SAFETY EFFECTS OF CROSS-SECTION DESIGN ON RURAL MULTI-LANE HIGHWAYS

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ABSTRACT

Over 35,000 miles 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 to 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 the selected data elements. Supplemental roadway variables which 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.

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 to 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 are multi-lane rural highways. In fact, over 35,000 miles of arterial highways in the United States are multi-lane, non-Interstate roads in rural areas (*4*).

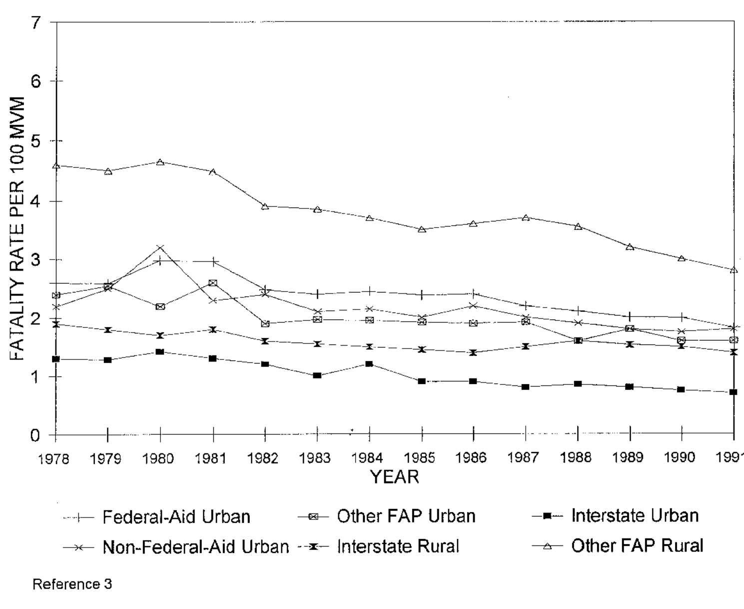

FIGURE 1 U.S. Fatality Rates by Highway System (1978-1991)

In recent years, a considerable amount of highway safety research has been conducted in the U.S. 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 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 paper 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 data 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 data and integrate data on roadside condition and intersection/driveway access by 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 by the 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. 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 kilometer (0.3 mile) was chosen as the minimum section length. Sections on local road systems were also 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. In addition, animal related accidents were also eliminated from the accident database.

The databases for 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 very important factors as both control variables and independent variables in the sense that they greatly affect accident rate (*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 films 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 for this study, especially for the modeling analysis. 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 data 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 file via a common linking system (i.e., 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 a 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 7-point pictorial scale and the data collector should choose the rating value (1 through 7) that most closely matches the roadside hazard level for the roadway section in question.

Preliminary data analysis and previous studies all indicate that intersections, driveway accesses 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 driveway access, intersections, and interchange ramps be collected from the PLV/LRDC system for the roadway sections included in the analysis.

Seven types of intersection/driveway/interchange ramp 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 was also used in verifying other data elements for correctness. One such application for this study was to correct and supplement data on median width based on PLV image estimation for better modeling purpose because a large number of roadway segments in the original data set contained median width value as a character "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:

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

where

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

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 (2) it follows that

$$Log\, E(Y_i) = \beta_T\, Log\,(DVMT_i) + \beta_0 + \qquad (3)$$

where *Log* denotes the logarithm to base e, and the exposure variable is 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

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

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

$$f_{ij} = e^{\beta_j X_{ij}} \qquad (5)$$

are multipliers which 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 collected. One can obtain expected annual accidents by dividing the length of the study period in years (i.e., in this case divided by six 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., *(17, 18)* They have recently been employed in several highway safety studies for estimating truck accident rates (*19*), for modeling relationships between truck involvements and highway geometric designs (*20*), and for examining the relationship between vehicle accidents and vehicle miles of travel (*21*).

RESULTS

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 have been 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 kilometer (0.3 mile) to 9.79 kilometers (6.08 miles) with a mean length of 1.14 kilometers (0.708 miles). Over 90 percent of these were 4-lane divided roads; the others were 3-lane or 4-lane undivided roads. Most of them (93 percent) were also 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 period 1985-1990. 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 3-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.

TABLE 1 Roadway and Accident Statistics with Various Characteristics for Minnesota Rural Multi-Lane Highways

Category	No. of Sections	Kilometers	No. of Accidents	Accident Rate (MVK)
Roadway Type:				
3-Lane Undivided	32	11.46	66	0.54
4-Lane Undivided	14	32.65	549	1.35
4-Lane Divided	625	721.09	2895	0.25
Traffic Volume:				
< 5,000 vpd	230	296.74	657	0.27
5,000 - 9,999 vpd	244	263.36	1218	0.32
10,000 - 14,999 vpd	161	173.32	1246	0.29
15,000 -19,999 vpd	34	29.75	366	0.34
≥ 20,000 vpd	2	2.03	23	0.24
Outside Shoulder Width:				
0 ft	18	15.30	563	2.42
1 - 3 ft	11	12.04	132	1.06
4 - 6 ft	34	30.86	93	0.24
7 - 9 ft	179	230.41	1131	0.25
≥ 10 ft	429	476.62	1591	0.23
Outside Shoulder Type:				
No shoulder	18	15.30	563	2.42
Gravel or stone	52	66.32	275	0.40
Paved	601	683.61	2672	0.24
Median Type (if divided highway):				
Raised median	41	40.78	524	0.69
Depressed median	578	670.39	2356	0.22
Barrier median	1	1.38	3	0.19
Unknown	5	8.52	12	0.12
Median Width (if divided highway):				
1 - 10 ft	24	29.61	422	0.74
11 - 30 ft	8	5.30	14	0.16
> 30 ft	398	442.48	1379	0.21
Varies	195	243.68	1080	0.27
Access Control:				
No access control	452	492.18	2464	0.36
Partial access control	219	273.02	1046	0.21

1km = 0.621 mile

TABLE 2 Characteristics of Roadway Database Used in Statistical Analysis

Category	No. of Sections	Kilometers
Overall	622	694.55
Functional Class:		
Rural principal arterial	579	644.61
Others	43	49.94
Roadway Type:		
4-Lane divided	592	663.04
4-Lane undivided	30	31.51
Road Surface Width:		
< 40 ft	2	5.74
40 - 50 ft	555	623.02
50 - 60 ft	56	57.52
> 60 ft	9	8.27
Median Width:		
1 - 10 ft	35	43.16
11 - 30 ft	16	11.93
> 30 ft	527	580.07
Unknown	14	27.89
Median Type:		
Raised median	39	39.45
Depressed median	547	613.68
Barrier median	1	1.38
Unknown	4	3.94
Traffic Volume:		
< 5,000 vpd	215	274.12
5,000 - 9,999 vpd	226	233.31
10,000 - 14,999 vpd	149	160.78
15,000 -19,999 vpd	30	24.31
≥ 20,000 vpd	2	2.03
Percent Commercial Vehicles:		
< 10 %	270	309.58
10 - 20 %	338	369.53
> 20 %	14	15.44
Driveways Per Mile:		
0	431	434.80
0 - 1	22	53.78
1 - 2	72	117.72
2 - 3	51	49.49
3 - 4	16	14.43
4 - 5	10	8.37
> 5	20	15.96

TABLE 2 Characteristics of Roadway Database Used in Statistical Analysis (Continued)

Category	No. of Sections	Kilometers
Unsignalized Intersection with Turn Lanes Per Mile:		
0	544	596.75
0 - 1	10	35.29
1 - 2	21	29.16
2 - 3	35	26.31
> 3	12	7.04
Unsignalized Intersection without Turn Lanes Per Mile:		
0	429	433.36
0 - 1	21	60.00
1 - 2	67	102.38
2 - 3	61	55.51
3 - 4	24	22.30
4 - 5	9	9.47
> 5	11	11.53
Average Shoulder Width:		
0 ft	14	11.96
1 - 3 ft	7	7.79
4 - 6 ft	14	15.96
7 - 9 ft	232	279.83
> 9 ft	355	379.01
Average Roadside Hazard Rating:		
Not available	66	89.79
0 - 1	31	34.58
1 - 2	133	144.72
2 - 3	260	292.92
3 - 4	98	101.08
4 - 5	21	18.64
5 - 6	9	7.76
6 - 7	4	5.06
Access Control:		
No access control	421	459.06
Partial access control	201	235.49
Area Location Type:		
Rural municipal	71	638.44
Non-rural municipal	551	56.11

1km = 0.621 mile

TABLE 3 Data Set Statistics for Two Classification Variables in Model Analysis

Classifications	No. of Sections	Kilometers	No. of Accidents	Acc./ Section
Rural principal arterial	579	644.64	2280	3.94
Rural others	43	49.91	724	16.84
Rural municipal	71	56.18	876	12.34
Rural nonmunicipal	551	638.37	2128	3.86
Rural other and/or rural municipal	97	92.73	1140	11.75
Neither	525	601.82	1864	3.55

1km = 0.621 mile

It was also 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 the summary statistics of the data set regarding roadway sections, length (in kilometers), distributed by the considered roadway independent variables for 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 small part of the sample, the accidents occurring on these roadways were disproportionally 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 were also explored by excluding these two variables or fitting the model on only those sections which were principal arterials and not rural municipal.

Based on 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 (an indicator of partially controlled access vs. no access control)
- area location type (indicator of a 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 parameter and their standard errors, chi-square statistics, and level of statistical significance for each of the independent variables. The model accounted for 67% of the total deviance in the dependent variable. Based on this result, the accident predictive equation can be expressed as:

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

where:

DVMT = Daily vehicle miles of travel
Y = Predicted annual accidents
X_1= Average roadside hazard rating
X_2= Access control (partial control = 1, no control = 0)
X_3= Driveways/mile
X_4= Intersections with turn lanes/mile
X_5= Intersections without turn lanes/mile
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 All Roadway Types

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/mile	0.034	0.008	19.36	0.0001
Ints with Turn Lane/mile	0.163	0.019	70.99	0.0001
Ints. no Turn Lane/mile	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.

The results in equation (6) appear to have reasonable coefficients for a model for total accidents as a function of the ten 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 multi-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 to road sections classified as rural other, and accidents on rural municipal roads are increased by the factor

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

compared to rural non-municipal roads.

IMPLICATIONS OF THE MODEL

This model can be used for a variety of applications such as accident predictions for different rural, multi-lane highway design alternatives and estimation of accident reductions due to cross-section related improvements on rural multi-lane highways. To illustrate these applications, an example is shown in Table 5 and Figures 2 to 4 to estimate number of accidents occurring per year with different design alternatives of shoulder widths and median widths under certain conditions. In this example, consider hypothetical roadway conditions which are 6,440 DVKT (Daily vehicle kilometers of travel, 4,000 DVMT), 2.8 average roadside hazard rating, no access control, 0.3 driveways per kilometer (0.5 driveways per mile), no intersections with turn lanes and 0.6 intersection without turn lanes per kilometer (1 intersection per mile). Under these specific circumstances of rural, multi-lane highways, Table 5 shows predicted annual accidents for three different shoulder widths associated with five median width values for the four categories of roadways. The four categories of rural, multi-lane roadways are:

- Non-principal arterial, municipal
- Non-principal arterial, non-municipal
- Principal arterial, municipal
- Principal arterial, non-municipal.

The combined effects of median width, shoulder width, and the four categories of roadways on annual accident frequencies for the specific roadway conditions are also graphically illustrated in Figures 2 through 4. They show clearly the higher numbers of accidents predicted for roads classified as other than principal arterial and also for roads classified as in rural municipal areas. In a similar fashion, the effects of any combinations of the several independent variables on annual accident frequencies can be easily computed and illustrated.

CONCLUSIONS

This study represents an attempt to establish a quantitative relationship between accident frequency and various cross sectional and related roadway design elements on rural, multi-lane, non-freeway highways. Although there were many studies in the literature relating to safety effects of roadway geometric designs, in general the literature on the safety effects on rural, multi-lane, comprehensive geometric design elements is quite sparse. Thus, there is little available information on the issue of how to improve geometric design (especially cross sectional design) to accommodate increased travel demand of multi-lane, arterial highways and to alleviate vehicle accidents on vast rural environment.

This study benefitted from the use of a more comprehensive database and advanced in-house data collection means through a PLV system. The data used are also more current than those in older studies. This study employed the method of Poisson regression which represents a more appropriate model for accident count data than those used in many earlier studies (*22*).

The data indicated that a large proportion of the accidents on multi-lane highways occurred at intersections and interchange areas. Therefore, intersections, interchanges and driveway accesses were part of the major consideration in both data screening and modeling processes. The model results show that intersections and driveways were significant predictors of accident occurrences.

There are, however, some necessary caveats that must be stated. This study was primarily conducted to provide a safety model that could guide highway engineers in consideration of safety effects of various multi-lane roadway design alternatives.

TABLE 5 Example of Predicted Annual Accidents Using the Model

Shoulder Width (m)	Median Width (m)	Predicted Accidents (Acc./Yr.)			
		A	B	C	D[a]
1.83 (6 ft)	0 (0 ft)	2.31	1.50	1.30	0.85
1.83 (6 ft)	3.05 (10 ft)	2.24	1.46	1.26	0.82
1.83 (6 ft)	7.63 (25 ft)	2.14	1.39	1.21	0.79
1.83 (6 ft)	15.25 (50 ft)	1.99	1.29	1.12	0.73
1.83 (6 ft)	30.50 (100 ft)	1.71	1.11	0.97	0.63
3.05 (10 ft)	0 (0 ft)	1.58	1.03	0.89	0.58
3.05 (10 ft)	3.05 (10 ft)	1.54	1.00	0.87	0.57
3.05 (10 ft)	7.63 (25 ft)	1.47	0.96	0.83	0.54
3.05 (10 ft)	15.25 (50 ft)	1.36	0.89	0.77	0.50
3.05 (10 ft)	30.50 (100 ft)	1.17	0.76	0.66	0.43
3.66 (12 ft)	0 (0 ft)	1.31	0.86	0.74	0.48
3.66 (12 ft)	3.05 (10 ft)	1.27	0.83	0.72	0.47
3.66 (12 ft)	7.63 (25 ft)	1.22	0.79	0.69	0.45
3.66 (12 ft)	15.25 (50 ft)	1.13	0.74	0.64	0.42
3.66 (12 ft)	30.50 (100 ft)	0.97	0.63	0.55	0.36

[a] A = Nonprincipal arterial, municipal
B = Nonprincipal arterial, nonmunicipal
C = Principal arterial, municipal
D = Principal arterial, nonmunicipal

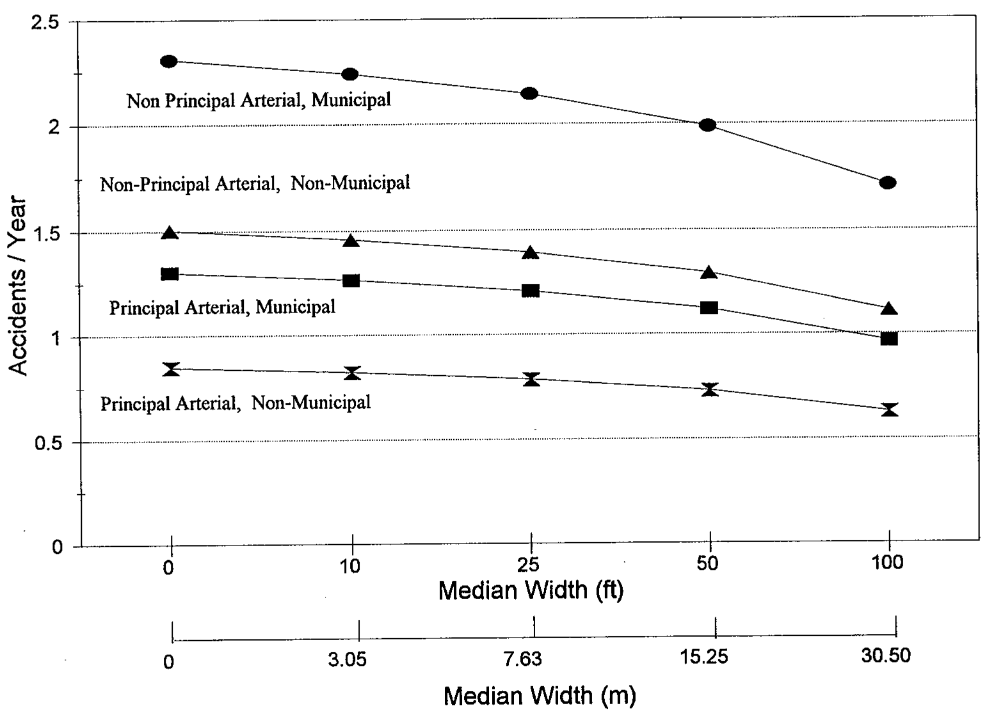

FIGURE 2 Predicted Annual Accidents by Median Width Using the Model for Shoulder Width = 1.83 m (6 ft)

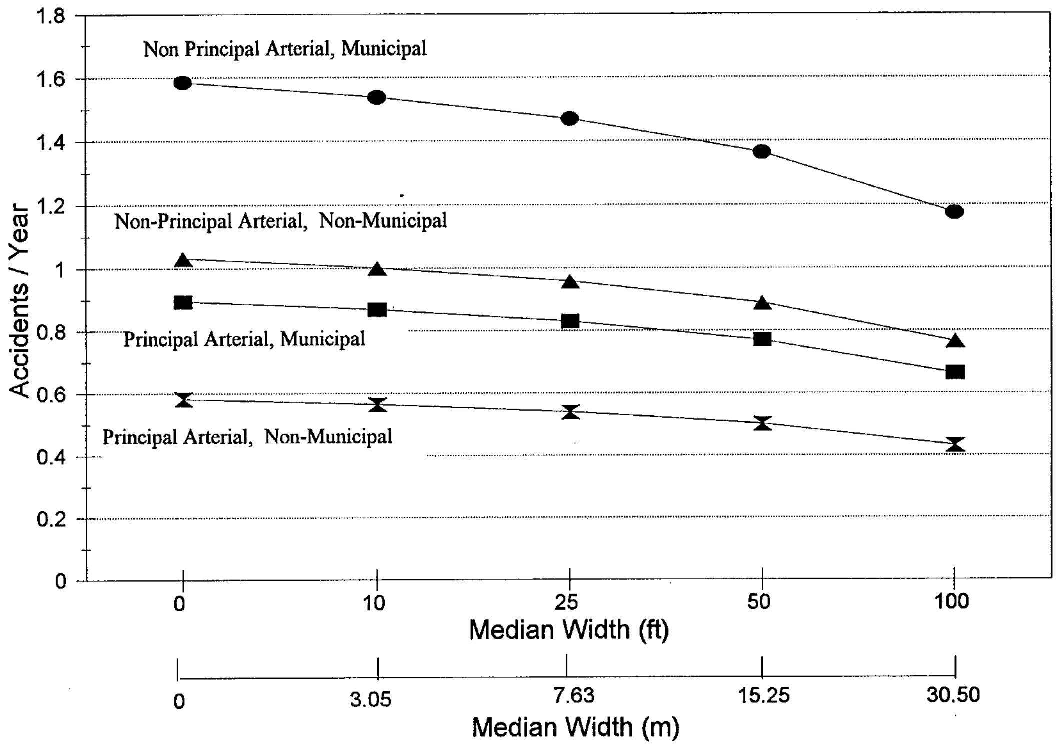

FIGURE 3 Predicted Annual Accidents by Median Width Using the Model for Shoulder Width = 3.05 m (10 ft)

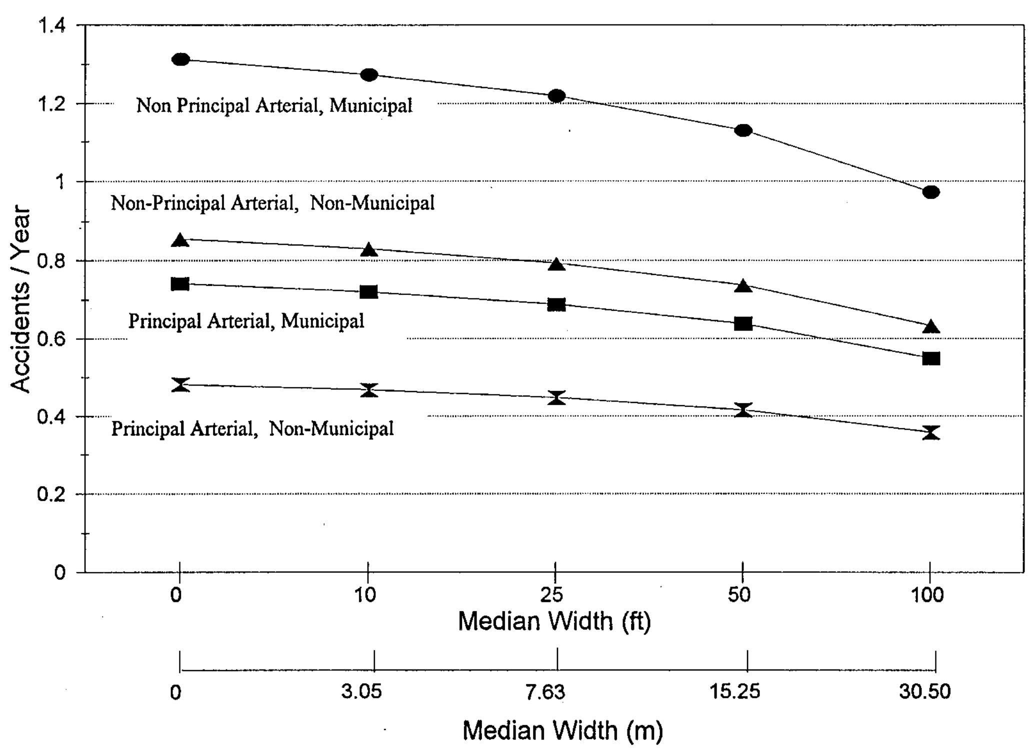

FIGURE 4 Predicted Annual Accidents by Median Width Using the Model for Shoulder Width = 3.66 m (12 ft)

For this purpose, it seemed preferable to include in the model only variables directly related to the geometric design and to exclude those of a more descriptive nature such as functional class. Models were also estimated which did not contain the indicator variables for principal arterials and rural municipal areas. These models were estimated using both the complete data set and a restricted data set which contained only road segments that were principal arterials and were not classified as rural municipal. Neither of these models, however, provided very satisfactory estimates of accidents on those roadways which were classified as not principal arterials or as rural municipal. Thus, it was decided that the model which contained these descriptive variables was most appropriate. Guidelines for classifying road segments according to these variables were obtained from discussions with Minnesota traffic engineers.

The discussions with Minnesota traffic engineers revealed that, in terms of urban/rural municipal variable, urban and rural are defined based on census tracts. An urban area is defined as a census tract having a population of 5,000 or greater. A rural area is obviously any tract with less than 5,000 persons. A municipality is simply defined as an incorporated area; thus, the boundaries of a municipality would be the incorporated limits. In terms of roadway functional classes, the specific roadway types are defined based on the definitions within the AASHTO Green Book (*23*). However, two notes need to be mentioned here: For roads that are planned for upgrades during the 3 to 5 year planning cycle, the improved functional classification is used. Thus, some roads could actually be "over-classified" for some period of time until the improvement is actually made. For some roads, the regional offices try to develop their plans so that the distribution of volume and mileage by functional class approximates what is provided in the Green Book for rural and urban systems. In general, some roads may be overclassified during the planning stages for funding consideration; however, other roads may be underclassified to avoid having to upgrade certain design elements. Overall, it seems the selection of a specific functional class is somewhat arbitrary, specifically with regard to the lower classes (e.g., local/collectors/minor arterial). However, a computer check of the data sets used for developing the model revealed that the lower class roads constitute only 7 percent of total data sample in terms of roadway mileage (i.e., 3.8 percent for rural minor arterial, 3.2 percent for major collectors and 0.2 percent for minor collectors). Based on this discussion, it might be seen that the two descriptive variables can be used as more classification-type predictor variables. It also seems that the two variables can be applied to other states' practices since there is likelihood that the other states are experiencing similar practice as Minnesota does regarding the two variables.

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. Within various subsets, ranges of variation were, of course, even more restricted. For example, on the subset of principal arterial roads which were not classified as rural municipal, over 90 percent had outside shoulder widths between 2.4 and 3.1 meters (8 and 10 feet). The analyses of these data have shown that accidents are statistically associated with a number of characteristics of the roadway, some of which are cross-section related and some of which are of a more descriptive nature. From the modeling results, it seems clear that accidents are generally lower on roads with wide shoulders and similarly with respect to road separations. The Poisson model gives estimates of these effects which can be applied to roads of different types.

It is recommended that additional studies of similar analysis should be conducted using other states' data of a similar type to shed more light regarding the specific nature of the relationships among the variables mentioned above.

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