Safety Effects of Cross-Section Design for Rural, Four-Lane, Non-Freeway Highways

PUBLICATION NO. FHWA-RD-98-071

MAY 1998

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

This research study was conducted under the Federal Highway Administration's (FHWA) Highway Safety Information System (HSIS) contract DTFH61-92-C-00086. The HSIS is a roadway-based system that provides quality data on numerous accident, roadway, and traffic variables. The HSIS can be used to analyze a large number of safety problems. The HSIS is used in support of the FHWA safety research program and as input to program and policy decisions. The HSIS is also available to analysts conducting research under the National Cooperative Highway Research Program, university researchers, and others involved in the study of highway safety.

The results of the HSIS effort presented in this report represent a preliminary effort to establish a quantitative relationship between accident frequency and cross-section design elements for rural, four-lane, non-freeway highways. While the basic data set used for the statistical modeling analysis was relatively small and the range of variation in many of the variables was quite limited, the study should be viewed as an initial step toward the development of improved safety relationships linking geometric design characteristics and accident occurrence. An HSIS four-page report (FHWA publication FHWA-RD-97-027) summarizes the findings of the subject report.

Copies of these reports will be available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A limited number of copies will be available from the R&T Report Center, HRD-11, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD 20706. The phone number for the R&T Report Center is (301) 577-0818.

A. George Ostensen
Director
Office of Safety and Traffic
Operations Research and Development

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-98-071		

4. Title and Subtitle	
SAFETY EFFECTS OF CROSS-SECTION DESIGN FOR RURAL, FOUR-LANE, NON-FREEWAY HIGHWAYS	5. Report Date May 1998 6. Performing Organization Code
7. Author(s) Jun Wang, Warren E. Hughes, Richard Stewart	8. Performing Organization Report No.
9. Performing Organization Name and Address 1) LENDIS Corporation, - McLean, VA 2) Bellomo-McGee, Inc., - Vienna, VA 3) Highway Safety Research Center, UNC - Chapel Hill, NC	10. Work Unit No. (TRAIS) 3A3B 11. Contract or Grant No. DTFH61-92-C-00086
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296	13. Type of Report and Period Covered Final Report 2/1/94 - 12/31/96 14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officer's Technical Representative (COTR): Michael S. Griffith, HSR-20

16. Abstract

Over 56,000 kilometers of arterial highways in the United States are multi-lane, non-interstate roads in rural areas. Fatality rates on rural federal-aid primary highways have been significantly higher compared with the fatality rates for urban and rural interstate highways and urban primary highways. Unfortunately, very little is known concerning the effects of geometric design elements on the safety for rural, multi-lane, non-freeway highways since little past research has concentrated on these roads.

This paper presents a study of the effects of the various cross-section-related design elements on the frequency of accidents for rural, multi-lane, non-freeway roads. Data extracted from the Highway Safety Information System (HSIS) for four States were utilized for data exploration and descriptive analysis. Minnesota data were used for a statistical modeling due to the availability of accident, traffic, roadway inventory, and supplemental inventory data for selected data elements. Supplemental roadway variables that were needed included roadside condition and intersection/driveway access points. To collect those supplemental data elements, an advanced Photolog Laser Videodisc (PLV) data recording system was developed and applied for the study. These data were integrated into the HSIS database for the modeling analysis.

The objective of the statistical modeling analysis was to identify cross-section-related variables that were statistically associated with the occurrence of accidents on selected roadway segments and to estimate model parameters. A Poisson regression model was used to model the relationship between expected accident frequency and various roadway and traffic variables. The study results establish a quantitative relationship between accident frequency and various cross-section-related roadway design elements on rural, multi-lane, non-freeway highways.

17. Key Words	18. Distribution Statement
Rural Multi-Lane Highways, Accident Prediction Model, Highway Safety Information System	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	28	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This form was electronically produced by Elite Federal Forms, Inc.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

TABLE OF CONTENTS

LIST OF FIGURES

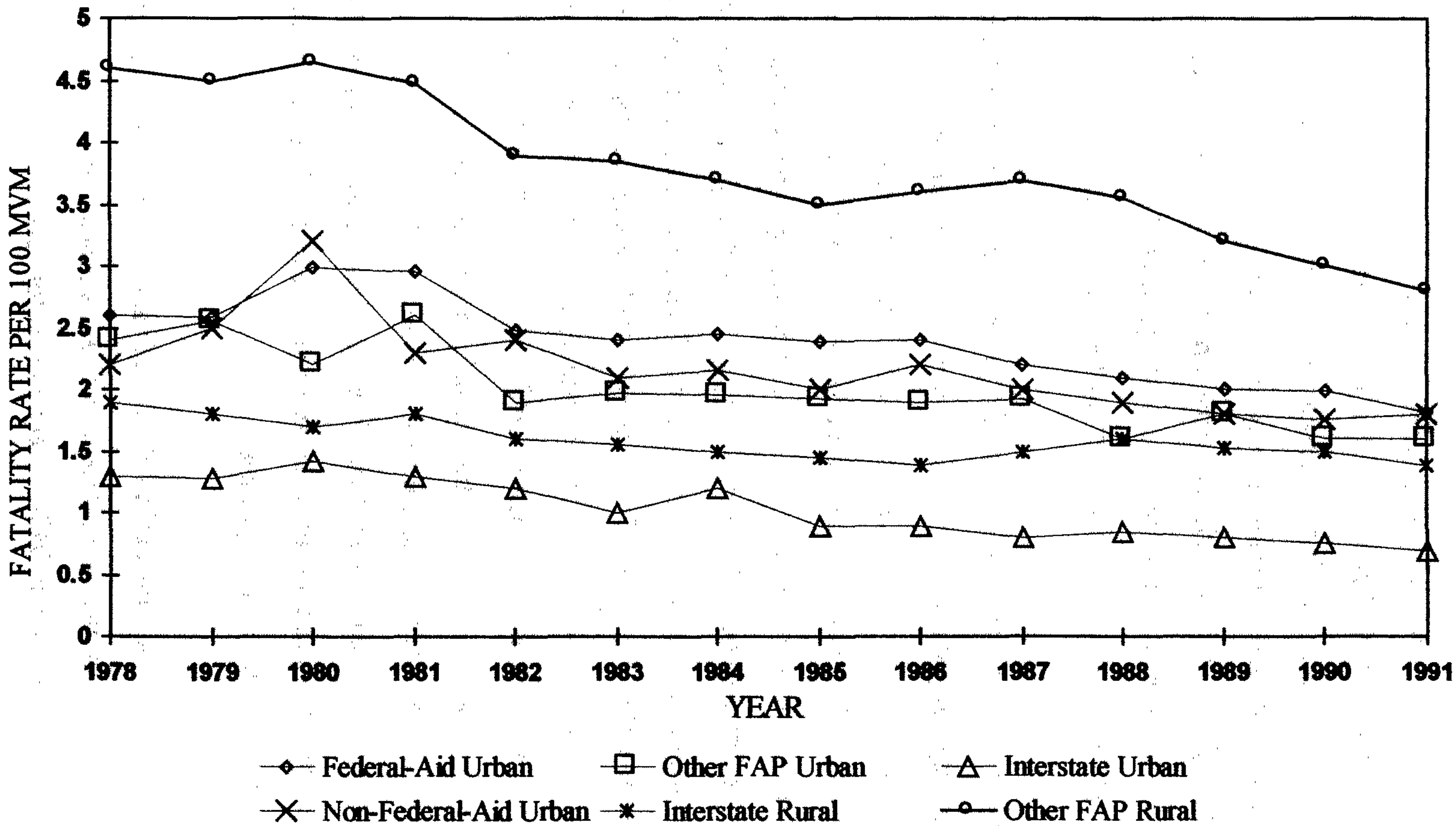
LIST OF TABLES

INTRODUCTION

In the United States, arterial highways constitute only 9.3 percent of the total mileage of the Nation's highway system but carry 48 percent of total travel.[1] In 1992, approximately 44 percent of all fatal crashes and 47 percent of all injury crashes occurred on arterial highways.[2] Fatality rates on rural federal-aid primary highways have been significantly higher compared with those for urban and rural interstate highways and urban primary highways, as shown in Figure 1.[3] Although this group includes two-lane rural roads, an important component of the rural federal-aid primary highways is multi-lane rural highways. In fact, over 56,000 km (35,000 mi) of arterial highways in the United States are multi-lane, non-interstate roads in rural areas.[4]

In recent years, a considerable amount of highway safety research has been conducted in the United States regarding the safety effects of various traffic and geometric roadway features, especially on two-lane rural roads. For example, a 1987 study by Zegeer, et al. examined safety relationships of lane width, shoulder width, shoulder type, and roadside conditions on two-lane rural roads.[5] Several other studies have attempted to address specific elements of multi-lane roads in terms of safety effects, such as the study by Foody and Culp on median type in 1974.[6] A study done by Knuiman, et al. examined the effect of median width on accident rates.[7] Two National Cooperative Highway Research Program (NCHRP) studies by Harwood investigated multi-lane design alternatives for improving suburban highways in 1986 and the effective utilization of street width on urban arterials in 1990, respectively.[8,9] In these two studies, traffic operation and safety effects on different suburban and urban multi-lane cross-section design alternatives were analyzed. The studies provided comparisons of the advantages, disadvantages, and relative merits of the various design alternatives for suburban highways and urban streets. To date, however, no study has adequately investigated the effects of multiple traffic and roadway features on multi-lane rural highways.

This report describes a study of the influence of various cross-section design elements on the frequency of accidents on rural, multi-lane, non-freeway roads. Data extracted from the Highway Safety Information System (HSIS) were utilized for data exploration and preliminary



MVM = million vehicle miles, FAP = federal-aid primary highway

1 mi = 1.61 km

Figure 1. U.S. fatality rates by highway system (1978 - 1991).

analysis. Due to the availability of supplemental videodisc photologs, only data from Minnesota were used for statistical modeling analysis. A specialized software application was developed to collect and integrate data on roadside condition and intersection/driveway access using a Photolog Laser Videodisc (PLV) system. After integrating data on roadside and access features, Poisson regression models were constructed to model the relationships between related road design elements and accidents. It was determined that traffic volumes, functional class, location/area type, frequency of intersections with turn lanes per mile, access control, roadside hazard rating, outside shoulder width, frequency of intersection without turn lanes per mile, and driveways per mile affect accidents on rural, multi-lane, non-freeway highways. Additional research is warranted to determine if these relationships are applicable to other States.

METHODOLOGY

Database and Initial Data Analysis

The HSIS is a multi-State highway safety database developed and maintained by the Federal Highway Administration (FHWA) and Highway Safety Research Center (HSRC) of the University of North Carolina.[10] At the time this study was conducted, the database consisted of multiple years of accident, roadway inventory, and traffic volume files for five States (i.e., Illinois, Maine, Michigan, Minnesota, and Utah). All accidents reported by the police are included in the accident files. The road inventory files contain the characteristics of homogeneous highway sections. The traffic volume files contain data on the average annual daily traffic volume, among other parameters. Using a common linking system, these three files (and other compatible files such as intersection and interchange files) can be linked to derive the number, rate, severity, and type of accidents that have occurred on specific highway sections over a given period of time.

Preliminary checking and investigation indicated that the accident and roadway data for four of the five HSIS States were of adequate sample size and reliability for an explorative analysis investigating the effect of multi-lane cross-section design on accident rates. A full description of the data for the four States can be found in references 11 through 14. The HSIS was not designed to combine the data from the participating states into a single database. There is no common system of variable definitions applied across all HSIS States; therefore, the analyses performed in this study were separated for each State database. In this study, the 1990 roadway files with traffic volume data were used.

The analyses were restricted to rural, multi-lane, non-freeway sections. One-way, multi-lane, rural streets were eliminated from the analysis. Based on consideration of the reliability of reported accident location and variance related to the accident rate estimates, a section length of 0.48 km (0.3 mi) was chosen as the minimum section length. Sections on local road systems also were eliminated due to large sample size differences between the States and the initial finding that data were missing or potentially erroneous for the local road systems.

For each multi-lane, non-freeway, rural roadway section, accident data that were reported over the 6-year period of 1985-1990 were obtained from the HSIS database. A review of these data indicated that there were very few pedestrian and bicycle accidents reported on multi-lane rural roads. As a result, these accidents were excluded in an attempt to restrict accidents to those that are more highly correlated to cross-section design of multi-lane rural road segments. For the same reason, animal-related accidents also were eliminated from the accident database.

The data sets of the four HSIS States were subjected to preliminary data analysis. At the time of this analysis, supplemental videodisc photologs were only available for the State of Minnesota. Consequently, it was decided to conduct the current study using Minnesota data only for the modeling analysis.

The PLV Data Collection

It has been shown by past studies on safety effects of various roadway geometric designs that roadside conditions are among the most important factors affecting accident rates.[5] While the HSIS contains a wealth of information on both accidents and roadways, data on roadside conditions are not included in the existing roadway files as these data items are not usually collected. This type of data had to be collected in an efficient and economical manner for this study. One efficient way to collect these data is to use State roadway photologs.

In recent years, several State highway agencies have moved from the use of 35-mm film to the use of laser videodiscs for the storage of photolog images. These images can be randomly accessed in seconds under the control of a microcomputer. The HSIS is equipped with a PLV system that can be used to collect those data that do not exist in the HSIS data files. At the time this study was conducted, the PLV system only applied to Minnesota's State-maintained highways among all HSIS States.

In order to efficiently collect the needed data and to incorporate these data into HSIS data files, a Longitudinal Roadway Data Collection (LRDC) program was developed for this study. By running this LRDC program under a PLV system, the data collectors can directly record data values (including location of the data items) for any pre-defined items along the roadway to an output file while they are "navigating" the roadway images through the PLV system. The output data file is in a format compatible with the HSIS data file; thus, the collected PLV data can be easily linked with HSIS roadway files via a common linking system (e.g., route system, route number, and milepost).[15]

A roadside hazard rating was used to describe roadside conditions collected from the PLV images. The roadside hazard rating was developed by Zegeer et al. for an FHWA study in 1987.[16] It is a subjective measure of the hazard associated with the roadside environment. The rating values indicate the accident damage likely to be sustained by errant vehicles on a scale from one (low likelihood of an off-roadway collision or overturn) to seven (high likelihood of an accident resulting in a fatality or severe injury). The ratings are determined from a seven-point pictorial scale, and a data collector can choose the rating value (one through seven) that most closely matches the roadside hazard level for the roadway section in question.

Preliminary data analysis and previous studies all indicate that intersections, driveways, and interchanges are major factors that cause roadway accident occurrence. Although major intersections can be partitioned through an intersection/interchange file (e.g., the HSIS database contains the Minnesota intersection file), the large majority of driveways and minor intersections cannot be screened from the intersection/interchange file since they are not included in the file. Therefore, it was decided that the data on driveways, intersections, and interchange ramps be collected from the PLV/LRDC system for the roadway sections included in the analysis.

Seven types of access points and their location reference (i.e., route system, route number, and milepost) were recorded into a data file via LRDC program. They are:

- Driveway.
- Signalized intersection.
- Unsignalized intersection with turn lane in both major and minor roads.
- Unsignalized intersection with turn lane in major roads.
- Unsignalized intersection with no turn lane in both roads.
- Interchange beginning ramp.
- Interchange ending ramp.

All of these PLV data were collected from 1988-1990 visual database (laser videodiscs) and the output data file was then converted into SAS data sets and integrated with the analysis data file. In addition, the PLV system also was used in verifying other data elements for correctness. One such application for this study was to correct and supplement data on median width on the basis of PLV image estimation for better modeling purposes because a large number of roadway segments in the original data set contained median width value coded as "varies."

Statistical Methods

A statistical modeling analysis was performed to establish mathematical relationships between accidents and various cross-section-related roadway variables. The specific aims of the modeling analysis were to determine which of a number of cross-section-related variables were statistically associated with the occurrence of accidents on selected roadway segments and to estimate model parameters by the fitting procedure.

A Poisson regression model was used in the model development. The underlying assumption with such a model is that, for a given roadway segment, I, the number of accidents, Y_i, that occur over a specified time interval is distributed as a Poisson random variable with mean $E(Y_i) = \mu_i$. Thus, the probability function of the Poisson distribution can be expressed as:

$$P(Y_i) = \frac{\mu_i^{Y_i} e^{-\mu_i}}{Y_i!} \tag{1}$$

where:

$$\mu_i = E(Y_i) = T_i^{\beta_T} [e^{\sum_{j=1}^{k} X_{ij} \beta_j + \beta_0}] \tag{2}$$

where I = 1, 2, 3, ..., n; T_i is a measure of exposure on the section I; X_{ij} are the cross-section-related and other variables of interest; and β_0, β_T, β_j are model parameters. From equation (2) it follows that:

$$Log\ E(Y_i) = \beta_T\ Log\ (DVMT_i) + \beta_0 + \sum_{j=1}^{k} \beta_j X_{ij} \tag{3}$$

where Log denotes the logarithm to base e, and the exposure variable is average daily vehicle miles of travel (DVMT) on the roadway section in this study. Therefore, with this type of model, for roadway section I, the expected number of accidents during the study period will be of the form:

$$\hat{A}_i = C_0 \ (DVMT_i)^{\beta_T} f_{1i} f_{2i} \cdots f_{ki} \tag{4}$$

In this equation, the factor $C_0(DVMT_i)^{\beta_T}$ would be the expected accident frequency based on only DVMT and corresponds to the case where all of the explanatory variables X_{ij} are equal to zero. The other factors:

$$f_{ij} = e^{\beta_j X_{ij}} \tag{5}$$

are multipliers that scale the baseline value up or down depending on the estimated coefficients and the values of the explanatory variables. Note that equation (4) estimates the expected number of accidents for the entire study period over which the data were included. One can obtain expected annual accidents by dividing the length of the study period in years (i.e., in this case divided by 6 years).

Equations (4) and (5) show that the Poisson model yields expected accident frequencies given as a product of non-negative factors representing exposure and the other explanatory variables. Poisson regression models have been widely used in statistical analyses of count data (e.g., Cameron and Trivedi, 1986; Frome, Cragle, and McLean, 1990).[17,18] It has recently been employed in several highway safety studies by Joshua and Garber for estimating truck accident rates,[19] Miaou, et al. for modeling relationships between truck involvements and highway geometric designs,[20] and Jovanis and Chang to examine the relationship between vehicle accidents and vehicle miles of travel.[21]

MODEL DEVELOPMENT

The preliminary data analysis was designed to address database characteristics and general accident characteristics for the rural, non-freeway, multi-lane highways; to identify the specific safety problems on the multi-lane highways; and to provide insights for determining important variables for the model development.

Table 1 gives roadway and accident statistics with various roadway characteristics for Minnesota road sections that were used in the preliminary data analysis. These initial Minnesota data included 671 roadway segments of rural, multi-lane, non-freeway roads. The length of these segments ranged from 0.48 km (0.3 mi) to 9.79 km (6.08 mi), with a mean length of 1.14 km (0.708 mi). Over 90 percent of these were four-lane divided roads; the others were three-lane or four-lane undivided roads. Most of them (93 percent) also were classified as rural principal arterial (non-interstate). A total of 3,510 accidents were associated with these segments for an average of 5.2 per segment over the 1985-1990 period. An examination of accident data also revealed that a large proportion (30 percent of total accidents on these highways) occurred at intersection areas in Minnesota. The proportion was even larger if interchange and driveway access accidents were counted. This finding proves the assumption that intersections, driveway accesses, and interchanges are major factors causing traffic crashes on multi-lane highways. Thus, variables on intersections, driveways, and interchanges should be considered as independent variables in the modeling process.

Following some initial modeling analyses, decisions were made to restrict the analyses by eliminating roadway sections involving three-lane roads, containing signalized intersections, or containing interchange ramps since these sections tend to have different safety and operation characteristics than the other multi-lane highways. It also was decided to examine photologs of the 195 roadway sections where median width had been coded as "varies" in the original data file and to attach an estimated average median width value in these sections.

After this screening, the resulting data set contained 622 roadway sections on which 3,004 accidents had occurred. Table 2 presents summary statistics of the numbers of roadway sections and total length (in miles), distributed across the values of the independent variables used in the model development. Table 3 gives distributions of roadway sections, length, and accident experiences for two classification variables in the model data set. As we can see for the functional class variable (i.e., rural principal arterial vs. rural other functional class) and the area location variable (i.e., segment is within a rural municipality vs. outside a rural municipality), it clearly shows that, while rural other and rural municipal road sections constituted a relatively

Table 1. Roadway and accident statistics with various characteristics for Minnesota rural multi-lane highways.

Category	No. of Sections	Mileage	No. of Accidents	Accident Rate (per MVM)
Roadway Type:				
3-Lane Undivided	14	7.12	66	0.87
4-Lane Undivided	32	20.28	549	2.18
4-Lane Divided	625	447.88	2895	0.41
Traffic Volume:				
< 5,000 vpd	230	184.31	657	0.44
5,000 - 9,999 vpd	244	163.58	1218	0.51
10,000 - 14,999 vpd	161	107.65	1246	0.46
15,000 -19,999 vpd	34	18.48	366	0.55
≥ 20,000 vpd	2	1.26	23	0.39
Outside Shoulder Width:				
0 ft	18	9.50	563	3.90
1 - 3 ft	11	7.48	132	1.71
4 - 6 ft	34	19.17	93	0.38
7 - 9 ft	179	143.11	1131	0.41
≥ 10 ft	429	296.04	1591	0.37
Outside Shoulder Type:				
No shoulder	18	9.50	563	3.90
Gravel or stone	52	41.19	275	0.65
Paved	601	424.61	2672	0.39
Median Type (if divided highway):				
Raised median	41	25.33	524	1.11
Depressed median	578	416.39	2356	0.36
Barrier median	1	0.86	3	0.30
Unknown	5	5.29	12	0.20
Median Width (if divided highway):				
1 - 10 ft	24	18.39	422	1.19
11 - 30 ft	8	3.29	14	0.25
> 30 ft	398	274.83	1379	0.33
Varies	195	151.36	1080	0.43
Access Control:				
No access control	452	305.70	2464	0.58
Partial access control	219	169.58	1046	0.33

1 mi = 1.61 km, 1 ft = 0.3048 m, vpd = vehicles per day, MVM = million vehicle miles.

Table 2. Characteristics of roadway database used in statistical analysis.

Category	No. of Sections	Mileage
Overall	622	431.40
Functional Class:		
Rural principal arterial	579	400.38
Others	43	31.02
Roadway Type:		
4-Lane divided	592	411.83
4-Lane undivided	30	19.57
Road Surface Width:		
< 40 ft	2	3.57
40 - 50 ft	555	386.97
50 - 60 ft	56	35.73
> 60 ft	9	5.14
Median Width:		
1 - 10 ft	35	26.81
11 - 30 ft	16	7.41
> 30 ft	527	360.29
Unknown	14	17.32
Median Type:		
Raised median	39	24.50
Depressed median	547	381.17
Barrier median	1	0.86
Unknown	4	2.45
Traffic Volume:		
< 5,000 vpd	215	170.26
5,000 - 9,999 vpd	226	144.91
10,000 - 14,999 vpd	149	99.87
15,000 - 19,999 vpd	30	15.10
≥ 20,000 vpd	2	1.26
Percent Commercial Vehicles:		
< 10 %	270	192.29
10 - 20 %	338	229.52
> 20 %	14	9.59
Driveways Per Mile:		
0	431	270.06
0 - 1	22	33.41
1 - 2	72	73.12
2 - 3	51	30.74
3 - 4	16	8.96
4 - 5	10	5.20
> 5	20	9.92

Table 2. Characteristics of roadway database used in statistical analysis (continued).

Category	No. of Sections	Mileage
Unsignalized Intersection With Turn Lanes Per Mile:		
0	544	370.65
0 - 1	10	21.92
1 - 2	21	18.11
2 - 3	35	16.34
> 3	12	4.37
Unsignalized Intersection Without Turn Lanes Per Mile:		
0	429	269.17
0 - 1	21	37.27
1 - 2	67	63.59
2 - 3	61	34.48
3 - 4	24	13.85
4 - 5	9	5.89
> 5	11	7.16
Average Shoulder Width:		
0 ft	14	7.43
1 - 3 ft	7	4.84
4 - 6 ft	14	9.91
7 - 9 ft	232	173.81
> 9 ft	355	235.41
Average Roadside Hazard Rating:		
Not available	66	55.77
0 - 1	31	21.48
1 - 2	133	89.89
2 - 3	260	181.94
3 - 4	98	62.78
4 - 5	21	11.57
5 - 6	9	4.82
6 - 7	4	3.14
Access Control:		
No access control	421	285.13
Partial access control	201	146.27
Area Location Type:		
Rural municipal	71	34.85
Non-rural municipal	551	396.55

1 mi = 1.61 km, 1 ft = 0.3048 m, vpd = vehicles per day.

Table 3. Data set statistics for two classification variables in model analysis.

Classifications	No. of Sections	Mileage	No. of Accidents	Acc. / Section
Rural principal arterial	579	400.4	2280	3.94
Rural others	43	31.0	724	16.84
Rural municipal	71	34.9	876	12.34
Rural non-municipal	551	396.6	2128	3.86
Rural other and/or rural municipal	97	57.6	1140	11.75
Neither	525	373.8	1864	3.55

1 mi = 1.61 km.

small part of the sample, the accidents occurring on these roadways were disproportionately higher. Therefore, the statistical model was mainly formulated to fit over the entire data set and contained dummy variables to indicate rural principal arterials and rural municipal sections. Nevertheless, other models also were explored by excluding these two variables or fitting the model on only those sections that were principal arterials and not rural municipal. Neither of these models, however, provided very satisfactory estimates of accidents on those roadways that were classified as not principal arterials or as rural municipal. Thus, it was decided that the model that contained the two descriptive variables was most appropriate.

On the basis of available variables in the analysis file and prior data analysis results, the basic independent variables considered in the modeling analysis were:

- functional class (indicator of rural principal arterial).
- number of lanes.
- road surface width.
- indicator of divided or undivided highway.
- median width.
- median type.

- percent commercial vehicles.
- driveways per mile.
- unsignalized intersections with turn lanes per mile.
- unsignalized intersections with no turn lanes per mile.
- average shoulder width.
- average roadside hazard rating.
- access control (indicator of partially controlled access vs. no access control).
- area location type (indicator of rural municipal area vs. non-rural municipal area).

Application of the modeling process yielded the results shown in Table 4. The table gives model estimates for the parameters and their standard errors, chi-square statistics, and level of statistical significance for each of the independent variables. The model accounted for 67 percent of the total deviance in the dependent variable. On the basis of this result, the accident predictive equation can be expressed as:

$$Y = 0.0002(DVMT)^{1.073} e^{(0.131X_1 - 0.151X_2 + 0.034X_3 + 0.163X_4 + 0.052X_5 - 0.572X_6 - 0.094X_7 - 0.003X_8 + 0.429X_9)} \qquad (6)$$

where:

Y	=	Predicted annual accidents.
DVMT	=	Average daily vehicle miles of travel.
X_1	=	Average roadside hazard rating.
X_2	=	Access control (partial control = 1, no control = 0).
X_3	=	Driveways/mi.
X_4	=	Intersections with turn lanes/mi.
X_5	=	Intersections without turn lanes/mi.
X_6	=	Functional class (rural principal arterial = 1, rural others = 0).
X_7	=	Shoulder width (ft).
X_8	=	Median width (ft).
X_9	=	Area location type (rural municipal = 1, rural non-municipal = 0).

Table 4. Model results for rural four-lane highways.

Variables	Estimates	Standard Error	χ^2	P-Value
Intercept (β_0)	-6.572	0.293	501.80	0.0001
Roadside Hazard Rating	0.131	0.025	28.09	0.0001
Access Control[a]	-0.151	0.047	10.43	0.0012
Driveways/mi	0.034	0.008	19.36	0.0001
Intersections With Turn Lane/mi	0.163	0.019	70.99	0.0001
Intersections With No Turn Lane/mi	0.052	0.008	40.99	0.0001
Functional Class[b]	-0.572	0.070	66.82	0.0001
Outside Shoulder Width	-0.094	0.011	70.15	0.0001
Median Width	-0.003	0.009	10.01	0.0016
Area Location Type[c]	0.429	0.064	44.48	0.0001
Log (DVMT) (β_T)	1.073	0.028	1428.42	0.0001

[a] Access Control = 1 if partial control, 0 if no control.
[b] Functional Class = 1 if rural principal arterial, 0 otherwise.
[c] Area Location Type = 1 if rural municipal area, 0 otherwise.
1 mi = 1.61 km.

The results in equation (6) appear to have reasonable coefficients for a model for total accidents as a function of the 10 variables listed. That is, predicted accidents increase with worsening roadside conditions and with increasing exposure measures (i.e., daily vehicle miles of travel), numbers of driveways, and intersections (with and without turn lanes). Predicted accidents decrease as outside shoulder widths and median widths (including inside shoulder widths) increase. The model coefficients also show lower accident frequencies on four-lane roads with partial access control, lower frequencies on rural principal arterials (as opposed to rural other non-freeways), and higher accident frequencies when the road segment is classified as rural municipal area. In fact, the χ^2 statistics show functional class and area location type to be among the more significant variables in the model. The estimated coefficients show that, on principal arterials, expected accidents are decreased by the factor

$$f_6 = e^{-0.572} = 0.564$$

compared with road sections classified as rural other, and accidents on rural municipal roads to be increased by the factor

$$f_9 = e^{0.429} = 1.535$$

compared with rural non-municipal roads.

Guidelines for classifying roadways according to the variables of "functional class" and "area location type" were obtained from discussions with Minnesota traffic engineers. The discussions revealed that the rural municipal area is simply defined as an incorporated area in rural locations; thus, the boundaries of a municipality would be the incorporated limits. Functional classifications such as rural principal arterial highways, rural minor arterial roads, and rural collector roads are based on the definitions within the American Association of State Highway and Transportation Officials (AASHTO) Green Book.(22)

It is noted that the data set used in this modeling analysis was relatively small and the variations in many of the variables were quite limited. For example, it would be desirable to have an indicator variable of divided or undivided highway in the model. However, this variable was found to be statistically insignificant due to a very limited sample size for undivided roadway sections (see Table 2). Nevertheless, these undivided roads can be characterized as having zero median width.

MODEL APPLICATIONS

This model can be used for a variety of applications, such as developing accident predictions for different rural, four-lane highway design alternatives and estimating the accident reductions attributed to changes in the cross-section of rural four-lane highways. To illustrate these applications, Figures 2 and 3 present predicted annual accidents for four illustrative, rural, four-lane cross-section design alternatives under two exposure conditions, respectively. In this example, the model was applied to four-lane roadway design alternatives for both principal arterial and non-principal arterial highways in non-municipal areas. The two exposure conditions considered were 6,440 DVKT (daily vehicle km of travel, 4,000 DVMT) and 12,880 DVKT (8,000 DVMT). Other roadway conditions considered in this example were 2.8 average roadside hazard rating, no access control, 0.3 driveways/km (0.5 driveways/mi), 0.18 intersections with turn lanes/km (0.3 intersections with turn lanes/mi), and 0.6 intersections without turn lanes/km (one intersection without turn lanes/mi). For these specific conditions of rural, four-lane highways, the safety effects of the four alternatives of different cross-section designs can be quantitatively assessed. The alternatives included:

- *"Base" alternative:* An undivided highway with no shoulders (median width=0 and shoulder width=0).
- *Alternative A:* An undivided highway with a 1.83-m (6-ft) shoulder width.
- *Alternative B:* A divided highway with a 5.5-m (18-ft) median width and a 2.4-m (8-ft) shoulder width.
- *Alternative C:* A divided highway with a 9.2-m (30-ft) median width and a 2.4-m (8-ft) shoulder width.

Figure 4 depicts incremental accident reduction factors (percent of accidents that would be reduced) for alternatives A, B, and C compared with the "base" alternative while keeping all variables the same except for changes in median width and/or shoulder width.

CONCLUSIONS

This study benefitted from the use of a more comprehensive database and advanced data collection means through a PLV system. The data used are also more current than those in older studies. The study employed the method of Poisson regression, which represents a more appropriate model for accident count data than those used in many earlier studies.[23]

This study represents a preliminary effort to establish a quantitative relationship between accident frequency and cross-section design elements for rural, four-lane, non-freeway highways. While the basic data set used for the statistical modeling analysis was relatively small and the range of variation in many of the variables of interest was quite limited, the study should be viewed as an initial step toward development of improved safety relationships linking geometric design characteristics and accident occurrence. With improved knowledge of the safety relationships, highway and traffic engineers can make more informed design decisions. As illustrated in the results section of this report, models such as this could be applied to assess the incremental safety effects among various cross-section alternatives. Additional research involving these types of models and other methodologies will result in greater understanding of the safety consequences of designs. This in turn could result in improved highway designs and, ultimately, enhance highway safety.

It should be noted that research is currently under way to develop an Interactive Highway Safety Design Model (IHSDM). The IHSDM, which will consist of several modules, will be a tool that transportation engineers can use within the computer-aided design (CAD) environment to analyze and compare highway design alternatives at preliminary and final engineering stages. It is envisioned that a highway designer will be able to apply an accident analysis module at the project planning/preliminary engineering stage to compare alternatives in terms of accidents. Predictions of the expected changes in accidents will be based on a knowledge base that draws upon the results of accident prediction models, well-designed before-after accident studies of highway improvements, and accident modification factors. This study will serve as preliminary research into the development of accident prediction models for rural four-lane segments.

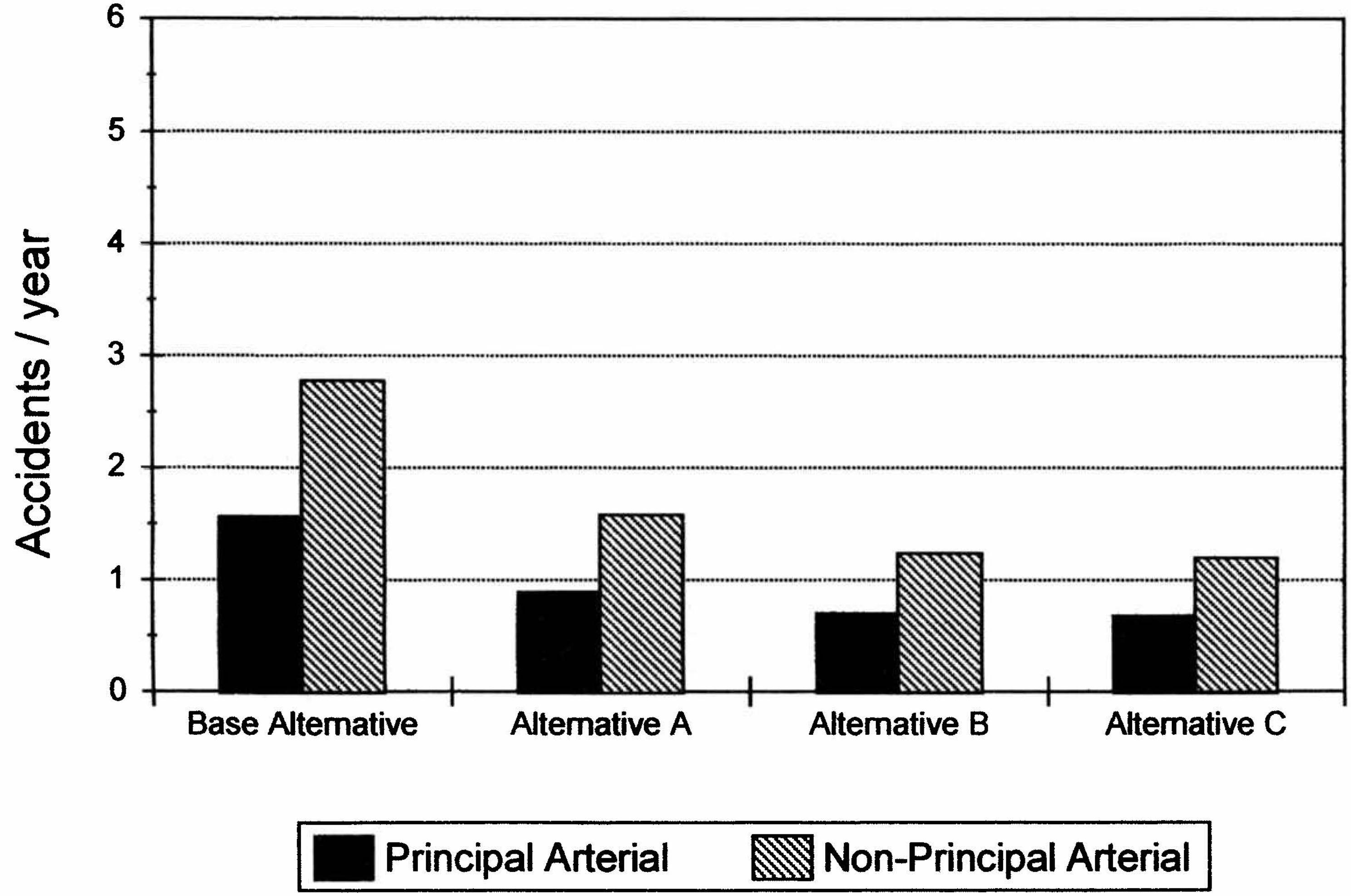


Figure 2. Predicted annual accidents by four cross-section alternatives using the model for DVKT = 6,440 (DVMT = 4,000).

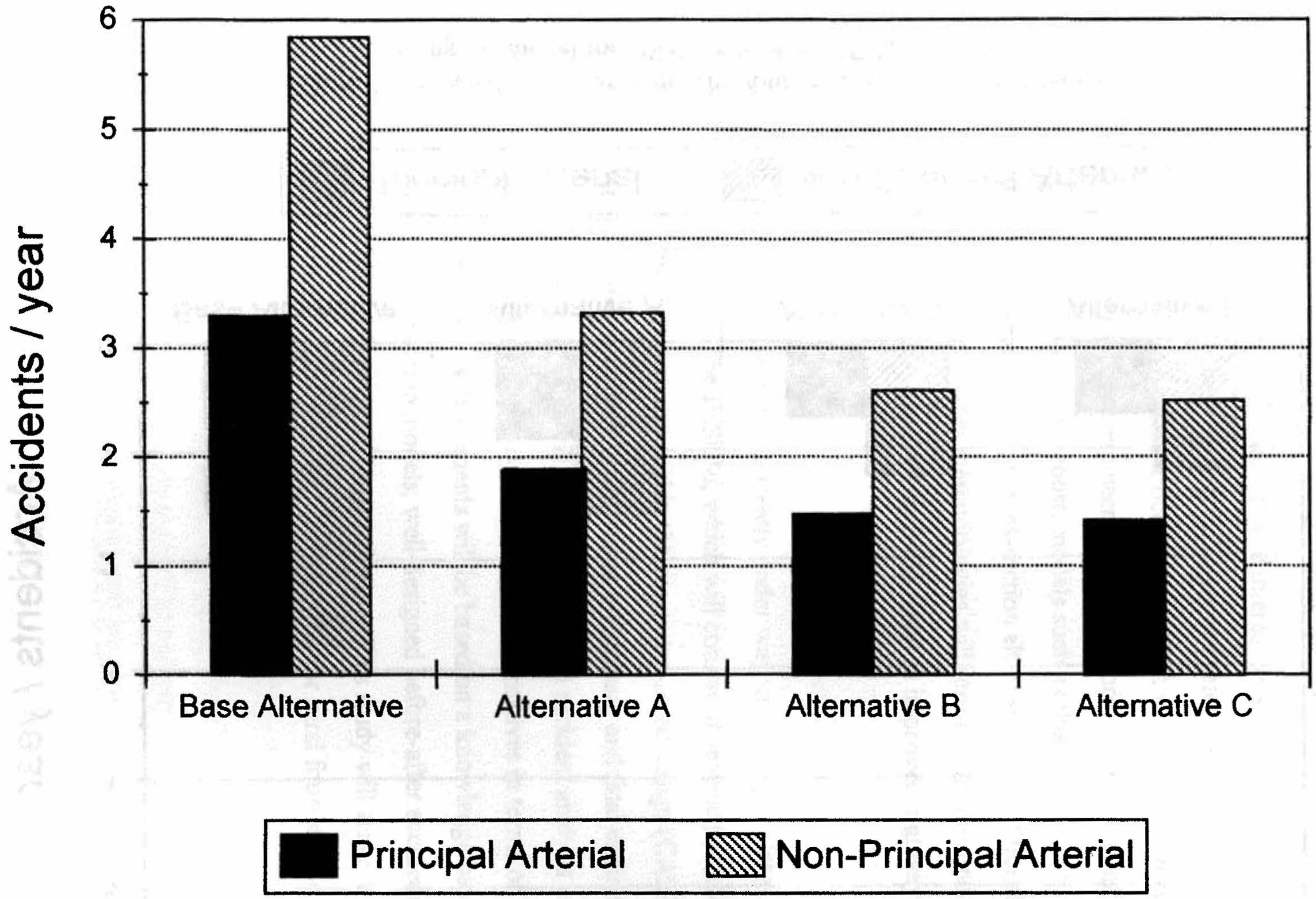


Figure 3. Predicted annual accidents by four cross-section alternatives using the model for DVKT = 12,880 (DVMT = 8,000).

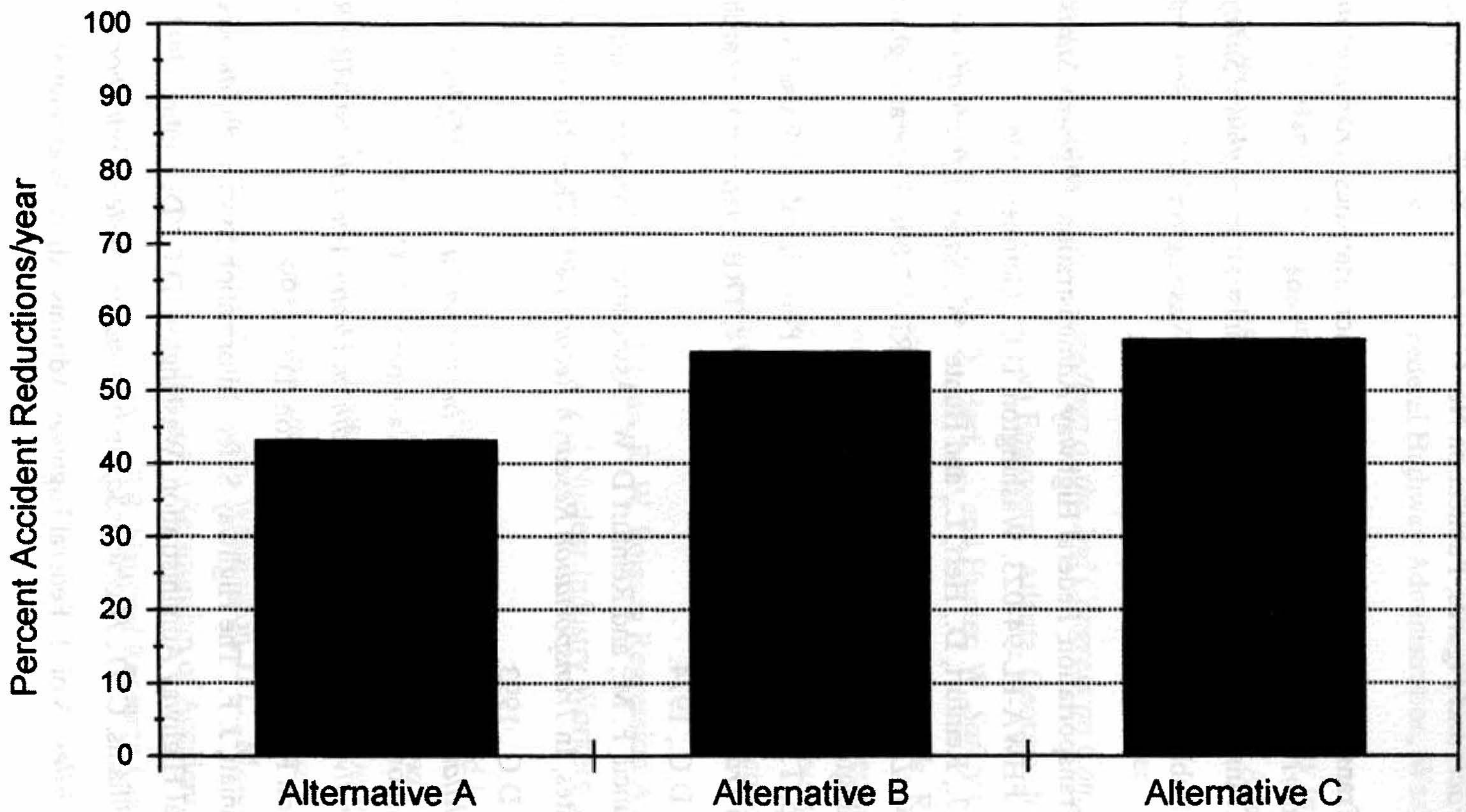


Figure 4. Accident reduction factors of three alternatives compared with base alternative using the model.

REFERENCES

1. U.S. Department of Transportation, Federal Highway Administration, *Our Nation's Highways: Selected Facts and Figures*, Publication No. FHWA-PL-90-024, Washington, D.C., 1990.
2. U.S. Department of Transportation, Bureau of Transportation Statistics, *Transportation Statistics: Annual Report 1994*, Washington, D.C., January 1994.
3. U.S. Department of Transportation, Federal Highway Administration, *Highway Safety Performance - 1991*, Publication No. FHWA-SA-94-032, Washington, D.C., September 1993.
4. U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics - 1993*, Publication No. FHWA-PL-94-023, Washington, D.C., October 1994.
5. Zegeer, C., Hummer, J., Reinfurt, D., Herf, L., and Hunter, W., *Safety Effects of Cross-Section Design for Two-Lane Roads.* Report No. FHWA-RD-87-008, Federal Highway Administration, Washington, D.C., October 1987.
6. Foody, T. J., and Culp, T. B., A Comparison of the Safety Potential of the Raised vs Depressed Median, In *Transportation Research Record 514*, TRB, National Research Council, Washington, D.C., 1974.
7. Knuiman, M. W., Council, F. M., and Reinfurt D. W., Association of Median Width on Highway Accident Rates, In *Transportation Research Record 1401*, TRB, National Research Council, Washington, D.C., 1993.
8. Harwood, D. W., *Multilane Design Alternatives for Improving Suburban Highway*. NCHRP Report No. 282, Transportation Research Board, Washington, D.C., 1986.
9. Harwood, D. W., *Effective Utilization of Street Width on Urban Arterials*, NCHRP Report No. 330, Transportation Research Board, Washington, D.C., 1990.
10. Council F. M., and Paniati, J. F., The Highway Safety Information System, *Public Roads*. Vol. 54, No. 3. Federal Highway Administration, Washington, D.C., December 1990.
11. Council F. M., and Williams, C. D., *Highway Safety Information System Guidebook for the Minnesota State Data Files*, Vol. 1. Federal Highway Administration, Washington, D. C., March 1991.

12. Council F. M., and Williams, C. D., *Highway Safety Information System Guidebook for the Michigan State Data Files*, Vol. 1. Federal Highway Administration, Washington, D.C., March 1991.

13. Council F. M., and Williams, C. D., *Highway Safety Information System Guidebook for the Illinois State Data Files*, Vol. 1. Federal Highway Administration, Washington, D.C., March 1991.

14. Council F. M., Hamilton, E. G., and Williams, C. D., *Highway Safety Information System Guidebook for the Utah State Data Files*, Vol. 1. Federal Highway Administration, Washington, D.C., March 1991.

15. Wang, J., Liu, C. C., and Paniati, J. F., Application of Photolog Laser Videodisc Technology in Highway Safety Research, *Proceedings of the 2nd Congress on Computing in Civil Engineering*, American Society of Civil Engineers, Atlanta, Georgia, June 1995.

16. Zegeer, C., Hummer, J., Reinfurt, D., Herf, L., and Hunter, W, *Safety Cost-Effectiveness of Incremental Changes in Cross-Section Design: Informational Guide*, Report No. FHWA-RD-87-094, Federal Highway Administration, Washington, D.C., December 1987.

17. Cameron, A. C., and Trivedi, P. K. Econometric models based on count data: Comparisons and applications of some estimators and tests. *Journal of Applied Econometrics*. Vol. 1, 1986.

18. Frome, E. L., Cragle, D. L., and McLean, R. W. Poisson Regression Analysis of the Mortality among a Cohort of World War II Nuclear Industry Workers. *Radiation Research 123*, 1990.

19. Joshua, S. C., and Garber, N. J. Estimating Truck Accident Rate and Involvements Using Linear and Poisson Regression Models. *Transportation Planning and Technology*, 15, 1990.

20. Miaou, S. P., Hu, P. S., Wright, T., Davis, S. C., and Rathi, A. K. *Development of Relationship between Truck Accidents and Geometric Design: Phase I.* Report No. FHWA-RD-91-124. Federal Highway Administration, Washington, D.C., March 1993.

21. Jovanis, P. P., and Chang, H. L. Modeling the Relationship of Accidents to Miles Traveled, In *Transportation Research Record 1068*, TRB, National Research Council, Washington, D.C., 1986.

22. American Association of State Highway and Transportation Officials (AASHTO), *A Policy on Geometric Design of Highway and Streets*, Washington, D.C., 1990.

23. Miaou, S. P. and Lum, H. Modeling Vehicle Accidents and Highway Geometric Design Relationships, *Accident Analysis and Prevention*, Vol. 25, No. 6. Pergamon Press Ltd., London, U.K. 1993.

HSR-20/5-98(475)E