section on Research Approach explains that any further consideration of the incremental effects of specific roadside features or roadway geometrics would have required a detailed inventory of highway sections that would have been far beyond the resources available to the study. Nevertheless, we believe that the results reported in the paper address the objectives defined by the sponsor of the research.

Hall notes, as we did, that the highway sections constructed under the 4:1 clear zone policy contained some embankment slopes steeper than 4:1 and some fixed objects within the 30-ft clear recovery zone. We addressed the issue by using the model in NCHRP Report 148 (6) to estimate that, if the 4:1 clear zone policy had been uniformly applied, the resulting accident rates would have been 5 percent less than the reported results on freeways and 25 percent less than the reported results on two-lane highways.

Hall correctly observes that highways in the three states considered--Illinois, Minnesota, and Missouri--are slightly less likely to contain horizontal curves than highways in the nation as a whole. Based on our field survey sample, horizontal curves constitute approximately 13 percent of the total length of the study sections. (But we wish to point out that this is not the same as saying that only 13 percent of the study sections contained horizontal curves.) By contrast, the geometric inventory of highway sections assembled for the FHWA study, "Effectiveness of Alternative Skid Reduction Measures" (12), which included more than 2,000 miles of highway in 15 states from all regions of the country, found 15 percent of the total length of these sections to be on horizontal curves.

Hall raises the question of whether slopes shorter than 5 ft were measured. We wish to reassure him that the slope and length of all embankments, however short, were measured.

Hall makes a valid semantic point about possible misinterpretation of the term "unprotected fixed object," by which we meant a fixed object that was not behind a guardrail. Although the meaning of the term unprotected used in this sense is obvious, we agree that another term such as "exposed fixed object" might be preferable.

Finally, we are in complete agreement with Hall's statements that ROR accidents are not distributed uniformly or randomly along the roadway and that the effectiveness of improved roadside designs will be greater at locations where roadside encroachments are more likely to occur. It may be far more cost effective to concentrate the available dollars on improving the roadside at specific locations with the greatest need (such as on the outside of horizontal curves) than to require a uniform roadside design over extended sections of roadway. We strongly believe that further research is needed to quantify the roadside accident rates on horizontal curves and other high-encroachment-rate locations to provide a basis for more flexible and cost-effective design policies.

We are gratified that the comments by Mulinazzi echo this need for flexibility in roadside design. The results of this study indicate that improvements in roadside design can be cost effective, but unfortunately we are a long way from achieving the goal of maximum cost-effectiveness through flexible design.

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Abridgment

Comparing Operational Effects of Continuous Two-Way Left-Turn Lanes

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In this paper the operational effects of continuous two-way left-turn lanes (TWLTLs) were compared with four-lane sections and five-lane Z-turn-pattern sections. Both three-lane and five-lane TWLTL sections were examined. These comparisons were made in order to determine under which circumstances a particular alternative will produce the best results from the standpoint of movement efficiency and safety. The following variables were monitored and evaluated in this study: traffic counts, speed surveys, lateral placement, conflicts, accident histories, site accesses, turning movements, day or night operations, and dry or wet pavement conditions. The TWLTL treatments were effective under a variety of turning and main line volumes. Statistically, lower mean conflict rates were observed for the five-lane TWLTL when compared with either the four-lane or Z-pattern treatments. Three-lane TWLTLs were superior to four-lane segments under more selective circumstances.

One of the consequences of locating retail establishments outside the confines of a central business district (CBD) has been the advent of strip commercial areas. These areas rely on the linear high densities provided by traffic on arterial systems as a substitute to the CBD, while catering to the public's desire for drive-up convenience. Although such areas have been successful for some retail establishments, the transportation implications of strip commercial zones create one of the toughest design problems for the transportation engineer.

In developed strip commercial areas, continuous two-way left-turn lanes (TWLTLs) have been used as a possible arterial improvement. In this paper the operational effects of TWLTLs were compared with four-lane sections and five-lane Z-turn-pattern sections. This comparison was made in order to determine under what circumstances a particular alternative will produce the best results from the standpoint of movement efficiency and safety.

LITERATURE REVIEW

A literature search revealed several aspects about TWLTL operations. Glennon and others (1) suggested that the use of a TWLTL is warranted when the average daily traffic (ADT) volumes are between 10,000 and 20,000. This range is typical of the operating conditions found in the literature. In many cases the volume data were not broken down further than ADT. The appeal of using peak-hour data was alluded to by Cribbins and others (2): "Findings of this investigation indicate that median openings, per se, are not necessarily accident prone under conditions of low volumes, wide medians, and light roadside development; however, as volumes increase and development increases commensurately, the frequency of median openings does have a significant effect on accident potential." Following this logic, the proper condition for monitoring problems in median control is under high-volume, peak-hour use.

Left turns from median openings account for the largest proportion of driveway accidents. Of the left-turn accidents, rear-end occurrences are the