ACCIDENT SURROGATES FOR USE IN ANALYZING HIGHWAY SAFETY HAZARDS

VOL. 3 APPENDICES A-G

Research, Development, and Technology

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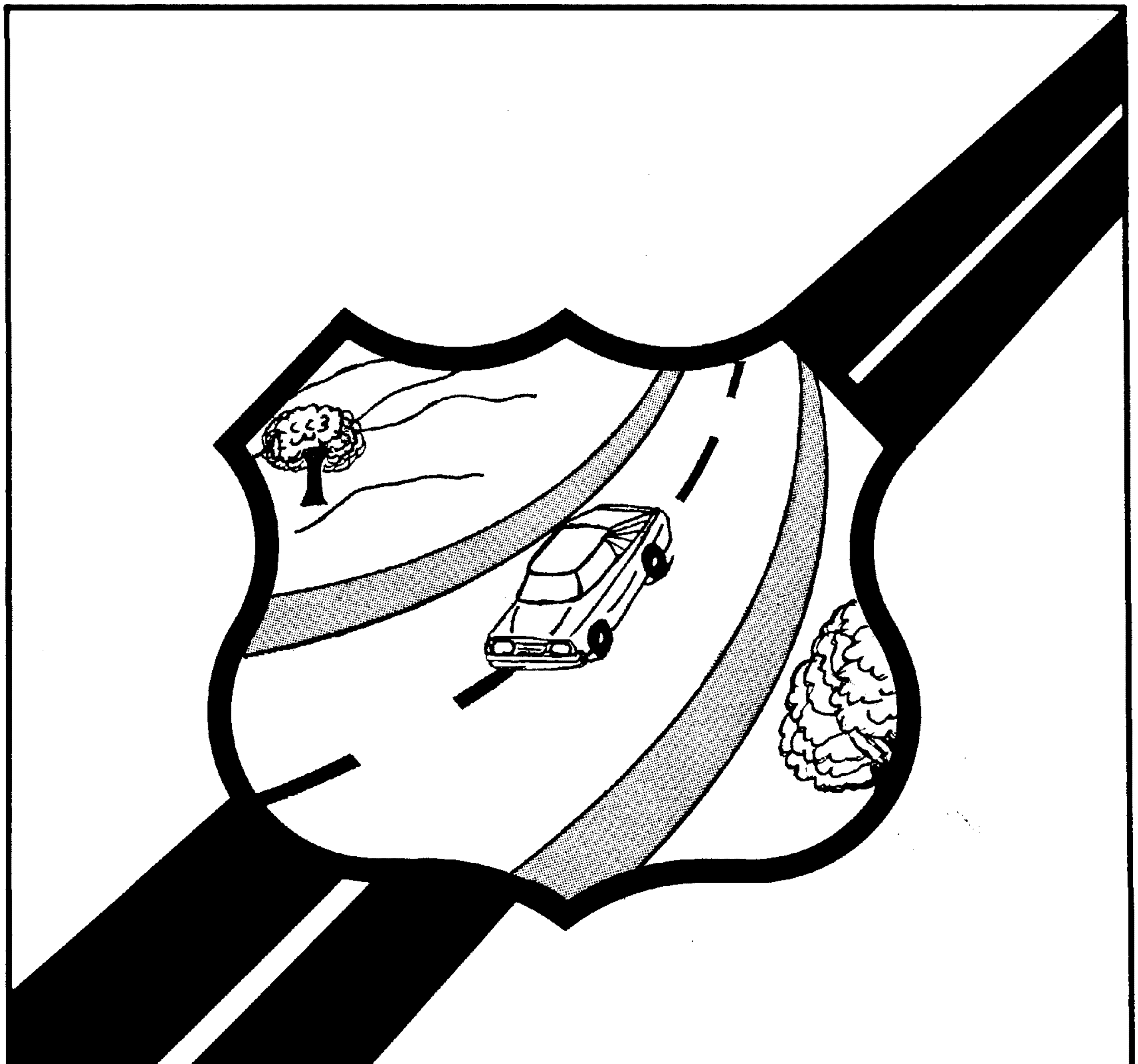

FOREWORD

This report presents the initial efforts to develop surrogate measures that can be used to supplement or replace accident data for highway safety analyses. Additional studies to validate and refine the results for application at rural locations are being conducted.

This report describes the results of a study in Project 1X, "Highway Safety Program Effectiveness Evaluation," of the Federally Coordinated Program of Research and Development. The study was conducted for the Federal Highway Administration, Office of Safety and Traffic Operations Research and Development, Washington, D. C., under contract DOT-FH-11-9492.

This report is being distributed according to the report request forms returned from the RD&T Digest titled "Accident Surrogates for Use in Analyzing Highway Safety Hazards" dated March 1983.

Stanley R. Byington
Director, Office of Safety and
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16. Abstract

The principal objective of this research project was to investigate the feasibility of using accident surrogate measures in highway safety analyses. An accident surrogate measure is defined as a quantifiable observation that can be used in place of or as a supplement to accident records.

The study provides evidence that surrogate measures for accident experience can be identified. A procedure for developing and using accident surrogates is presented. Analyses were performed to develop accident surrogate measures for hazardous location identification and countermeasures evaluation at rural isolated curves on two-lane roads, rural signalized intersections and two-lane tangent sections in urbanized areas.

This report is the third in a series. The series is composed of:

FHWA/RD-82/103 Volume I - Executive Summary
FHWA/RD-82/104 Volume II - Technical Report
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METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
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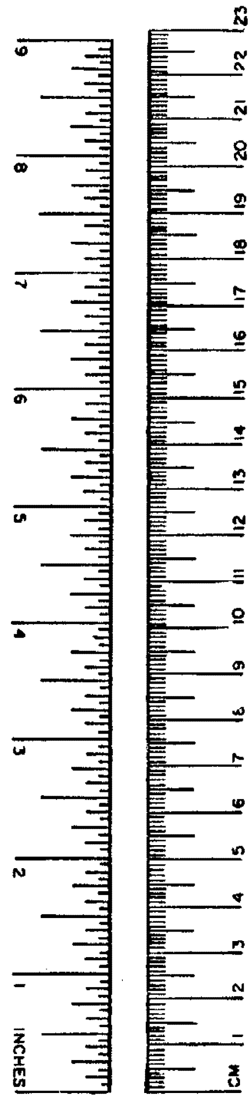

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

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	LENGTH			
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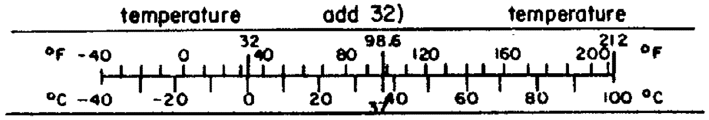
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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APPENDIX A

Literature and Annotated Bibliography

OVERVIEW

The literature review identified fifty-two highway system elements as potential accident surrogates for the ten highway situations (Table 1). The variables and variable combinations fell into two general categories; non-operational and operational. Non-operational variables are generally related to roadway geometry and cross-sectional elements, traffic control devices and environmental features. Operational variables are generally related to traffic operations, driver performance and driver behavior. Tables 2 and 3 summarize the variables identified in the literature review and categorized as non-operational and operational respectively.

To ensure that a highway element warranted consideration as a potential surrogate, criteria were established for the purpose of identifying studies with a high degree of practical and statistical realiability. The criteria upon which each study was measured were:

1. The study should have a sufficiently large sample of accidents and locations to support the study results.

2. The study should be based on research procedures designed to minimize rival explanations for observed accident relationships.

3. The study should use appropriate tests to assess the statistical validity of the study results.

4. Study conclusions should be logical and consistent with analysis results.

The potential surrogates for each highway situation were categorized as "strong" or "other" according to the degree of convergence of research evidence and the reliability of the research study. A "strong" potential surrogate is a variable that was found to be related to accident experience in at least one reliable study. The reliability of a study was generally based on the acceptability of the article by the highway safety community, the validity of experimental design, the sample size, and the number and type of variables controlled for in the study. The strength of the conclusions and the validity of the analysis were carefully considered before classifying the measure as a "strong" potential surrogate. If there were conflicting results from two or more reliable sources, the surrogate was not labelled as "strong".

An "other" potential surrogate is defined as a measure for which there is less empirical evidence and no specific relationship is defined in the literature. Standards and guidelines such as AASHTO design standards were selected as "other" potential surrogates. Other examples include length of taper at lane drop locations and sight distance. These variables and their relationship to accidents are logical from an engi-

Table 1. Highway situations considered in the literature review.

1. Rural Isolated Horizontal Curves
2. Rural Undivided Tangent Sections
3. Rural Undivided Winding Sections
4. Rural Signalized Intersections
5. Rural Non-Signalized Intersections
6. Urban Undivided Tangent Sections
7. Urban Non-Signalized Intersections
8. Lane Drop Locations
9. Exit Gore Areas
10. Narrow Bridges

Table 2. Non-operational variables identified in the literature review.

1. Degree of Curve
2. Frequency of Curves
3. Grade
4. Grade Continuity
5. Surface Cross Slope
6. Sight Distance
7. Visibility of Signal and Sign
8. Pavement Width
9. Lane Width
10. Approach Width
11. Pavement Shoulder Presence
12. Shoulder Width
13. Percent Shoulder Reduction
14. Median Width
15. Bridge Width
16. Ratio of Bridge Width to Pavement Width
17. Difference Between Roadway Width and Bridge Width
18. Taper Length
19. Number of Lanes Dropped
20. Length of Deceleration Lane
21. Bridge Safety Index
22. Structural Adequacy of Guardrail and Bridgerail
23. Access Control
24. Number of Commercial Driveways per Mile
25. Number of Intersections per Mile
26. Number of Traffic Signs per Mile
27. Type of Delineation Treatment
28. Raised Marker Delineation
29. Signing and Delineation
30. Type of Advance Warning
31. Intersection Design
32. Type of Traffic Control Device
33. Illumination Level
34. Skid Resistance

Table 3. Operational variables identified in the literature review.

1. Traffic Volume
2. Major and Minor Road Volumes
3. Opposing Traffic Volume
4. Percent Diverging Traffic
5. Traffic Mix
6. Volume/Capacity Ratio
7. Posted Speed
8. Vehicle Speed
9. Speed Differential
10. Speed Variance
11. Lateral Placement
12. Traffic Conflicts
13. Erratic Maneuvers
14. Cycle Length
15. Signal Phasing
16. Number of Phases
17. Total Stopped Vehicle Delay
18. Red and Yellow Light Violations

neering practice viewpoint but there is either no evidence of statistical significance or the studies were based on a small sample.

Some operational surrogates (such as erratic maneuver rates) have been used in several studies for evaluating the operational effects of various improvements. Such operational surrogates attempt to quantify the level of driver error that is logically related to the level of hazardousness. The use of such operational surrogates in accident studies, based on their logical relationship to safety, justify their selection as "other" potential surrogates, even though their relationship to accidents has not been validated.

Figures 1 and 2 summarize non-operational and operational variables (respectively) identified for each highway situation and the associated potential surrogate designation. An "S" indicates a "strong" potential surrogate and an "O" indicates an "other" potential surrogate.

A synthesis of the literature review is provided in the following sections. The overview summarizes the results of the literature review. The summary of the state-of-the-art contains a synopsis of the highway elements and associated research findings for each of the ten highway situations. The annotated bibliography contains a brief summary of each study referenced in the literature review.

Non-Operational Variables / Situations	Rural Isolated Horizontal Curves	Rural Undivided Tangent Sections	Rural Undivided Winding Sections	Rural Signalized Intersections	Rural Non-Signalized Intersections	Urban Undivided Tangent Sections	Urban Non-Signalized Intersections	Lane Drop Locations	Exit Gore Areas	Narrow Bridge
Degree of Curve	S									
Frequency of Curves			S							
Grade	S									
Grade Continuity										O
Surface Cross Slope	O									
Sight Distance		O		O				O	S	O
Visibility of Signal & Sign				O						
Pavement Width	O	O								
Lane Width			S							
Approach Width				O			O			
Paved Shoulder Presence									O	
Shoulder Width		O	S							
Percent Shoulder Reduction										O
Median Width					O					
Bridge Width										S
Ratio of Bridge Width to Pavement Width										S
Difference Between Roadway Width and Bridge Width										S
Taper Length								O		
Number of Lanes Dropped								O		
Length of Deceleration Lane									S	
Bridge Safety Index										O
Structural Adequacy of Guard-rail and Bridge Rail										O
Access Control		S								
Number of Commercial Driveways per Mile						S				
Number of Intersections per Mile						S				
Number of Traffic Signs per Mile						S				
Type of Delineation Treatment								O	O	
Raised Marker Delineation				O						
Signing and Delineation	O									
Type of Advance Warning								O		
Intersection Design				O						
Type of Traffic Control Device							S			
Illumination Level							O			
Skid Resistance	O	S		O	O					

Figure 1. Potential surrogate classifications for non-operational variables.

Situations \ Operational Variables	Traffic Volume	Major and Minor Road Volumes	Opposing Traffic Volume	Percent Diverging Traffic	Traffic Mix	Volume/Capacity Ratio	Posted Speed	Vehicle Speed	Speed Differential	Speed Variance	Lateral Placement	Traffic Conflicts	Erratic Maneuvers	Cycle Length	Signal Phasing	Number of Phases	total Stopped Vehicle Delay	Red & Yellow Light Violations
Rural Isolated Horizontal Curves	0							0	0									
Rural Undivided Tangent Sections	S									0								
Rural Undivided Winding Sections	0																	
Rural Signalized Intersections		S					S					0		0	0	0	0	0
Rural Non-Signalized Intersections		S										0						
Urban Non-Signalized Intersections	0																	
Urban Undivided Tangent Sections		S										0						
Lane Drop Locations													0					
Exit Gore Areas				S									0					
Narrow Bridge	0		0		0	0		0			0							

Figure 2. Potential surrogate classifications for operational variables.

SUMMARY OF THE STATE OF THE ART

This section contains a summary of selected publications and reports relating to the ten highway situations listed in Table 1. Emphasis was given to extracting pertinent information on highway systems elements from articles that deal with specific highway situations. This approach often resulted in a limited number of information sources due to the specificity of the highway situation. For example, many studies are available on the affects of shoulder width on highway safety. However, a critical examination of these references revealed that the majority of available documentation deals with the affects of shoulder width on safety on rural tangent and winding sections. Consequently, only a limited amount of information was available on the affects of shoulder widths at rural isolated curves.

Each highway situation is considered individually in this section. Under each situation a summary of the relevant research findings is provided in chronological order of the date of study or publication.

A conclusion is also provided to describe the degree of convergence of research evidence based on the reported findings.

Rural Isolated Horizontal Curves

Degree of Curve

A positive relationship between degree of curvature and accident rates has been documented in several research reports. The increase in the accident rate is apparently relatively small for increases in degree of curvature up to 4 degrees, but increases quite rapidly for curves with a degree of curvature greater than 4 degrees.

- Raff (1953) reported a significant relationship between degree of curve and accident rate on two-lane rural highways (but found no such significant relationship on four-lane rural highways). Accident rates by degree of curvature for two- and four-lane undivided highways are shown in Table 4.

- Coburn (1962) found this relationship to be quite important for sharp curves, with the injury accident rate increased by a factor of 3 when comparing curves between 6 and 10 degrees with those greater than 10 degrees.

- Kihlberg and Tharp (1968) used a broader range of curves and reported that increases in the degree of curvature up to about 4 degrees have relatively little effect on accident rates, but as the degree of curvature is increased beyond 4 degrees the accident rate increases sharply.

- Leisch (1971) reported the results of several studies relating curvature to accidents, including one study by Babkov that also found 4 degrees to be the critical value.

- Gupta and Jain (1973) considered other variables, but concluded that degree of curvature is the most significant geometric explanatory variable in predicting accident rates.

Conclusion: Curves with degree of curvature greater than 4 degrees are indicative of a potential hazard, with the risk increasing with increasing degree of curvature.

Volume and Degree of Curve

Only one study was found which attempted to identify the joint effect of volume and curvature on two-lane roads. Even though the results were statistically inconclusive, Raff (1953) found that the effect of degree of curve was different at low volumes than at high volumes. At volumes below 5,000 vpd the accident rate increased steadily with increasing curvature. However, at volumes over 5,000 vpd, the accident rate was lower on sharp curves (6 degrees or more) than on moderate curves. The lower accident rates may be due to the presence of other traffic which provides visual cues which aid the motorist in identifying isolated curves.

Table 4. Accident rates by degree of curve.

Curvature	Two-Lane		Four-Lane Undivided	
	No.	Rate (per MVM)	No.	Rate (per MVM)
0 - 2.9	504	1.6	98	1.9
3 - 5.9	596	2.5	90	2.6
6 - 9.9	338	2.8	16	3.3
10 or more	354	3.5	3	1.2

Source: Raff, M.S., "Interstate Highway - Accident Study", Highway Research Board Bulletin No. 74, 1953.

Conclusion: The hazard potential of a high degree curve is probably greater on low volume roads than on high volume roads.

Grade and Degree of Curvature

Three studies were found which attempted to define the relationship between grade and curvature and accidents. Although these studies are in general agreement that steep grades and sharp curves result in relatively high accident rates, the specific effect of combinations of grade and curvature has not been determined.

- Raff (1953) reported a tendency for accident rates to be more affected by grade at higher traffic volumes and by degree of curve at lower traffic volumes.
- Bitzel (1957) showed accident rates increasing with increasing grade and curvature. Results showed curves in the range of 2 to 4 degrees with greater than 6 percent grade to have accident rates 8 times the rate for level tangent sections.
- Billion and Stohner (1957) found sections with curvature greater than 5 degrees and grade steeper than 5 percent to have over 19 times as many accidents as the average section of highway.

Conclusion: Locations with a combination of sharp curves and steep grades appear to experience high accident rates.

Pavement and Shoulder Width

Only one study was found which investigated the effect of pavement and shoulder width on accidents at horizontal curves.

- Billion and Stohner (1957) reported that accident rates decreased with increased shoulder width on horizontal curves.

Conclusion: There is insufficient data to determine the relationship between pavement and/or shoulder width and accidents on horizontal curves.

Skid Resistance

Although specific relationships between skid resistance on horizontal curves and accidents have not been established, studies suggest that the high accident rate normally associated with combinations of steep grade and sharp curvature, (as well as wet weather accidents on flat curves) may be more closely related to values of skid resistance than to percent grade, degree of curve, or their interaction.

- Giles (1957) found the probability of a skidding accident on curves over 5 degrees and grades over 5 percent to be several times that of straight and level sections. Further, the occurrence of skidding accidents on curves greater than 11 degrees was approximately 27 times that of curves less than 4 degrees, and the occurrence of skidding accidents on grades greater than 5 percent to be over 3 times that of grades less than 5 percent.

- Dunlap, et al., (1978) showed very flat curves (about 1 degree) with relatively flat surface cross slope to have higher than normal wet weather accidents due to partial hydroplaning. The thickness of water film on a flat curve with a paved shoulder that slopes in the same direction was almost twice that on a crowned tangent section that had the same cross slope.

Conclusion: The literature is not specific on the effect of skid resistance but indicates that skid resistance may be a factor in accident occurrence on both very sharp and very flat curves.

Access Control

Kihlberg and Tharp (1968) investigated the effect of grade, curvature, presence of intersections, and roadside structures on accidents. Results indicate a general increase in accident rates when any one, or any combination of those factors is present. In particular, the simultaneous presence of intersections and curvature appeared to consistently produce higher accident rates.

Conclusion: The presence of access points appears to increase the potential for accidents on horizontal curves.

Speed Differential

No specific relationship between speed differential and accidents has been established. However, a study by Stockton, et al., (1976) of low volume roads reported a close correlation between calculated critical speed differentials and those horizontal curves observed to be hazardous.

Conclusion: The difference between approach speed and safe curve speed may be indicative of a potential hazard.

Traffic Control Devices

The effectiveness of speed advisory signs and post mounted delineators in reducing accidents has been investigated in several studies. Although specific relationships were not determined, the studies indicate speed advisory signs and post mounted delineators along the outside edge of sharp curves to be effective in reducing single vehicle accidents, injury accidents, and total accidents.

- Taylor and Foody (1966) determined post mounted delineators along the outside edge of a curve to be cost-effective in reducing accidents on all curves with greater than 5 degrees of curvature. Post mounted delineators were also found to be cost-effective on all curves of 10 degrees or less with central angles between 20 and 40 degrees. Before and after data from this study are shown in Table 5.

- Leisch (1971) reports on the findings of several studies investigating the effectiveness of traffic control devices. One study of 15 curves showed a 21 percent reduction in single vehicle accidents following installation of speed advisory signs.

- Another study reported by Leisch (1971) shows delineators mounted along the outside edge of a curve to be effective in reducing injury and total accident rates. The effectiveness of delineators was shown to be statistically significant only where the degree of curvature was greater than 11 degrees.

- Taylor, et al., (1972) recommended installation of post mounted delineators along the outside edge of curves of 5 degrees or more having a central angle exceeding 20 degrees.

Conclusion: Speed advisory signs and post mounted delineators have been found to reduce accidents, especially at high accident locations and for curvature greater than or equal to 5 degrees.

Table 5. Effect of delineation on accidents.

Section Type	Accident Frequency		
	Before	After	Total
Study	279	218	497
Control	106	138	244
Total	385	356	741

Source: Taylor, W.C., and Foody, T.J., "Ohio Curve Delineation Program - An Analysis", Traffic Engineering, June, 1966.

Rural Undivided Tangent Sections

Traffic Volume

A strong relationship between traffic volume and accidents has been reported in several studies. Some studies show accident rates increasing with increasing volume up to a particular ADT range, after which the rate decreases. Other studies, however, show that there is no volume above which accidents decrease.

A primary difference in these studies is that in the first case, unequal segment lengths were used in the analysis (Baldwin, 1946 and Raff, 1953), whereas in the second case, equal segment lengths were used (Schoppert, 1957 and Kihlberg and Tharp, 1968). Kihlberg and Tharp found accident rates to be dependent on segment length due to the correlation which existed between segment length and the presence of factors which cause traffic disturbances.

- Slatterly and Cleveland (1969) report on studies by Baldwin (1946) and Raff (1953) which show accident rates on two-lane roads increasing as volume increases to about the 8,000 to 9,000 ADT range. Beyond that range accident rates decrease with increasing volume.

- Raff (1953) found that a similar phenomenon occurs on four lane undivided highways, with the highest accident rates occurring at the 15,000 to 20,000 ADT range.

- Schoppert (1957) found that the accident frequency continued to increase with increasing volume through the entire volume range from 2000 to 8000 ADT.

- Kihlberg and Tharp (1968) found that accident rates increased with increasing volume up to 20,000 ADT. They also found multi-vehicle accidents increasing with increasing volume, whereas, single-vehicle accidents decreased with increasing volume.

Conclusion: The literature shows a strong positive relationship between accident rates and traffic volume on rural tangent highways.

Traffic Mix

Both Raff (1953) and Kihlberg and Tharp (1968) investigated the effect of commercial traffic accidents. No significant relationship was determined in either study.

Conclusion: Traffic mix appears to be unrelated to accidents on rural undivided tangents.

Access Control

The literature is in general agreement that accidents increase as the frequency of access points increase. In particular, the frequency of intersections and commercial driveways appears to have the most significant effect on accidents.

- Raff (1953) showed a tendency for accident rates to increase (1.8 to 2.7 acc/MVM) with an increase in intersection frequency (0.5 to 3/mile) when traffic volumes were low (0 to 4,900 vpd). However, at higher traffic volumes (5,000 to 9,900 vpd) accident rates decreased (5.0 to 2.5 acc./MVM) as the frequency of intersections increased. No statistical significance could be determined for either relationship. The use of unequal segment lengths (discussed in the section entitled "Traffic Volume") could have accounted for the negative relationship between frequency of intersections and accidents at the higher traffic volumes.

- Prisk (1957) found the type of access control to have a significant effect on accidents. Data from the study are shown in Table 6. These data show fatal, injury, and total accident rates decreasing as access control changes from none to full.

- Schoppert (1957) showed driveways and intersections to be directly related to accidents at all ADT levels, with the strongest relationships occurring at the higher ADT levels (3,000 and over). Of the three access types investigated, intersections and commercial driveways had the most significant effect, and residential driveways the least significant effect.

- Kihlberg and Tharp (1968) also found the type of access control to have a significant effect on accidents. This study found full control of access to reduce accident rates by as much as 67 percent. This study also showed intersections to be the most significant access type.

- Dart and Mann (1970) reported that the accident rate increased as the total number of minor road intersections and principal access driveways per mile increased.

Conclusion: As the frequency of intersections and commercial driveways increases accident rates on rural tangents increase. Type of access control (full, partial, and none) is indicative of the accident experience on rural highways.

Table 6. Accident rates on rural highways with no, partial, and full control of access.

Access Control	Fatalities Per 100 MVM	Injuries Per 100 MVM	Total Acc. Per 100 MVM
None	10.3	214	344
Partial	6.3	148	209
Full	3.4	136	156

Source: Prisk, C.W., "How Access Control Affects Accident Experience", Public Roads, Vol. 29, No. 11, December, 1957.

Pavement Width

Reported relationships between pavement width and accidents on rural tangents are inconsistent. Several studies found no significant relationship while others report that, within certain width and volume ranges, there is a significant relationship between pavement width and accidents. In general, it appears that some safety benefit is derived when lanes are widened to 12 feet.

- Raff (1953) concluded that neither shoulder width nor pavement width, nor any combination of them had a determinable effect on accident rates.
- Cope (1955) reported a significant decrease in accident rates on two-lane pavements when lanes were widened from 9 to 12 feet, particularly on sections with high accident rates and traffic volumes.
- Stohner (1956) reported that variations in pavement width between 16 and 24 feet were not substantially related to accidents.
- Perkins (1957) reported a similar finding where total surface width was found to be unrelated to accident rates.
- Schoppert (1957) found lane width to be more closely related to ADT than to accident rates.
- Dart and Mann (1970) showed that accident rates decreased as lane width increased to 11 feet, then remained relatively constant beyond that point.
- Gupta and Jain (1973) reported that roadway width rating (adequacy rating), when grouped by ADT, had a significant effect on all but single-vehicle accident rates at volumes less than 1,400 vpd. When volumes ranged from 1,500 to 2,900 ADT pavement width affected only single-vehicle accident rates. No significant effect was found for any accident type in the higher ADT range (3,000 to 6,900).
- Jorgensen (1978) reported a general tendency for accident rates to increase when the pavement is widened beyond 24 feet. For other width categories (18 or less, 19 to 20, and 21 to 23) there was a general decrease in the accident rate with increased width. However, no significant relationship could be determined.

Conclusion: The pavement width does not appear to be an indicative factor of accidents on rural undivided tangent sections.

Shoulder Width

The precise effect of shoulder width on accidents cannot be determined from the literature. While some studies conclude that no relationship exists, others report a general decrease in accidents with increasing shoulder width. However, this relationship does not appear to be consistent across all traffic volumes.

- Raff (1953) concluded that no relationship existed between accident rates and shoulder width.

- Belmont (1954) reported that 6 foot shoulders were safer than narrower shoulders at volumes below 5,000 ADT; and, that 6 foot shoulders were safer than either narrower or wider shoulders at volumes above 5,000 ADT.

- Head and Kaestner (1956) reported a significant relationship between total and property damage only rates and shoulder width in the 3,600 to 5,500 ADT range, where both rates decreased as shoulder width increased from 5 to 13 feet.

- Belmont (1956) reported a tendency for injury accidents to increase with an increase in paved shoulder width, except for volumes below 2,000 vpd where the trend was reversed.

- Stohner (1956) showed fatal and injury rates to decrease as shoulder width increased for 3 to 8 feet. However, both rates increased at shoulder widths greater than 8 feet.

- Perkins (1957) found no relationship between accidents and total surface width.

- Billion and Stohner (1957) reported that, on 20 foot wide pavements, shoulders 5 to 7 feet wide had lower accident rates than narrower shoulders.

- Blenskly and Head (1960) reported total and property damage only rates decreasing with increasing shoulder width in the intermediate volume ranges. However, at lower volumes (2,000 to 2,900 vpd) both rates increased with increasing shoulder width.

- Jorgensen (1978) reported a general tendency for accident rates to decrease as shoulder width increased.

Conclusion: The majority of the literature reports that accidents decrease with increasing shoulder width. The specific relationship, however, appears to be dependent upon traffic volume, and possibly, pavement width.

Grade

Studies by Raff (1953) and Kihlberg and Tharp (1968) reported percent grade to be unrelated to accidents. Other investigators have found varying relationships between accident rates and gradient (Bitzel, 1957; Mullins and Keese, 1961; Bowman, 1958), but these studies were conducted on multilane facilities, and the results have been inconsistent.

Conclusion: Relationships between grade and accidents on rural undivided tangents are not indicated in the literature.

Sight Distance Restrictions

Only two studies were found which attempted to define relationships between sight distance and accidents. The study by Schoppert (1957) reported a tendency for accidents to increase with restricted sight distance. However, when sight distance restriction was included in the regression equations along with other variables, the effect was so small that it was eliminated from the equations.

Raff (1953) investigated the frequency of sight distance restrictions on accident rates. Sight distance restrictions were defined as distances less than 600 feet in flat or rolling terrain, and less than 400 feet in mountainous terrain. Results showed accident rates increasing from 2.0 to 3.1 acc./MVM as the frequency of sight distance restrictions increased from zero to about three per mile. Beyond that frequency the relationship was inconsistent.

Conclusion: Restricted sight distance does not appear to be related to accidents on rural undivided tangent sections.

Delineation

Studies relating the effect of delineation on accidents are not conclusive. One study by the Arizona Highway Department (1963) reports delineation (edgelines and post mounted delineators) to be unrelated to accidents; another study by Musick (1960) shows edgelines to be effective in reducing total, fatal, injury, and night accidents; while yet another study by Basile (1962) reports edgelines to be effective in reducing fatalities, but not total or injury accidents. Further, no distinction is made between curved and tangent sections in any of these studies.

Conclusion: The effect of edgelines on accidents on rural undivided tangent sections cannot be determined from these studies.

Roadside

Studies of the effects of roadside features on accidents include a study by Raff (1953) of the frequency of fixed objects and a study by Huelke (1967) of the distance from the pavement edge to a fixed object. Neither study reported conclusive results. Glennon and Tamburri (1967) investigated the effect of foreslopes and embankments heights on accident severity ratios. Results show the relative severity of fatal, injury and property damage only accidents increasing as foreslopes steepen and embankment heights increase.

Conclusion: Steep foreslopes and high embankments increase accident severity.

Skid Resistance

A relationship between skid resistance and wet accident involvement has been established in the literature. The decrease in accidents is fairly rapid as skid numbers increase to about 40, but decrease only slightly as skid numbers increase beyond that value.

- McCullough and Hankins (1966) reported a general tendency for accident rates to decrease as the coefficient of pavement friction increased.

- Holbrook (1976) reported that wet accidents appeared to be a continuously decreasing function of surface friction. With a skid number of 30 or less, wet accident incidence increased at a slightly increasing rate with declining surface friction.

- Rizenbergs, et al., (1977) reported that the ratio of wet-to-dry pavement accidents correlated best with pavement friction. This ratio decreased rapidly as the skid number increased to approximately 40. Further increases in skid number resulted in only a slight reduction in the ratio of wet-to-dry pavement accidents.

Conclusion: Pavements with skid numbers less than 40 are indicative of a potential hazard, with the risk of wet accidents increasing rapidly with decreasing pavement friction.

Speed

There is a general agreement in the literature that the risk of sustaining more severe injury increases with increasing speed. However, relationships between speed values and accident occurrence are inconclusive. Positive relationships between speed distribution and accidents are documented in several research reports. Studies investigating the relationship between speed deviation and accident involvement rates show a U-shaped distribution with minimum involvement rates occurring for those traveling at average speeds. It has also been shown that a change in speed distribution from non-normal to normal produces a significant reduction in accidents.

- Cleveland (1970) reports the findings of several studies investigating the relationship between speed and accidents. Pertinent relationships identified in that report are:

  1. Analysis of driver speed and accident rates indicate that both extremely slow and extremely fast drivers had much higher accident rates than average for the traffic stream.

  2. There is a pronounced linear decrease in percentage of rear-end accidents as speed increases above 30 mph, and an exponential increase in percentage of single-vehicle accidents as speed increases.

  3. Analysis of speed and accident data from two- and four-lane rural highways showed involvement rates to be highest at very low speeds, lowest at about the average speed, and increased again at the very high speeds. The study also reported that the minimum involvement rate occurred when travel speeds ranged from the average speed to 10 mph above the average speed.

  4. The fatal accident rate decreases with a decrease in the dispersion of speeds.

  5. A study of the absolute change of mean speed and accident rates indicated that the speed change parameter may be a measure of accident potential.

  6. Data from 15 miles of rural highway indicate a significantly higher accident rate when the speed distribution is skewed (non-normal). It was further concluded that where the speed

distribution is normal, the resulting accident rate is approximately half that found under any other condition.

- A report by the Research Triangle Institute (1970) reports a U-shaped relationship between speed deviation and accident involvement rate. This study, which included data from 70 miles of state and county highways where the mean speed was 40 mph or more, show a minimum involvement of 0.8/MVM when speeds ranged from 15.5 mph below average to 5.5 mph above the average. (Accidents involving a turning maneuver were not included in the analysis).

Conclusion: Accident involvement rates increase as speed increases or decreases from the mean speed. Further, the accident potential is greater when the speed distribution is skewed.

Rural Undivided Winding Sections

Frequency of Curves

Three of the four studies investigated show a general tendency for accident rates to decrease as the tangent distance between curves decreases (or, the frequency of curves increases). However, the specific relationship between accident rates and frequency of curves cannot be determined. Further, data from one of these studies shows accident rates to be higher on curves when curves are separated by more than 3 miles than when they are separated by 3 miles or less. This condition may be more representative of an isolated curve situation than winding sections. The fourth study reports no consistent effect of frequency of curves on accident rates.

- Leisch (1971) reports on a study by Baldwin (1946) which shows accident rates decreasing as the frequency of curves increases. Data shown in Figure 3 show that at low curve frequencies (less than one per mile) the accident rate is more dependent on degree of curvature than on frequency of curves.

- Kipp (1952) reports that accident rates are lower on both tangents and curves when curves are separated by tangents less than 3 miles in length. When the tangent length is less than 3 miles accident rates on tangents and curves are 1.3 and 2.1 accidents/MVM, respectively. At tangent lengths greater than 3 miles the accident rates on tangents and curves are 1.6 and 2.5 accidents/MVM, respectively.

- Raff (1953) reports that the frequency of curves did not appear to have any consistent effect on accident rates on curves, even when the curves were subdivided by degree of curvature. Further, the frequency of curves did not have any independent effect on accident rates on tangent sections.

- Coburn (1962) reports that as the frequency of curves increases accident rates decrease, and at the higher frequencies, accident rates are lower than for either tangent sections or roadway sections with infrequent curves.

Conclusion: In general, it appears that accident rates decrease when the frequency of curves increases.

Traffic Volume

No studies were found which attempted to define the relationship between traffic volume and accidents on rural winding sections. The

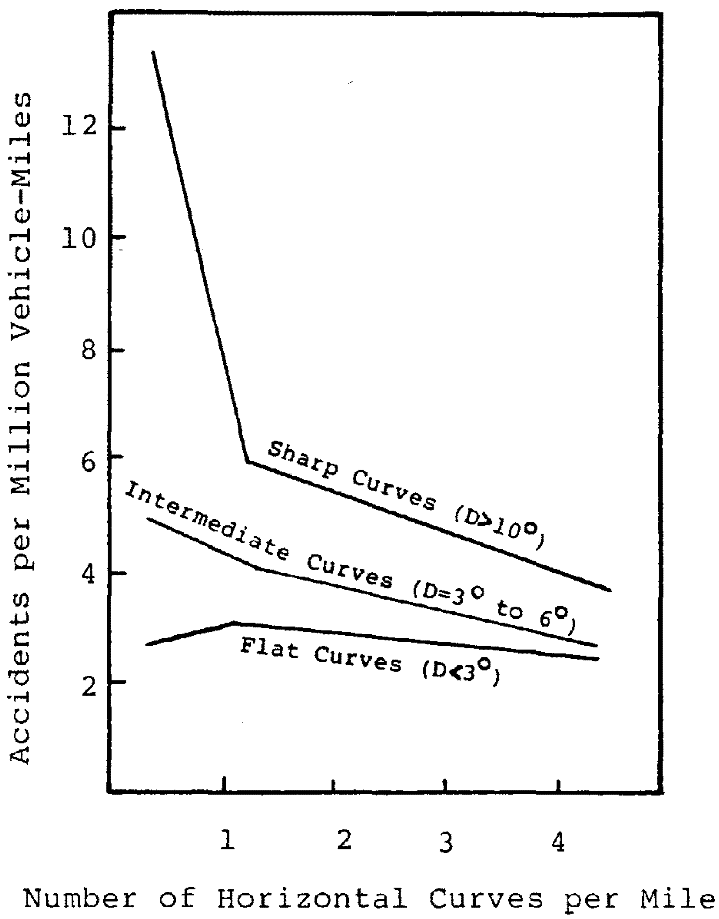

Figure 3. Accident rate related to horizontal curvature and frequency of curves.

Source: "The Relation of Highway Design to Traffic Accident Experience," by D.M. Baldwin, AASHO Convention Group meetings, 1946, p. 107 (8).

effect of volume on accident rates on horizontal curves and on tangents was discussed in the two previous sections entitled Rural Isolated Horizontal Curves and Rural Undivided Tangent Sections.

On horizontal curves the effect of volume is different at high and low degrees of curvature. At volumes below 5,000 vpd accident rates increased steadily with increasing curvature, whereas, at volumes above 5,000 vpd the trend is reversed.

At rural tangent sections accident rates increase with increasing traffic volume.

Raff (1953) attempted to determine the relationship between accident rates on tangent sections and curve frequency, tangent length, and traffic volume, but the results were inconclusive.

Conclusion: The literature reports no conclusive relationships between volumes and accident experience on rural winding sections.

Lane Width

Several studies have examined the relationship between accidents and lane width on rural roads. Most of these have dealt with rural roads as a group, without separating curves and tangents. Raff (1953) reported that 24-foot curve sections were consistently safer than 20-foot sections but no other conclusions could be drawn from the data. Dart and Mann (1970) found that accident rates decreased as lane width increased to 11 feet, with no significant difference between 11 and 12 feet. Cope (1955) reported a substantial reduction in accident rates when 18-foot pavements were widened to 24-feet, with the largest reductions in the higher volume ranges.

Conclusion: There is general agreement that wider lanes result in lower accident rates. However, the specific relationship between lane width and accidents cannot be determined.

Shoulder Width

Studies reported in the two previous chapters show the effect of shoulder width on accident rates to be inconsistent. While the majority of the literature reports a general decrease in accident rates with increasing shoulder width, the relationship is not consistent for all shoulder widths or traffic volumes.

Further, it cannot be determined from the literature if the effect of shoulder width on accident rates is different on winding sections than on horizontal curves or tangent sections.

One study by Billion and Stohner (1957) reports that accident rates on curves and grades are much lower on sections with wide shoulders than on sections with narrow shoulders. They also found that these differences were almost totally obscurred when these data were combined with the data for level tangent sections.

Conclusion: No conclusive relationships between shoulder width and accident experience on rural winding sections are reported in the literature.

Rural Signalized Intersections

Traffic Volume

Only two studies were found which provide insight into the effects of volume on accident experience at rural signalized intersections. The study by Webb (1955) of the effect of traffic volume on accident frequency at rural, two-phase signalized intersections reported accident frequency to be a function of the product of the major and minor road volumes. The relationship developed from data at 14 cross-type intersections, without special left-turn provisions, and with approach speeds greater than or equal to 45 mph is as follows:

$$N = 0.280\ X^{0.51}\ Y^{0.29}$$

Where:

N = Average number of accidents per year
X = 1/100 of the average daily traffic on the major road
y = 1/100 of the average daily traffic on the minor road

This relationship is shown graphically in Figure 4. It should be noted, however, that all rear-end accidents occurring on the minor road were eliminated from the analysis. Thus, an estimate of the total number of accidents at an intersection cannot be obtained from this equation.

The other study by Stover, et al., (1970) reported that as the percent green time on the main road decreased, the accident rate increased. If it is assumed that percent green time is proportional to approach volumes, then this study also shows accidents to be related to some function of major and minor road volumes other than the sum of entering vehicles.

Conclusion: The literature indicates that some combination of major and minor road volumes, other than their sum, has an effect on accident experience.

Approach Speed

Webb (1955) also developed equations of the same form ($N=mx^a y^b$) as the one presented in the previous section for urban and semiurban signalized intersections. Approach speeds were used to establish the three categories where intersections with approach speed of 25 mph or less were classified as urban; intersections with approach speeds greater than 25 mph but less than 45 mph were classified as semi-urban; and intersections with approach speeds of 45 mph or more were classified as rural.

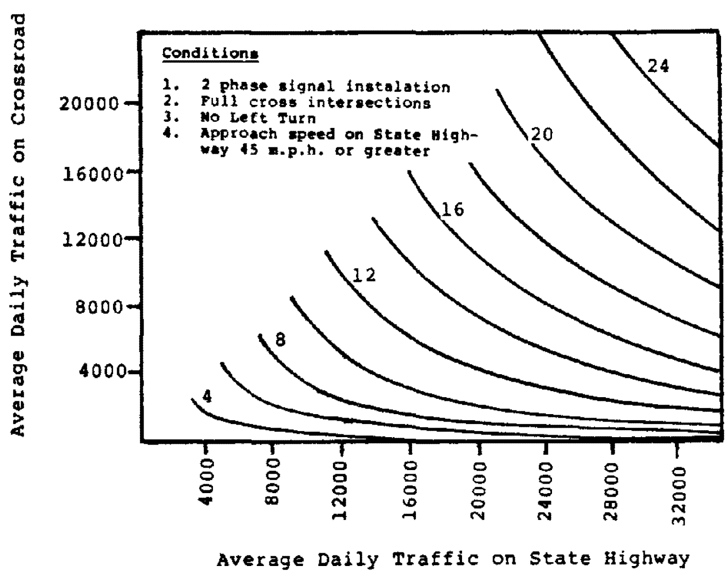

Figure 4. Average number of accidents per year related to traffic volume at rural type signalized intersections.

Source: Webb, G.M., "The Relation Between Accidents and Traffic Volumes at Signalized Intersections," Proceedings, Institute of Traffic Engineers, 1955.

Results show the coefficient m increases with increasing approach speed, and the effect of the minor road volume (y) decreases as the approach speed increases. However, it cannot be determined if these effects are specifically related to speed or to other characteristics of urban and semi-urban environments.

Conclusion: No specific relationship between approach speed and accident experience at rural signalized intersections can be determined from the literature.

Other Potential Surrogates

Several studies have identified other accident factors that may be related to accident occurrence at rural signalized intersections. Although specific relationships have not been determined, they are mentioned here because it seems logical that a relationship may exist.

Other factors that have been reported include signal and sign visibility (Malo, 1967), delineation (David and Norman, 1975), sight distance (Hanna, et al, 1976), and skid resistance (Holbrook, 1976).

In addition, Glauz and Migletz (1980) have prepared a comprehensive review of traffic conflicts, which indicate some potential for accident prediction. Shaw and Michael (1968) studied several urban and rural intersections and derived relationships between delay and several geometric and traffic variables. Accidents have been reported to be related to some of these variables, particularly ADT. Thus, a relationship may exist between accidents and delay. Zegeer (1977) reported that both conflicts and accidents were reduced following the installation of green extension systems at fully actuated signal locations. The predominant conflict type both before and after was run-red-light; the greatest accident reductions occurred with rear-end accidents.

Rural Non-Signalized Intersections

Traffic Volume

A strong positive relationship between accident experience and traffic volume at two-way stop controlled intersections is reported in the literature. Further, one study shows the effect of volume on accidents to be different at cross and T-type intersections, with cross intersections more affected by traffic volume when volumes exceed 1,500 vpd.

There is also strong evidence that accident experience at both undivided and divided highway intersections is more sensitive to the distribution of traffic on the through and cross road than to total entering volume. One study reports that when cross road volumes exceed 10 percent, accident rates (accidents/total entering vehicles) can be several times greater than when the cross road volume is less than 10 percent of the total entering volume. Two other studies report the relationship between accident frequency and traffic volume to be better expressed in terms of the product of the through and cross volumes than by their sum.

- Analysis by Kipp (1952) showed that when the cross traffic is greater than 10 percent, the accident rate is six times the rate at three-way intersections and eight times the rate at four-way intersections at which there is less than 10 percent cross traffic.

- Box (1970) reported on a study be Staffeld (1953) which showed that accident rates at three-way and four-way intersections are approximately the same at volumes less than 1,500 vpd. However, as the volume increases from 1,500 to 3,500 vpd the accident rate steadily increases at four-way intersections but remains relatively constant at three-way intersections. (Of the 593 intersections investigated 96 percent had less than 10 percent cross traffic). Accident rates by intersection type and traffic volume group are shown in Figure 5.

- Raff (1953) reported similar effects of cross traffic on accident rates. Data shown in Figure 6 indicate that when the cross traffic is greater than 10 percent, the accident rate is approximately three times higher at intersections with volumes up to 9,000 vpd.

  Data in Table 7 show the effect of increased cross traffic on accident rates on two- and four-lane roads. These data show that the greatest change in accident rates occurs when cross street volumes reach 10 percent; and that additional increases in cross street traffic to 20 percent have a lesser effect on accident rates.

- McDonald (1953) reported accident frequency at divided highway intersections to be related to the product of the through and

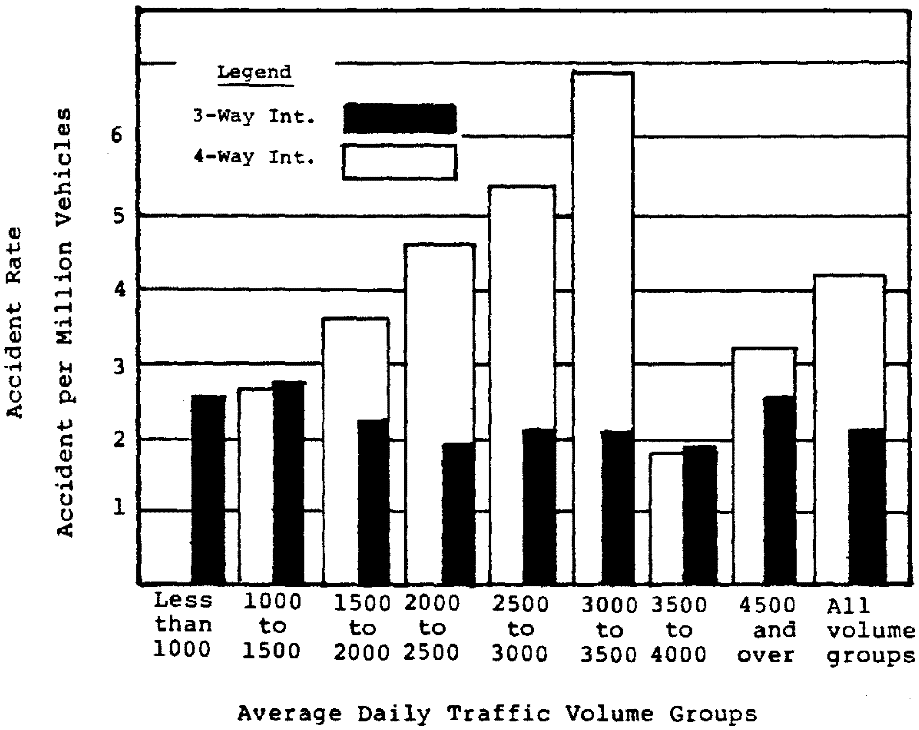

Figure 5. Accident rates at rural intersections by type of intersections.

Source: Staffeld, P.R., "Accidents Related to Access Points and Advertising Signs," Traffic Quarterly, January, 1953.

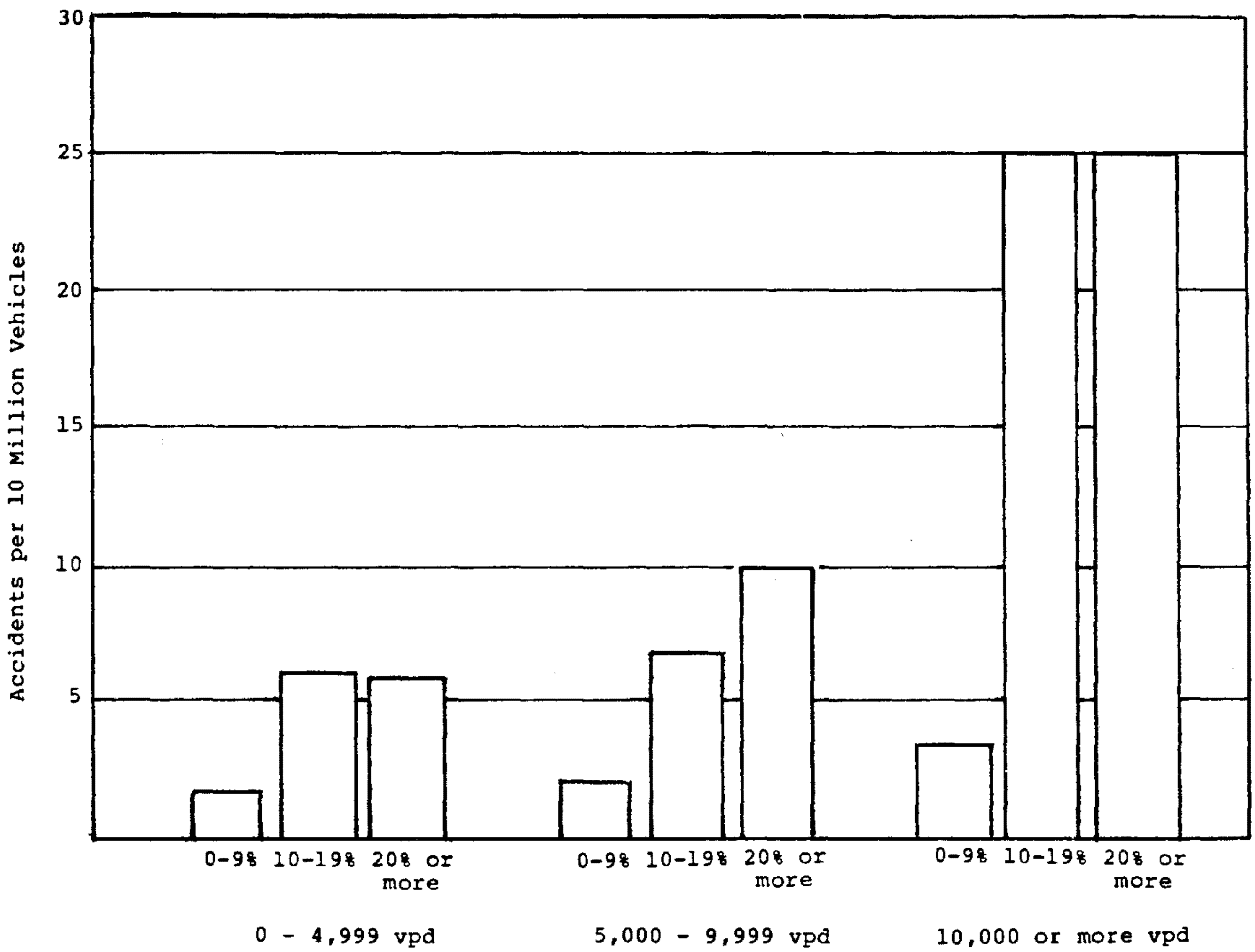

Figure 6. Accident rates at intersections (all roadway types), by total volume and percentage of cross traffic.

Source: Raff, M.S., "Interstate Highway-Accident Study," Highway Research Board Bulletin No. 74, 1953.

Table 7. Accident rates at intersections at grade on two-lane roads and on four-lane undivided and divided roads by total volume of traffic and percentage of cross traffic.

Percent Cross Traffic	0 - 4,900 vpd		5,000 - 9,900 vpd		10,000 or more vpd	
	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles
			Two-Lane Roads			
0 - 9	678	2.0	229	1.8	9	0.8
10 - 19	116	6.0	56	5.3	0	0.0
20 or more	162	6.5	118	7.5	3	1.9
			Four-lane undivided roads			
0 - 9	33	3.4	184	3.5	302	3.0
10 - 19	15	21.4	22	14.7	123	28.6
20 or more	0	0	34	18.9	236	35.2
			Four-lane divided roads			
0 - 9	15	3.2	131	3.2	309	4.2
10 - 19	7	17.5	25	10.0	130	24.5
20 or more	0	0.0	13	11.8	97	19.4

Source: Raff, M.S., "Interstate Highway - Accident Study", HRB Bulletin No. 74, 1953.

cross volumes, and that accident frequency was more sensitive to cross road volume than to through volume. The accident prediction equation developed in this study is as follows:

$$N = 0.000783 \, V_d^{0.455} \, V_c^{0.633}$$

Where:

N = the number of accidents per year

V_d = the ADT entering from the divided highway

V_c = the ADT entering from the cross road.

This relationship is shown graphically in Figure 7.

- Priest (1964) investigated the effect of traffic volume on accident frequency at divided highway grade intersections. Results indicate that accident frequency is a function of the product of the through and cross road volumes. Figure 8 shows the relationship between primary and secondary (through and cross) volumes and accident frequency. These data also show accident frequency to be more sensitive to cross road volumes than to through volumes on the divided highway.

Conclusion: The literature shows cross road volumes greater than 10 percent to have a significant affect on accident rates at rural non-signalized intersections, and that there is a relationship between accident frequency at divided highway intersections and the product of the through and cross volumes, with the accident frequency being more sensitive to changes in the cross road volume.

Median Width

Priest (1964) reported a relationship between three median width groups (0 to 19 feet, 20 to 39 feet, and 40 feet and over), exposure index, and accident frequency at rural non-signalized intersections. The exposure index is the product of the primary and secondary traffic volume code numbers. (Traffic volumes and their respective codes are shown in Table 8). The method of least squares was then used to determine the relationships between the three variables.

Figure 9 shows the relationship between accident frequency and exposure index for the three median width groups. Figure 10 shows the relationship between median width and accident frequency for constant values of exposure index. These data show accident frequency decreasing with increasing median width for exposure indices between 35 and 100. At the

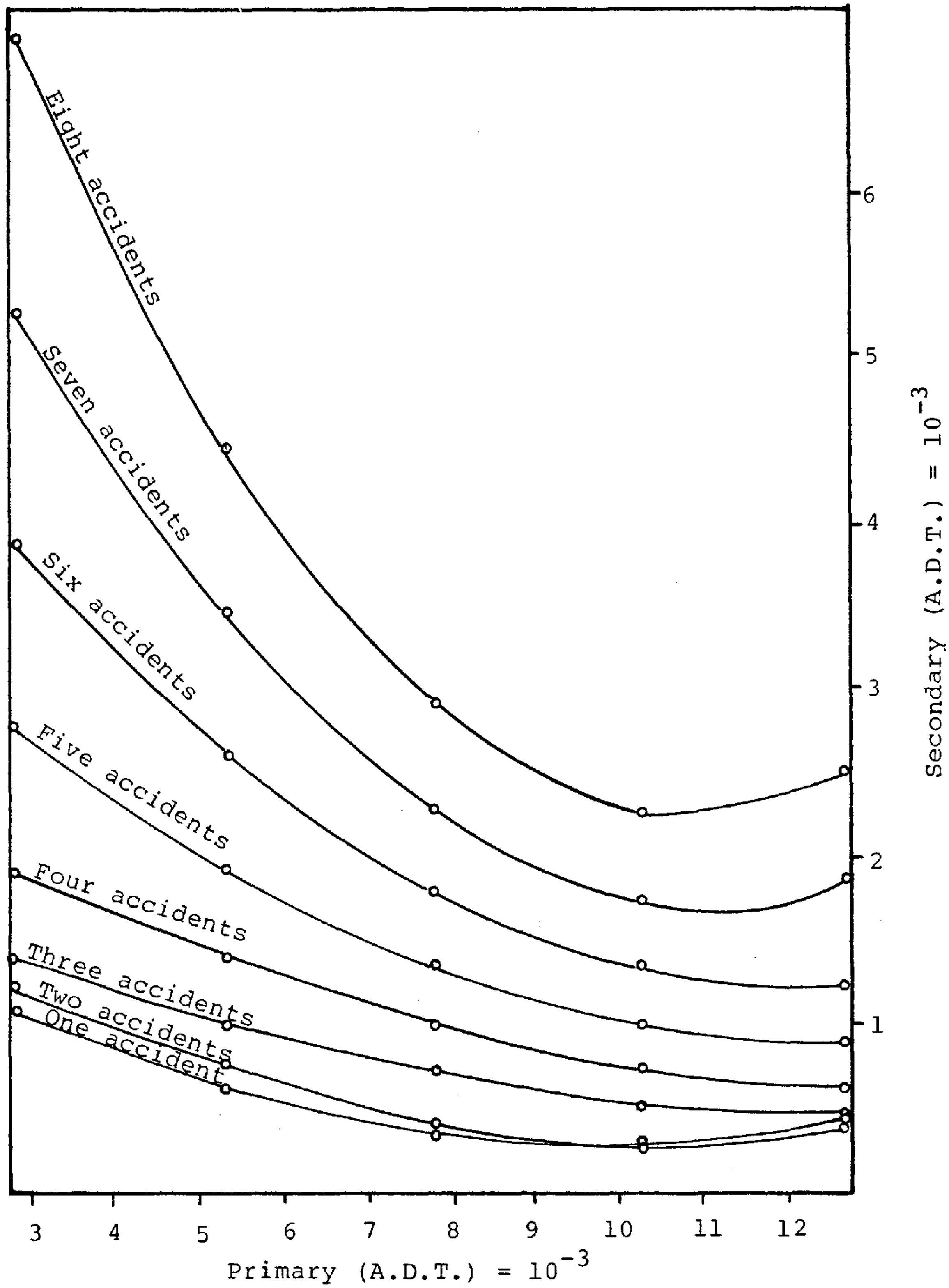

Figure 7. Number of accidents per year related to traffic volume at divided highway grade intersections.

Source: McDonald, J.W., "Relation Between Number of Accidents and Traffic Volume at Divided Highway Intersections", Highway Research Board Bulletin No. 74, 1953.

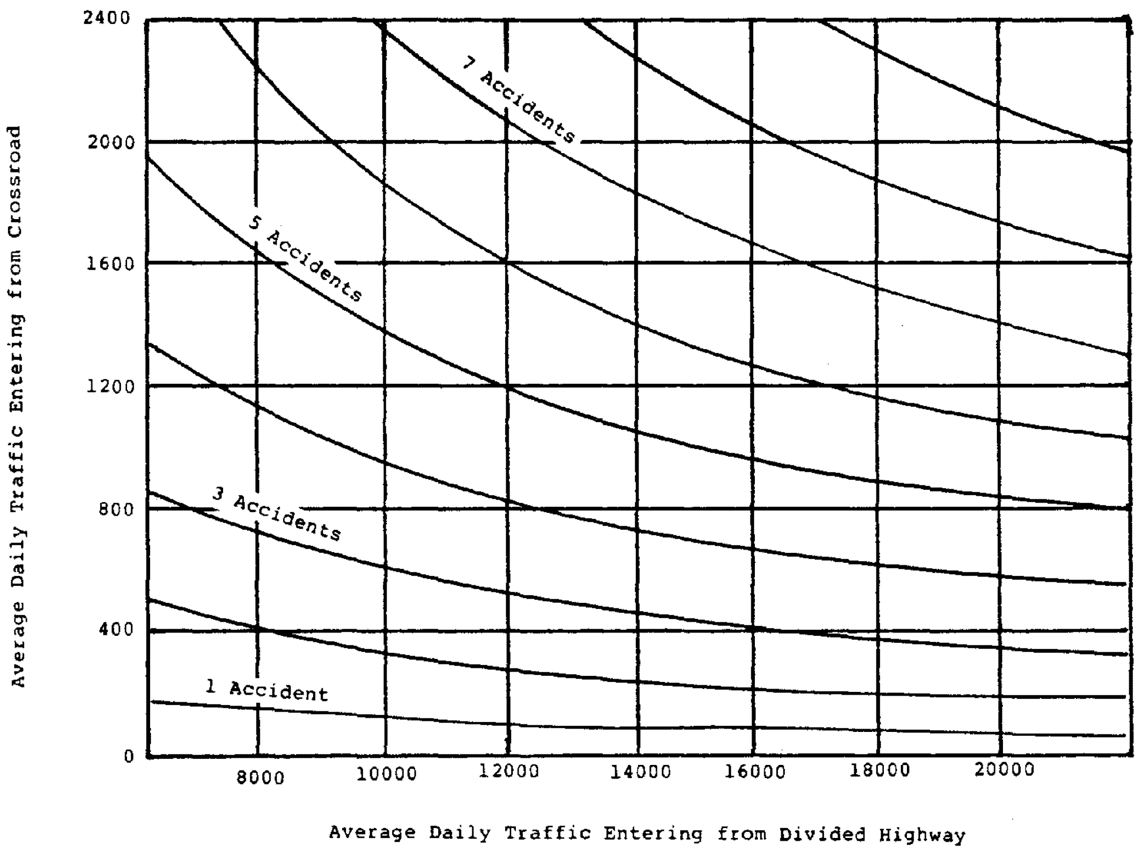

Figure 8. Average number of accidents per year related to volume at divided highway intersections.

Source: Priest, R.V., "Statistical Relationships Between Traffic Volume, Median Width, and Accident Frequency on Divided-Highway Grade Intersections," Highway Research News No. 13, June, 1964.

Table 8. Primary and secondary traffic volume codes.

Primary (ADT) x 10^{-2}		Secondary (ADT) 10^{-2}	
Traffic Vol. Code No.	Traffic Vol.	Traffic Vol. Code No.	Traffic Vol.
1	Under 10	1	Under 2
2	10- 15	2	2- 4
3	15- 20	3	4- 6
4	20- 25	4	6- 8
5	25- 30	5	8-10
6	30- 35	6	10-12
7	35- 40	7	12-14
8	40- 45	8	14-16
9	45- 50	9	16-18
10	50- 55	10	18-20
11	55- 60	11	20-22
12	60- 65	12	22-24
13	65- 70	13	24-26
14	70- 75	14	26-28
15	75- 80	15	28-30
16	80- 85	16	30-32
17	85- 90	17	32-34
18	90- 95	18	34-36
19	95-100	19	36-38
20	100-105	20	38-40
21	105-110	21	40-42
22	110-115	22	42-44
23	115-120	23	44-46
24	120-125	24	46-48
25	125-130	25	48-50
26	130-135	26	50-52
27	135-140	27	52-54
28	140-145	28	54-56
29	145-150	29	56-58
30	150-155	30	58-60
31	155-160	31	60-62
32	160-165	32	62-64
33	165-170	33	64-66
34	170-175	34	66-68
35	175-180	35	68-70

Source: Priest, R.V., "Statistical Relationships Between Traffic Volume, Median Width, and Accident Frequency on Divided-Highway Grade Intersections," Highway Research News No. 13, June, 1964.

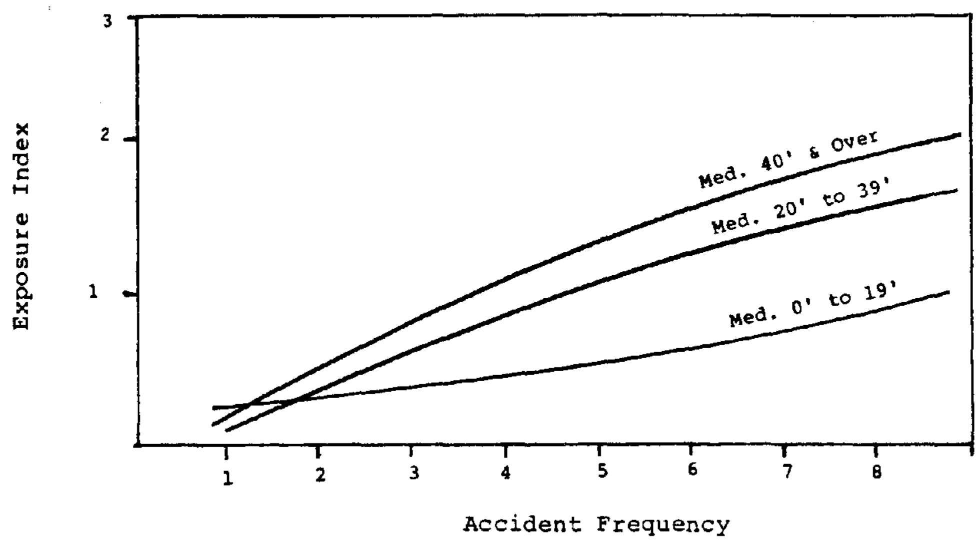

Figure 9. Number of accidents per year related to exposure index for various median width group.

Source: R.V., "Statistical Relationships Between Traffic Volume, Median Width, and Accident Frequency On Divided-Highway Grade Intersections," Highway Research News No. 13, June, 1964.

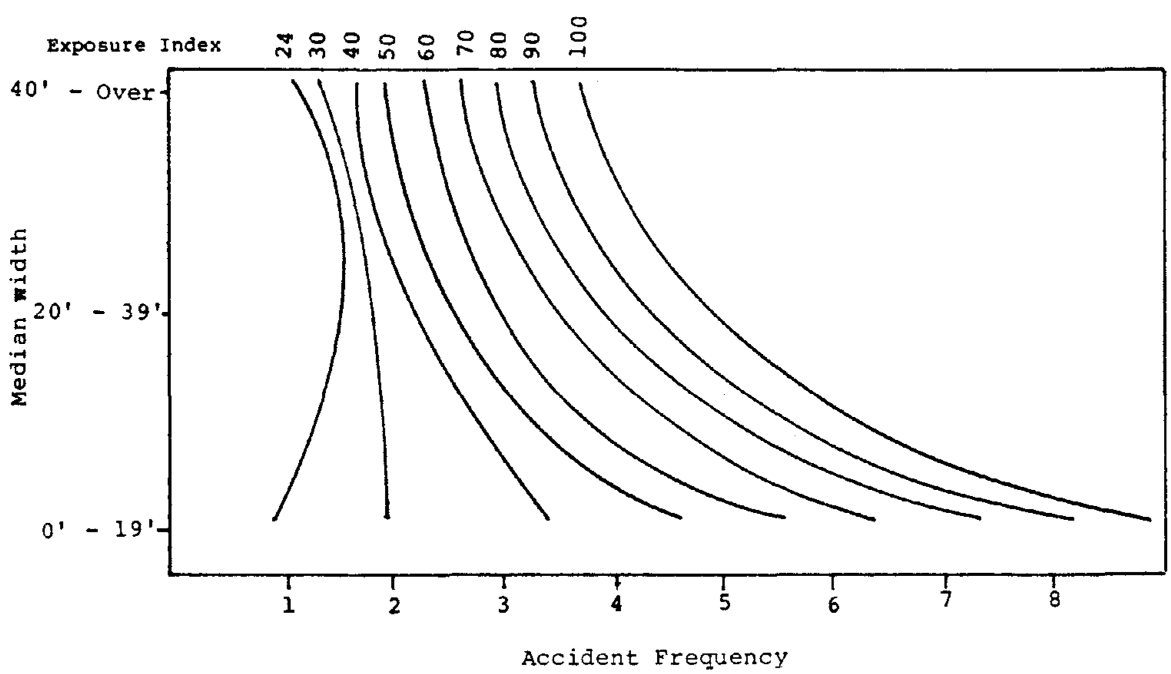

Figure 10. Number of accidents per year related to median width for constant exposure index.

Source: R.V., "Statistical Relationships Between Traffic Volume, Median Width, and Accident Frequency On Divided-Highway Grade Intersections," Highway Research News No. 13, June, 1964.

lower exposure index (24) the accident frequency tends to increase as the median width increases up to the 20 to 39 feet group. A possible explanation is that at low volumes there is a greater tendency for the driver to proceed through the intersection even if storage space is provided. Thus, for the lower exposure index, the distance traveled by a vehicle is greater with a wider median than with a narrower median. The greater distance increases the driver's exposure time, thus increasing the probability of collision.

Conclusion: One study reports that accident frequency decreases with increasing median width, with the greatest reduction occurring when median width increases from the 0 to 19 feet category to the 20 to 39 feet category.

Skid Resistance

Holbrook (1976) analyzed approximately 40,000 accidents reported at over 2,000 urban and rural intersections to develop a wet surface accident prediction model. The model incorporates skid number, surface wet time, and seasonal weather effects.

Results showed, that for all levels of wetness, wet accident incidence increased at a slightly increasing rate as the skid number decreased below a value of about 30. No critical skid number could be determined above which the wet accident hazard disappeared.

Conclusion: Approach pavements with skid numbers less than 30 are potentially hazardous, with the risk of wet accidents increasing at a slightly increasing rate with decreasing pavement friction.

Traffic Conflicts

As reported by Glauz and Migletz (1980), traffic conflicts have been used in several states to aid in solving operational problems at both rural and urban intersections. No definite correlations with accident experience have been derived, although logical relationships would seem to exist.

Conclusion: Specific relationships between traffic conflicts and accident experience are not reported in the literature.

Urban Undivided Tangent Sections

Of the studies investigating the effects of various geometric and operational variables on accident experience on urban roads, a large number report on the relationship between these variables and intersection accidents. Further, where non-intersection accidents, or all accidents, have been investigated no separate analysis has been conducted for tangent sections or, more specifically, undivided tangent sections.

Studies of the effects of geometric and operational variables on urban accident experience reported in this section apply to urban roads in general, and are considered applicable to this situation. However, the specific effects of these variables on accident experience on urban undivided tangent sections cannot be determined.

Street Width

Studies of the affect of street width on accident experience show street width to have little or no effect on accident experience on urban undivided tangent sections.

- Head (1958) reported pavement width to exhibit a positive relationship with accident rates on urban extensions of state highways. However, the relationship varies considerably and is normally quite weak.

- Mulinazzi and Michael (1967) reported street width to be unrelated to both accident rate and frequency on urban arterial highways with volumes up to 32,000 ADT.

- Gupta and Jain (1973) reported that street width is unrelated to accident rate on two-lane urban roads having up to 12,000 ADT.

Conclusion: Street width is unrelated to accident experience on urban undivided tangent sections.

Access Points

The type and frequency of access points has been reported in several studies to have a strong positive relationship with accident experience on urban highways. Studies show the presence of signalized intersections, total number of intersections, and commercial driveways to have a significant effect on accident occurrence, with the density of signalized intersections having the greatest effect and density of commercial driveways the least. The frequency of residential driveways was reported to have no significant effect on accident experience on urban tangent sections. One of these studies also shows driveway accidents increasing as the spacing between a driveway and an adjacent driveway or intersection decreases.

- Head (1958) analyzed data from 426 sections of two- and four-lane state primary and secondary urban highways. (It cannot be determined from the report whether or not data from divided sections were included in the analysis). This study concluded that, of the access types investigated:

    1. The number of traffic signals per mile to be the most important variable in predicting accident rates, with the importance of this variable increasing as traffic volumes increased.

    2. The number of intersections per mile was determined to be the second most important access variable.

    3. The number of commercial driveways per mile was considered to be important only on two-lane sections.

    4. The number of residential driveways per mile was determined to be unrelated to accident occurrence.

- Mulinazzi and Michael (1967) analyzed data from 100 study sections and reported number of traffic signals per mile, number of heavy volume intersections per mile, number of four-way intersections per mile, and number of medium and heavy volume commercial driveways per mile to be important variables in predicting the total number of accidents.

- McQuirk and Satterly (1976) analyzed driveway accident and roadway data from 100 sections of urban arterial highway. (Driveway accidents accounted for 13.95 percent of all reported accidents on those sections). Although site selection criteria prohibited including sections containing a median barrier, no other information pertaining to divided vs. undivided roadway is contained in this report. Examination of regression equations developed in this study shows number of intersections per mile and number of commercial driveways per mile to be important variables in predicting the frequency of driveway accidents. The specific effect of commercial driveways cannot be determined in that there is a strong interaction between this variable and traffic volume. Both variables tended to increase or decrease in value at approximately the same rate as the dependent variable.

  The study also found driveway accidents to be affected by the spacing between adjacent driveways and the spacing between a driveway and an adjacent intersection. In both cases driveway accidents per mile decreased as the distance between a driveway and an adjacent driveway or intersection increased.

Conclusion: Both accident rate and frequency increases as the frequency of traffic signals, intersections, and commercial driveways increases.

Traffic Volume

Studies relating traffic volume to accident experience report a general tendency for both accident rate and frequency to increase as volumes increase. However, the effect of traffic volume is not consistent for two- and four-lane roads or for all traffic volumes.

- Head (1958) analyzed data from 426 sections in developing accident prediction equations for two- and four-lane urban roads. Results show a positive relationship between ADT and accident rates on two-lane roads for both volume groups (5,000 - 9,000 ADT, and 10,000 or over ADT). Of the three equations developed for four-lane roads ADT was included, and exhibited a positive relationship, in the 18,000 or over ADT group, but was not included in the equations developed for the under 9,000 ADT and 9,000 to 17,999 ADT groups.

- Mulinazzi and Michael (1967) reported a positive relationship between ADT and accident frequency when data from 100 study sections were utilized. However, when only two-lane sections were analyzed a negative relationship between ADT and accident frequency was found. Further, ADT was not included in the accident prediction equations for either low volume (1,200 - 5,800 ADT) or high volume (7,000 - 32,000 ADT) urban roads.

- McGuirk and Satterly (1976) report a positive relationship between traffic volume and driveway accidents per mile on all two-lane roads and on all one-way roads. The relationship was also positive when data from all 92 study sections were included; but was negative when sections from the largest city (Indianapolis) were removed. ADT was included, and showed a positive relationship, in the accident prediction equation for two-way roads when the Indianapolis sections were omitted; but was not included in the prediction equation developed for all two-way roads.

Conclusion: No consistent relationship exists between traffic volume and accident occurrence on urban roads.

Urban Non-Signalized Intersections

Traffic Volume

Of the studies investigating the effect of traffic volume at intersections only a few have studied the effect of volume at urban non-signalized intersections. Box (1970) reports on studies by DeLeuw Cather and Company and Syrek which show accident rates to be affected by the distribution of traffic on the major and minor street approaches, and that the effect of volume varies with intersection control type. The studies by DeLeuw Cather and Company used a ratio of major and minor street volumes in developing accident prediction nomographs for yield controlled and two- and four-way stop controlled intersections.

Conclusion: The literature indicates traffic volumes on both the major and minor approaches to an intersection are important factors in accident occurrence. However, specific relationships between approach volumes and accident experience at urban non-signalized intersections have not been reported.

Type of Intersection Control

Studies reported by Box (1970) show the type of intersection control to have an effect on accident experience. However, the effect of yield control and two- and four-way stop control is influenced, to a large extent, by major and minor road volume combinations, and to a lesser extent by approach speeds, sight distance restrictions, street functional classification, and geographic area. Thus, the specific effect of the type of traffic control and accident experience cannot be determined from the literature. The literature is in general agreement that each type of control can be effective in reducing accidents when used as provided in the Manual on Uniform Traffic Control Devices.

Conclusion: Yield, two-way stop, and four-way stop control are effective in reducing accidents when properly applied with regard to intersection approach volumes.

Other Intersection Related Factors

Cleveland (1969) reports several studies in which intersection illumination is related to decreased night accident occurrence, particularly at problem locations.

The traffic conflict technique (Glauz and Migletz, 1980), although not fully validated, shows promise of being a useful tool in analysis and prediction of intersection accidents.

Box (1970) reported on a study by DeLeuw Cather and Company which included approach width in their accident prediction nomograph for two-way stop controlled urban intersections. Other investigators (e.g., Shaw and Michael, 1968) have investigated approach width, although many of these studies were conducted at rural intersections or at signalized intersections.

Lane Drop Locations

Lane Drop Configuration

Goodwin (1976) investigated 65 freeway lane drops to determine the relationship between type of lane drop and accident rates. Results showed lane drop configuration to be unrelated to accident rate.

Conclusion: The geometric configuration has not been shown to be related to accident occurrences.

Presence of a Lane Drop

Analysis of one-year before-and-after data indicated that the removal of a lane drop decreased accidents (Failmezger, 1975). Conditions before improvement involved 4 lanes of traffic merging into 2 lanes (freeway to freeway). Data revealed a high number of accidents at the final merge point and at points back in the queue. The improvement involved adding an additional lane such that 4 lanes merged into 3. Data included in Table 9 show a 77 percent reduction in total accidents in the after period. The data in Table 9 correspond to before-and-after rates of 4.69 and 1.30 accidents per million vehicle miles respectively.

Conclusion: The literature indicates that a 4 to 2 lane drop is hazardous in comparison to a 4 to 3 lane drop. Conclusions cannot be made regarding other lane transition combinations.

Raised Pavement Markers

A study to evaluate the effectiveness of various types of raised pavement markers indicated this type of delineation treatment to be effective in reducing erratic maneuvers at lane drop locations (Pigman and Agent, 1974). Data from 5 study sites showed daytime and nighttime erratic maneuver rates reduced by 20 and 44 percent respectively. No significant change in brake light rates was observed following installation of raised pavement markers.

Conclusion: Although a significant change in erratic maneuvers was observed in this study no relationship between erratic maneuvers and accidents was reported.

Table 9. Accidents before-and-after removal of a lane drop.

Type of Accident	No. Before	No. After	Change
Fatal	1	-	1
Injury	22	6	16
Property Damage Only	47	10	37
Total	70	16	54

Source: R.W., "Narrow Freeway Lanes for Increased Capacity", _Traffic Engineering_, June, 1975.

Design Features

Goodwin (1976) surveyed and rated 65 lane drop situations in various states using erratic maneuvers data, and developed a list of eight principles to serve as guidelines in lane drop design. These principles emphasize sight distance, proximity to other traffic maneuvering situations, delineation, geometric design and appearance, and placement and type of traffic control devices used to warn drivers of the impending lane drop and associated maneuver.

Conclusion: The design principles presented in this report show promise, but application procedures developed from them still must be verified in field tests to show the general applicability and effectiveness.

Exit Gore Areas

Taylor and McGee (1973) report that strong delineation treatments are effective in reducing erratic maneuver rates at delineation lane and exit gore areas during periods of darkness. Strong delineation was defined as a method of incorporating greater-than-normal numbers of post mounted delineators and/or raised pavement markers, in addition to standard paint markings. Before and after data shown in Table 10 indicate a significant reduction in erratic maneuver rates following the installation of additional delineation.

Conclusion: Strong delineation treatments are effective in reducing nighttime erratic maneuver rates. However, the relationship between erratic maneuvers and accidents was not determined in this study.

Paved Shoulders

Only one study was found which reported a relationship between shoulder conditions and accident experience at exit gore areas. This study by Cirillo, et al. (1969) reports that the presence of a paved right shoulder along a deceleration lane reduces annual accidents per 1,000 vpd by 0.042.

Conclusion: Results of one study show that the presence of a paved right shoulder reduces accident rates at exit gore areas.

Stopping Sight Distance

Available studies indicate sight distance to be a critical factor at exit gore areas, and that sight distances greater than that required for normal safe stopping sight distance are warranted. Data contained in these reports suggest a minimum safe stopping sight distance of 1,000 feet and a continuous reduction in accident rates as the stopping sight distance increases to 2,600 feet.

- An AASHO publication entitled Highway Design and Operational Practices Related to Highway Safety specifies that ramps should be located only where visibility is not restricted and that ramps, etc. should be located at points with maximum sight distance.

- Mullins and Keese (1961) report high accident rates at exit areas with poor visibility and high angles of divergence.

Table 10. Summary of before-and-after erratic maneuver (EM) rates.

Site No.	EM Rate (%)		Significant Change; Level of Confidence (%)
	Before	After	
1	1.17	0.86	95
2 left ramp	0.28	0.19	80
right ramp	0.51	0.39	80
3 left ramp	5.15	1.73	95
right ramp	2.39	2.36	50
4	0.60	0.33	95
5	0.20	0.08	95
6	0.30	0.26	60
7	0.80	1.50	95
8	0.39	0.21	95

Source: Taylor, J.I., McGee, H.W., Seguin, E.L., and Hostetter, R.S., "Roadway Delineation Systems", NCHRP Report 130, 1973.

- In a study of the effect of increased stopping sight distance on accidents at deceleration lanes Cirrillo, et al. (1969) shows annual accidents reduced by 0.0008 per 1,000 vpd for each additional 100 feet of stopping sight distance up to 2,600 feet.

- Taylor and McGee (1973) report that California specifies a minimum stopping sight distance of 1,000 feet to an exit on a freeway. They consider visibility of exit gores to be a critical parameter and recommended sight distances of at least 1,000 feet, and up to 2,000 feet at complex interchanges.

Conclusion: It is generally agreed that increased sight distance improves safety at exit gore areas. Further, one study reports accidents reduced by 0.0008 per 1,000 vpd for each additional 100 feet of stopping sight distance up to 2,600 feet.

Length of Speed Change Lane

Studies of the effect of length of speed change lane on accident experience are inconsistent. However, one study which considered the percent merging or diverging traffic in the analysis reports accident rates decreasing for all increases in deceleration lane length when the percent diverging traffic is equal to or greater than 8 percent.

- Lundy (1967) reports accident rates steadily increasing as the length of the deceleration lane increases up to 900 feet; then decreases sharply at lengths greater than 900 feet. Accident rates (approximate) as a function of deceleration lane lengths are shown in Table 11.

- Cirillo, et al., (1969) report ramp accidents decreasing as the length of the adjoining speed change lane increases. The reduction in ramp accidents attributable to an increase in ramp length is shown in Table 12.

- A later study by Cirillo (1970) of the relationship between length of speed change lane, percent merging or diverging traffic and accident rates shows accident rates increasing as the percent of diverging traffic increases; and, at greater than 8 percent diverging traffic, accident rates steadily decreasing as the length of the deceleration lane increases. These data are shown in Figure 11.

Table 11. Accident rates as a function of deceleration length.

Deceleration Length	Approx. Accident Rate (Acc./MC)
0 - 300 feet	0.9
300 - 600 feet	1.0
600 - 900 feet	1.1
900 feet	0.6

Source: Lundy, R.A., "The Effect of Ramp Type and Geometry on Accidents," Highway Research Record No. 163, 1967.

Table 12. Change in annual accidents as a function of increased lengths of speed-change lane.

Ramp Type	Change in annual accidents per 1000 vpd for a 100 ft. increase in the length of the adjoining speed-change lane
Direct and Semi-direct Connection	-0.058
Loop	-0.031
Ramp of Diamond	-0.018

Source: Cirillo, J.A., Dietz, S.K., and Beatty, R.L., "Analysis and Modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System," Bureau of Public Roads, August, 1969.

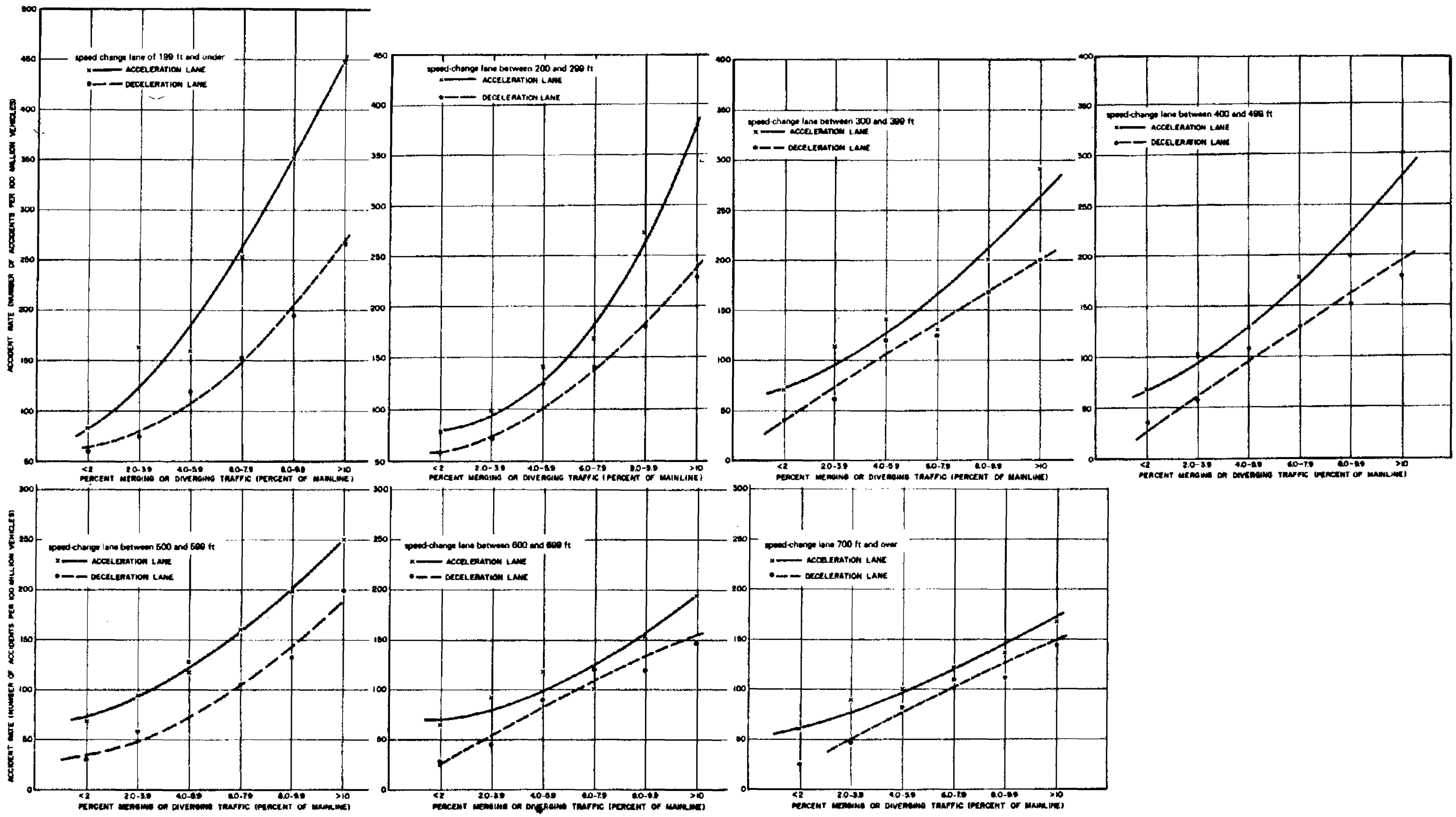

Figure 11. Accident rates by percentage of merging or diverging traffic and length of speed-change lanes.

Source: Cirillo, J.A., "The Relationship of Accidents to Length of Speed-Change Lanes and Weaving Areas on Interstate Highways," HRB Record No. 312, 1970.

Conclusion: Accident rates decrease with increasing deceleration lane lengths where the percent diverging traffic is equal to or greater than 8 percent.

Narrow Bridges

Bridge Width and Roadway Width

Studies of the effect of bridge width and roadway width on accident experience indicate that accident rates are significantly higher whenever the roadway width is greater than the bridge width. Further, one study reports that accident rates are lowest when the bridge is 7.1 to 9.0 feet wider than the approach pavement. This study also showed bridges less than 20 feet wide to have appreciably higher accident rates than wider bridges. Absolute bridge width and relative bridge width is also reported to have a significant effect on vehicle lateral placement.

- Raff (1953) investigated the effect of differences in approach width vs. bridge width on accident rates. As shown in Table 13 structures narrower than the approach pavements by more than 1 foot experienced significantly higher accident rates. These data also show the minimum accident rate occurring when the structure is wider than the roadway by 7.1 to 9.0 feet. This study also shows that, for bridges having the same relative roadway width, the actual width of the bridge also has an effect on accidents with bridges less than 20 feet wide having appreciably higher accident rates than wider bridges.

- Jorgensen (1966) analyzed data from two previous studies (Gunnerson 1961, and Williams and Fritts, 1955) in developing families of curves to forecast accident reduction through widening bridges. These curves are shown in Figure 12. Both studies reported accident rates decreasing when both the bridge and roadway were widened. However, when only the roadway was widened, the accident rate tended to increase. Figure 13 shows the relationship between accident rates and relative bridge width developed from these studies.

- Ivey, et al., (1979) reported relative bridge width and absolute bridge width to have a significant effect on vehicle lateral placement. The study shows that when the approaching roadway is 35 to 40 feet wide and the bridge width is equal to or greater than the approach width the lateral position of a vehicle is the same on the approach pavement as it is on the bridge. The assumption here is that accident potential is reduced when vehicles do not change their lateral position when crossing a bridge.

Conclusion: Accident rates are significantly higher whenever the bridge width is less than the approaching pavement width. Further, bridges less than 20 feet wide have higher accident rates than wider bridges regardless of the approach width. Although the relationship between relative bridge

Table 13. Accident rates at structures (on two-lane roads with approach pavements less than 30 feet wide) by relative width of structure roadway and adjoining pavement.

Relative Width	Bridges and overpasses		Underpasses	
Feet	Number	Per ten mil. vehicles	Number	Per ten mil. vehicles
Type 1 accident rates (All States, using adjustment factors)				
Structure narrower by more than 1 ft.	21	8.2	0	-
Structure from 1 ft. narrower to 1 ft. wider	56	5.8	2	2.9
Structure wider by:				
1.1 - 3.0	81	7.7	6	6.4
3.1 - 5.0	87	5.2	2	7.5
5.1 - 7.0	17	2.3	5	5.6
7.1 - 9.0	4	0.2	0	0.0
9.1 - 13.0	14	1.0	9	6.0
13.1 - 18.0	4	0.4	0	0.0
18.1 or more	10	1.6	3	2.5
Type 2 accident rates (Selected States, without adjustment)				
Structure narrower by more than 1 ft.	35	6.0	0	-
Structure from 1 ft. narrower to 1 ft. wider	28	4.7	2	3.3
Structure wider by:				
1.1 - 3.0	70	4.5	8	6.0
3.1 - 5.0	61	4.1	1	10.0
5.1 - 7.0	30	1.3	2	2.5
7.1 - 9.0	4	0.3	0	0.0
9.1 - 13.0	7	0.5	7	5.0
13.1 - 18.0	4	0.5	0	-
18.1 or more	30	1.5	2	1.4
Type 3 accident rates (All States, without adjustment)				
Structure narrower by more than 1 ft.	21	3.7	0	-
Structure from 1 ft. narrower to 1 ft. wider	56	3.6	2	2.8
Structure wider by:				
1.1 - 3.0	81	4.0	6	5.5
3.1 - 5.0	87	3.1	2	5.0
5.1 - 7.0	17	1.3	5	3.1
7.1 - 9.0	4	0.2	0	0.0
9.1 - 12.0	14	0.6	9	4.5
12.1 - 18.0	4	0.4	0	0.0
18.1 or more	10	1.1	3	1.9

Source: Raff, M.S., "Interstate Highway - Accident Study", HRB Bulletin No. 74, 1953.

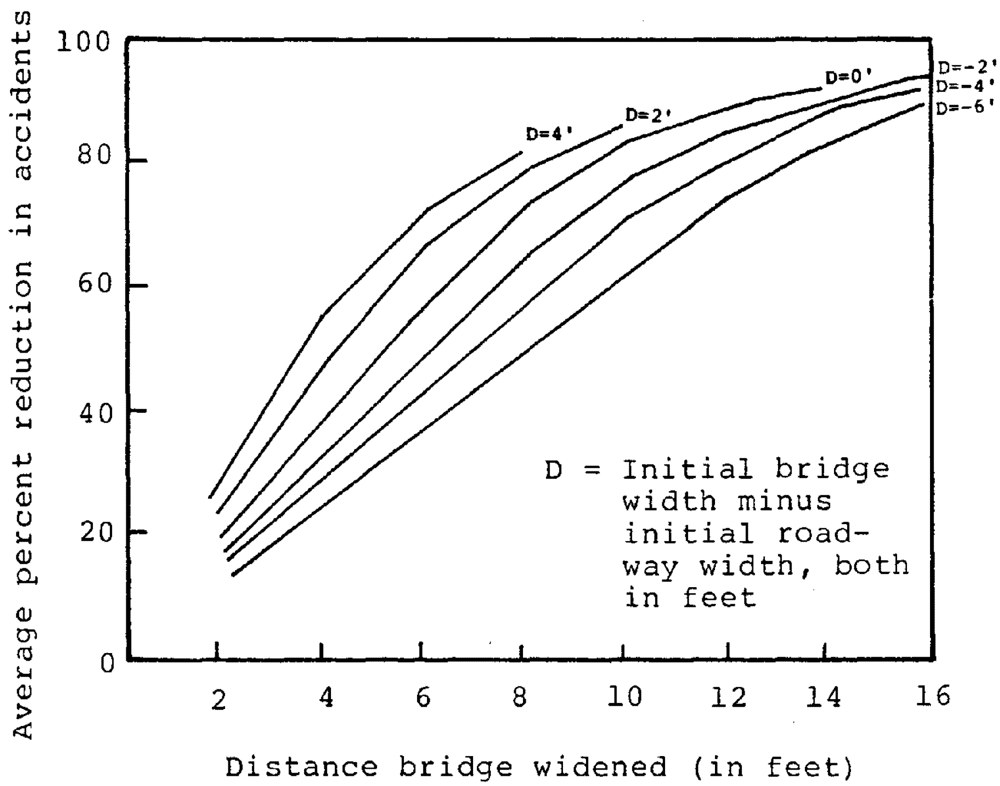

Figure 12. Forecast chart of accident reduction through widening bridges.

Source: Jorgensen, Roy & Associates, Inc., and Westat Research, Inc., "Evaluation of Criteria for Safety Improvements on the Highway", report to the Bureau of Public Roads, 1966.

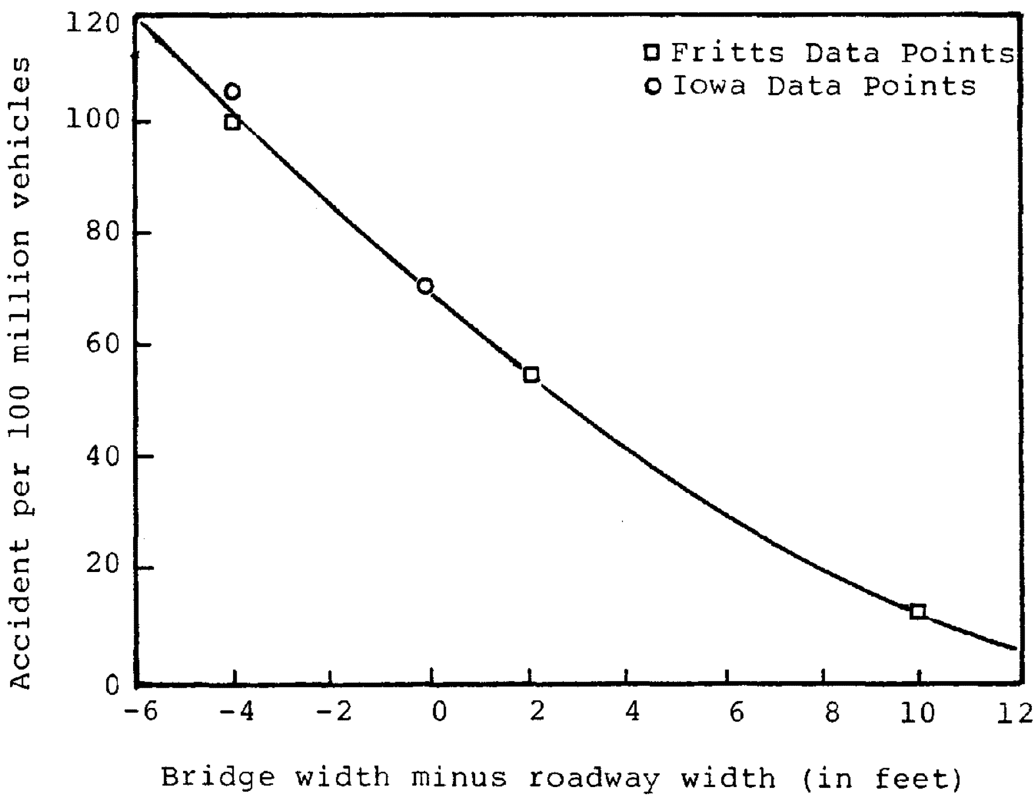

Figure 13. Accident experience at various bridge-roadway relative widths.

Source: Jergensen, Roy & Associates, Inc., and Westat Research, Inc., "Evaluation of Criteria for Safety Improvements on the Highway", Report to the Bureau of Public Roads, 1966.

width and lateral placement has intuitive appeal, no relationship between accident experience and lateral placement has been established.

Effect of Opposing Traffic

Only two studies were found which investigated the effects of opposing traffic on driver behavior. These studies report that, in the presence of oncoming traffic, drivers tend to reduce speed by 1 to 2 miles per hour and move to the right approximately 1 foot.

- Kozoil and Mengert (1978) observed speed reductions of 1 to 2 miles per hour and lateral shifts of up to 1 foot with the presence of oncoming traffic.
- Ivey, et al., (1979) reported a similar lateral movement under opposed traffic conditions. Results show a 1.2 foot lateral shift 1200 feet in advance of a bridge and 1.1 foot lateral shift at the bridge when vehicles face oncoming traffic.

Conclusion: Although data indicate a slight reduction in speed and a lateral shift to the right under opposed traffic conditions, no relationship between these driver behavior changes and accident experience has been established.

Sight Distance

Only one study was found which attempted to establish a relationship between sight distance and accident experience at bridge sites. The study by Behnam and Laguros (1975) reported sight distance in combination with traffic volume measures and bridge approach width to be related to nighttime accidents at two-lane bridge approaches.

Conclusion: The specific relationship between sight distance and nighttime accidents cannot be determined from this study.

Bridge Safety Index (BSI)

Recognizing that the narrow bridge problem is related to several factors in addition to the narrowness of the bridge, Ivey, et al., (1979) developed a Bridge Safety Index (BSI) to assess accident potential at bridge sites. The formula incorporates 10 non-accident factors which were selected based on a limited amount of data from 25 study sites plus the experience and judgment of the research staff. Factors included in the BSI and their proposed weights are shown in Table 14. Factor definitions,

Table 14. Factors used to determine simplified bridge safety index.

	BRIDGE EVALUATION FACTOR	FACTOR RATING FOR F_1, F_2, and F_3				
		0	5	10	15	20
1	Clear Bridge width (ft)	(See Figure 1)				
2	Bridge lane width (ft) / Approach lane width (ft)	$\leq$0.8	0.9	1.0	1.1	$\geq$1.2
3	Guardrail and Bridge rail structure	Critical	Poor	Average	Fair	Excellent
		FACTOR RATING FOR F_4 - F_{10}				
		1	2	3	4	5
4	Approach sight distance (ft) / 85% approach speed (mph)	$\leq$5	7	9	11	$\geq$14
5	100 + Tangent distance to curve (ft) / Curvature (degree)	$\leq$10	60	100	200	$\leq$300
6	Grade continuity (%)*	10	8	6	4	$\leq$2
7	Shoulder reduction (%)	100	75	50	25	None
8	Volume/Capacity	0.50	0.40	0.30	0.10	0.05
9	Traffic Mix	Wide discontinuities	Non-uniform	Normal	Fairly uniform	Uniform
10	Distractions and roadside activities	Continuous	Heavy	Moderate	Few	None

* Average grade + (Approach grade - exit grade).

Source: Ivey, D.L., et al., NCHRP Report 203, TRB Board, June, 1979.

including necessary figures, are included in Table 15. The general form of the Bridge Safety Index is:

$$BSI = F_1 + F_2 + \ldots + F_{10}$$

To account for the effect of speed on accident potential, BSI values are multiplied by the ratio of the appropriate speed to the 85th percentile speed at a given site.

Conclusion: The analysis of BSI is not accident-based and thus cannot be considered as an acceptable accident surrogate. However, factors included in this formula may warrant further investigation.

Table 15. Factor definitions.

F_1 -- Implicit in this work is the premise that the major problems are associated with two-lane, two-way bridges. F_1 is determined by entering Figure 15 with the clear bridge width. The clear bridge width includes shoulders if they are carried across the structure. In the case of a two-lane bridge without shoulders, the factor F_1 is obtained using twice the lane width from Figure 14

F_2 -- The ratio of bridge width to approach roadway width is a measure of the relative constriction of lateral movement as a vehicle travels from the approach lane onto the bridge. The upper value of 0.8 is derived from a reduction of a 12-ft wide approach lane to a 10-ft wide bridge lane (24-ft approach roadway to a 20-ft wide bridge). This represents a 16 percent width reduction. The 1.2 value is produced by a 20 percent increase in bridge lane width, representing a 10-ft approach lane to a 12-ft bridge lane (20-ft wide approach roadway to a 24-ft wide bridge).

F_3 -- The approach guardrail and bridge rail structural factor attempts to define the safety aspects of the rail and the contribution to bridge perspective that the approach rail offers to an oncoming driver. Desirable guardrail or bridge rail features are well documented in *NCHRP Report No. 86* Accepted safety treatments to approach guardrails (such as turned down, flared, or otherwise anchored end terminals; adequate structural anchorage at the bridge maintaining beam strength across the connection; continuation of approach rail onto or across the bridge, etc.) contribute to selection of a high value of F_3. Bridge rails exhibiting high probabilities of snagging, poor redirection characteristics, or vaulting (such as can be expected with use of step curbs in front of the rail) are considered to be unsafe and consequently the F_3 values are given a low rating.

F_4 -- The ratio of approach sight distance to approach speed indicates the time in which a driver may prepare for the bridge crossing. Using an assumed 10-second preparation time, the values of F_4 are computed for 60 mph and 30 mph as boundary conditions and are arbitrarily apportioned for intermediate values.

F_5 -- A driver exiting from a horizontal curve in advance of a bridge needs recovery time to position his vehicle for the bridge crossing. The need for recovery distance is apparent from research indicating large lateral movements at the ends of horizontal curves. The factor shown in the numerator (a constant plus the tangent distance from the bridge to the curve) to the curvature is proposed to be indicative of the hazard. In using a denominator of degree of curvature, it is recognized that the problem becomes more critical as the degree of curvature increases (other factors such as speed remaining constant).

F_6 -- Vertical alignment is treated independently in factor F_6. Vertical curvature in advance of the bridge creates additional perspective problems to an approaching driver. The grade continuity factor, F_6, denotes average grade throughout the bridge zone, (G_A), and the algebraic difference in approach and departing grades.

F_7 -- This factor is defined as the percentage that the shoulder width on the approach roadway is reduced as it is carried across the bridge. For example; if the full shoulder width is continued across the bridge, the reduction is zero; if an approach shoulder of 6 ft is decreased to 3 ft across the bridge, the factor is a 50 percent reduction. On an approach roadway with unpaved shoulders, the reduction would be zero.

F_8 -- The ratio of volume to capacity is an indirect way of accounting for the number of conflicts on the bridge. The most critical case is taken to be 0.5, since higher traffic volumes should result in progressively slower speeds. Thus, dense traffic should reduce the severity of collisions.

Table 15. Factor definitions. (Continued)

F_9 -- A bridge that is barely wide enough to permit opposing passenger cars to meet may be too narrow to permit two trucks to meet as they cross the structure simultaneously. If the traffic composition includes relatively high percentages of large truck traffic (> 10%), narrow bridges can become critically narrow. Similarly, slow-moving large vehicles such as farm machinery, logging trucks, or other atypical vehicles produce adverse effects on the traffic flow, particularly where pavement constrictions occur. Contributions of traffic composition to the bridge crossing problem are represented by F_9, a scalar quantification. The value of 5 would represent a low percentage of commercial vehicles (1 to 3 percent), whereas greater than 10 percent would yield a rating of 1. If a rating of 3 were selected after determining that there were 6 percent commercial vehicles, the rating might be decreased to 2 based on the knowledge that mobile farm machinery was common on the road.

F_{10} -- The distractions and roadside activities factor is the least objective of all factors proposed. Such things as distracting lights, advertisements, the presence of bars, or excessive roadside parking could result in ratings as low as 1. An occasional vehicle along the road or access from a farm road could be given a rating of 4. The goal should be consistency in the evaluation of a number of bridges within a geographical area. National consistency is not necessary.

Source: Ivey, D.L., Olson, R.M., Walton, N.E., Weaver, G.D., and Furr, L. Whitehurst, NCHRP Report 203, Transportation Research Board, June, 1979.

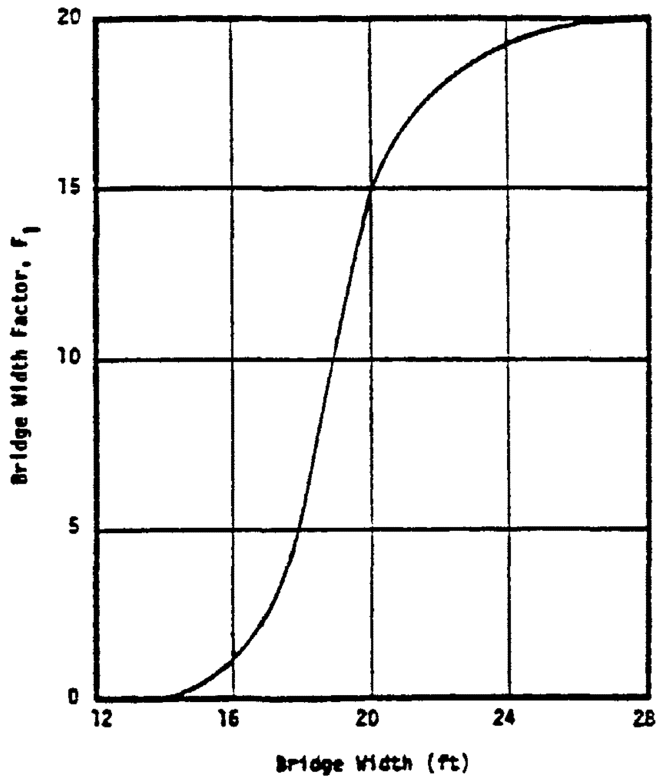

Figure 14. Weighting of bridge width factor.

Source: Ivey, D.L., et al., NCHRP Report 203, TRB Board, June, 1979.

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Arizona Highway Department, "Delineation vs. Edge-Stripe, Cost and Effect," June, 1963.

The purpose of this study was to determine the cost and effect of edgelining rural two-lane highways versus steelpost delineators.

Results indicate that neither edgelining nor post mounted delineators had any significant effect on accident occurrence.

Basile, A.J., "Effect of Pavement Edge Markings on Traffic Accidents in Kansas", Highway Research Board Bulletin 308, 1962.

A one-year before and after study of pavement edge markings on 384 miles of rural highway was undertaken to determine its effectiveness or its economic justification.

Twenty-nine pairs of study sections were used in the study. All sections were of bituminous pavement, 20 to 26 feet wider with turf shoulders 1 to 6 feet wide. One-half (192 miles) were selected for the placement of edgelines with the remainder to serve as control sections. The pairs were located adjacent to each other to provide similar traffic and roadway conditions.

Significant conclusions reached are:

1. On two-lane rural highways the use of edge markings resulted in a reduction in the number of fatalities.

2. There was no significant difference in the number of persons injured or in the total number of accidents.

3. Accidents at intersections and driveways were significantly reduced during both daytime and nighttime conditions. Accidents between access points were not significantly changed.

4. The turning collisions associated with access points were reduced during daytime conditions.

Behnam, J., and Laguros, J.G., "Accidents and Roadway Geometrics at Bridge Approaches," Public Works, April, 1973.

The purpose of this study was to develop relationships between accident frequency and geometric elements of a roadway at the vicinity of bridge locations.

Accident, roadway, and traffic data furnished by the Oklahoma Department of Highways was used in developing several accident prediction models for two- and four-lane rural highways. The multivariate regression analysis was employed in developing the models.

Results indicated ADT, sight distance available at night, degree of curve, length of bridge, and grade to be the most significant variables.

Billion, C.E., and Stohner, W.R., "A Detailed Study of Accidents as Related to Highway Shoulders in New York State", Proceedings, 36th Annual Meeting of HRB, 1957.

The primary objective of this study was to determine the relationship between fatal and serious injury accidents and the width of highway shoulders.

Data from 1,753 state accident reports covering a period from October, 1947 through July, 1955 were utilized in the analysis. Only accidents which occurred on two-lane rural highways with 16 to 24 feet wide pavements, with no speed restrictions, no intersections, and no structures present were used. Other data included in the study were pavement type and width, shoulder width, and horizontal and vertical alignment.

Results showed medium width shoulders (5 to 7 feet) to have lower accident indices than narrow shoulders (3 to 4 feet) under all conditions of horizontal and vertical alignment. Wide shoulders (8 feet and over) had lower accident indices than narrow or medium width shoulders on poor alignment. However, no such relation existed for either level grades or for grades over 5 percent. Accident index was defined as the ratio of the percentage of the total numbers of accidents to the percentage of total travel in any category of shoulder width and alignment.

Further results showed alignment to have more effect on accident experience than shoulder width. Regardless of shoulder width, the accident indices showed grades over 5 percent, curves over 5 degrees, and combinations of grades and curves had 2.4, 6.3, and 9.5 times, respectively, the accident frequency of level tangents. Poor alignment, grades and/or curves over 5 percent and 5 degrees, respectively, which comprised 13 percent of the travel, accounted for 40 percent of the accidents.

Bitzel, F., "Accident Rates on German Expressways in Relation to Traffic Volumes and Geometric Design", Roads and Road Construction, Vol. 35, January, 1957.

This study investigated the effect of grade in combination with horizontal curvature on accident rates on German Expressways.

Results indicated accident rates for equivalent gradient intervals to be two to three times higher on curves with radii of 400 to 1,000 meters as on curves of 4,000 meters radius.

Box, Paul C., "Intersections," Chapter 4, Traffic Control and Roadway Elements, Highway Users Federation for Safety and Mobility, Washington, D.C., 1970.

This report provides a summary of several studies conducted to examine the effects of intersection design and traffic control devices on accidents in rural and urban areas. Studies included show accident experience at urban intersections to be related to the type of intersection control and the distribution of traffic on the major and minor approaches.

One study of accident experience on 400 two-way stop controlled intersections in Los Angeles County reported accident rates increasing as the minor street volume increased, and accident rates decreasing as the major street volume increased when volumes ranged up to 4,000 ADT on the minor street and up to 32,000 ADT on the major street. Only right-angle, left-turn and rear-end type accidents were included in the analysis.

A study of the effects of traffic volume and type of intersection control on accidents in four cities revealed that at yield controlled intersections accidents were related to the ratio of cross street volume to the yield controlled approach volume. At two-way stop controlled intersections accidents were related to the ADT on the controlled approach and the ratio of cross street to controlled approach volume. At four-way stop controlled intersections accidents were related to the ADT on the cross street and the ratio of the major and minor approach volumes.

Cirillo, J.A., "The Relationship of Accidents to Length of Speed-Change Lanes and Weaving Areas on Interstate Highways", Highway Research Record No. 312, 1970.

The objective of this study was to determine the relationship between the geometrics of the Interstate Highway System and accident experience.

The analysis conducted was based on data collected for the Interstate System Accident Research, Study II, initiated in 1961, and investigated the relationship between accidents and length of weaving areas, acceleration lanes, and deceleration lanes.

Results indicate that increasing the length of weaving areas will reduce accident rates and that increasing the length of acceleration lanes will reduce accident rates if the percentage of merging vehicles is greater than 6 percent of the mainline volume. Increased length of deceleration lanes will also reduce accident rates, but to a lesser degree than the comparable increase in length of acceleration lanes.

Cirillo, J.A., Dietz, S.K., and Beatty, R.L., "Analysis and Modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System," Bureau of Public Roads, August, 1969.

This study was conducted by the Bureau of Public Roads in conjunction with 24 State Highway Departments. The study purpose was to investigate the effects of Interstate geometrics on the accident experience of the Interstate system.

The principal findings were:

1. An increase in traffic volume results in an increase in accidents and that geometrics alone account for only a small portion of the variance in accidents. This indicates that extensive Interstate geometric standards changes will not appreciably alter the accident experience of the system.

2. No relationships were established between fatalities and the geometrics studied.

The findings concerning geometrics were:

1. The Full Cloverleaf configuration was found to be the safest of the full interchanges. The Half Diamond was found to be the safest partial interchange.

2. On sections between interchanges there is evidence that delineators, paved right shoulders, bituminous paving, and

increased minimum stopping sight distances reduces accidents.

3. On interchange units these results were found:

   a. Paved right shoulders, increased minimum stopping sight distance and the presence of delineators reduce accidents.

   b. A bituminous surface reduces accidents in three of the four interchange study units investigated.

   c. Wider left shoulders were found to increase accidents in six study units and reduce accidents in two study units.

   d. Variables which showed mixed effects were: design speed, median width, curvature, gradient, lighting, pavement markings, difference between exit and entrance ramps and the number of informational signs.

   e. Variables which were not significant accident predictors included minimum daytime speed limit, design speed and number of lanes.

Cleveland, Donald E., "Illumination," Chapter 3, Traffic Control and Roadway Elements, Highway Users Federation for Safety and Mobility, Washington, D.C., 1969.

This document reports on the findings of several studies of the effect of increased illumination on accidents. Although these studies show an improvement in accident experience following the installation of improved street lighting, the specific relationship between levels of illumination and accidents cannot be determined.

Analysis of the study results show accident rates decreasing following installation of street lighting, particularly on those streets with high night-to-day accident ratios, lower design standards and intersections. Further, installation of street lighting has been shown to reduce night pedestrian fatalities.

Cleveland, Donald E., "Speed and Speed Control," Chapter 6, Traffic Control and Roadway Elements, Highway Users Federation for Safety and Mobility, Washington, D.C., 1970.

The purpose of this document was to synthesize the state-of-the-art concerning the effects of speed and speed control on accidents. Studies of rural highway sections show accident rates to be the highest at very low speeds, lowest at about the average speed, and increasing again at the highest speeds, forming a U-shaped distributions. Further, a change in speed distribution from non-normal to normal can reduce accidents by as much as one-half.

Study results also show that as speeds increase from 30 to 80 mph the percent of head-on and angle accidents increase linearly from approximately 10 to 20 percent and 10 to 17 percent, respectively; the percent of single vehicle accidents increases exponentially from approximately 10 to 45 percent; and, the percent of rear-end accidents decreases linearly from approximately 54 to 23 percent.

Coburn, T.M., "The Relation Between Accidents and Layout on Rural Roads", International Road Safety and Traffic Review, Autumn, 1962.

The primary objective of this study was to determine the effect of horizontal curvature on accident rates on rural roads in Great Britain.

Results indicate a tendency for accidents to increase as the degree of curve increases. For two- and three-lane highway accidents per million vehicle miles increased from 2.5 for tangents and curved sections with radii greater than 2,900 feet to 3.8 for curved sections with radii from 950 to 550 feet. Curved sections with radii less than 550 feet showed an average accident rate of 14.2 injury accidents per million vehicle miles.

The study also showed that, as the frequency of curves increased, accident rates decreased and was lower than for tangents and roadway sections that had infrequent curves.

Cope, J.A., "Traffic Accident Experience Before and After Pavement Widening", Traffic Engineering, December, 1955.

A before and after study of the widening of 244.3 miles of two-lane rural highways in Illinois (generally from 9- to 12-ft. lanes) showed significant decreases in the accident rate, particularly on sections with high accident rates.

A relationship between the percent of improvement in the accident rate, the traffic volume, and the before accident rate was established. The relationship shows that as the before accident rate increased from less than 1.5 to 2.5 and up, the after accident rate improved by 21.5% to 46.6% respectively.

Dart, Jr., O.K., and Mann, Jr., L., "Relationship of Rural Highway Geometry to Accident Rates in Louisiana", Highway Research Record No. 312, 1970.

The primary objective of this study was to determine those geometric variables which contribute most to traffic accidents.

The study involved approximately 1,000 miles of rural highways and included accident data covering a 5-year period from 1962 to 1966. Non-accident variables investigated were percentage of trucks, traffic volume ratio, lane width, shoulder width, pavement cross slope, horizontal alignment, vertical alignment, percentage of continuous obstructions, marginal obstructions per mile, and traffic access points per mile.

Results of regression analysis showed these variables to explain approximately 46 percent of all accident investigated. Based on their interaction with traffic volume, the two geometric variables having the most important effect on accidents were pavement cross slope and traffic conflict points (the total number of traffic access points on both sides per mile of highway section).

David, N.A., and Norman, J.R., "Motor Vehicle Accidents in Relation to Traffic Features of Highway Intersections", Report No. FHWA-RD-76-129, July, 1975.

The primary objective of this study was to determine the relationship between geometric intersection features and accidents. Accident data were collected at 558 urban and rural intersections in California covering a three year period.

Major findings include relationships between intersection accidents and traffic volume, turn lanes, sight obstructions and alignment, signalization, and delineation.

Dunlap, D.F., Fancher, P.S., Scott, R.E., MacAdam, C.C., and Segel L., "Influence of Combined Highway Grade and Horizontal Alignment on Skidding", NCHRP Report 184, Transportation Research Board, 1978.

The principal objective of this research was to develop tentative guidelines for highway geometrics and pavement surface characteristics to ensure adequate vehicle control during maneuvers on highway sections with combined vertical and horizontal alignment.

Accident data files from the Ohio and Pennsylvania Turnpike were used in obtaining a relationship between horizontal and vertical alignment and accident experience. Analysis of these data showed no evidence of effects that could be attributed to grades and curves in combination. The Pennsylvania Turnpike was not dependent on grade, but did increase with increasing curvature. The Ohio Turnpike showed no significant accident dependence on either grade or curvature, except that a specific 1 degree of curve on a 3 percent downgrade had a very high accident rate.

The Highway-Vehicle-Object Simulation Model/(HVOSM) was applied to determine those roadway and vehicle factors leading to loss of control and the onset of skidding on sections of highway with combined vertical and horizontal alignment. The maximum safe velocities, subject to operating conditions, for equilibrium covering, lane changes, and lane changing combined with braking were evaluated.

Failmezger, R.W., "Narrow Freeway Lanes for Increased Capacity", Traffic Engineering, June, 1975.

A one-year before and after study of merging two lanes of traffic from each of two interstate highways into three lanes of through traffic, as opposed to two through lanes in the before period, showed a marked decrease in accidents. The after condition involved restriping the bridge deck to provide the three through lanes in the 32 feet available width (outside lanes were 11.25 feet and the center lane was 9.5 feet).

Analysis of accident data showed total accidents decreasing from 70 in the before period to 16 in the after period. Before and after accident rates were 4.69 acc./MVM and 1.30 acc./MVM respectively. The report also concluded that both congestion and lack of discharge capacity were eliminated by the improvement.

Glauz, W.D., and Migletz, D.J., "Application of Traffic Conflict Analysis at Intersections", NCHRP Report 219, Transportation Research Board, 1980.

The objective of this research was to develop a standardized set of operational definitions and procedures that would provide a cost-effective method for measuring traffic conflicts.

Over 9 weeks of field data were collected using 17 trained traffic conflict observers. Data were obtained at more than 24 intersections having a variety of geometric and traffic control configurations.

Analysis of the data led to a recommended set of traffic events that should be observed and recorded, together with procedures for analyzing these data. Conclusions reached pertain to the applicability of the traffic conflicts technique in highway safety analysis.

Glennon, J.C., and Tamburri, T.N., "Objective Criteria for Guardrail Installation," Highway Research Record No. 174, 1967.

Reports of all 1963 and 1964 single vehicle embankment guardrail accidents were used in determining guardrail need for embankment conditions. Non-accident data included height of embankment, slope of embankment, size of embankment material, and slope of the original ground at toe of embankment.

Single vehicle main-line freeway fixed-object accidents for the same time period were used in establishing criteria for guardrail installation adjacent to freeway fixed objects. Objects included in the analysis were bridge rails, abutments (and piers), steel signposts, and lightpoles.

Goodwin, D.M., "Freeway Lane Drops", NCHRP Report 175, Transportation Research Board, 1976.

The primary objectives of this research were determining the effectiveness of existing designs, determining the effectiveness of the significant design parameters, recommending suitable lane drop configurations, and recommending remedial treatments for existing mainline lane drop situations.

Analysis of the design and operational characteristics of 65 lane drop sites resulted in the development of eight principles to serve as guidelines for lane drop design.

Gupta, R.C., and Jain, R., "Effects of Certain Geometric Design Characteristics of Highways on Accident Rates for Two-Lane, Two-Way Roads in Connecticut", University of Connecticut, Connecticut Department of Transportation, August, 1973.

Multiple linear regression techniques were applied to data from two-lane urban and rural state highways in Connecticut to relate

accident rates to various geometric characteristics ratings (adequacy ratings). Conclusions reached in that study are:

1. Restricted sight distance was found to have a significant effect on all rural accidents except total and multiple vehicle types.

2. Horizontal curvature had the highest correlation with accident rate when volumes ranged from 1,500 to 6,900 vehicles per day.

3. Roadway width was not related to accident rates on two-lane urban streets having up to 12,000 ADT.

4. Roadway width on rural highways, when grouped by ADT, had a significant effect on all accident rates, except single vehicle rates at volumes less than 1,400 vehicles per day.

Hanna, J.T., Flynn, T.W., and Tyler, W.L., "Characteristics of Intersection Accident in Rural Municipalities", Transportation Research Record No. 601, 1976.

The primary objectives of this study were to determine those areas in which urban and rural accident patterns and roadway conditions are both similar and different, and determine how the difference may affect traffic engineering decision making for rural areas.

A total of 232 rural intersections were included in the study. The typical rural municipality had an average population of about 15,000. More than 2300 accidents were summarized by intersection for a 24-month period between 1969 and 1973.

The article provides information on:

1. Accident types versus intersection traffic control.

2. Accident types versus intersection geometrics.

3. Signalized intersections.

4. Traffic volumes.

5. Severe grades, poor sight distance, and night versus day.

Conclusions which apply only to rural municipalities are:

1. Intersections with severe grade generally operate safely.

2. Signalized intersections with volumes exceeding the traffic volume warrants are no safer than signalized intersections with volumes below the warrants.

3. Signalized intersections with displays that meet approved standards are no safer than signalized intersections with substandard displays.

Head, J.A., "Predicting Traffic Accidents from Roadway Elements on Urban Extensions of State Highways", Highway Research Board Bulletin No. 208, 1958.

The primary objective of this study was to develop equations to predict accidents on urban extensions of state highways from roadway elements such as ADT, commercial and residential units and driveways, intersections, signalized intersections, indicated speed, pavement width, and the number of lanes.

The study utilized data from 426 sections with a total length of 186.4 miles. Data were analyzed by subgrouping the sections by number of traffic lanes and ADT groupings. Within these groups additional subgroups of urban extensions were studied for suburban, corporate, business, residential and mixed culture sections. The analysis used multiple correlation techniques with the end result of the analysis being a series of equations which indicate the relationships of the various roadway elements to accident rates on urban and subgroups of urban extensions of the highways in Oregon.

Major conclusions reached are:

1. Motor vehicle accident rates are related to certain physical features of urban extensions of the highway system. This relationship is strong enough in the higher ADT ranges to make it possible to predict accident rates with reasonable accuracy.

2. Accident rates on low volume roads do not have a strong relationship with any roadway feature.

3. Motor vehicle accident rates increase when:

   a. The number of commercial units adjacent to the section increases.
   b. The number of traffic signals increases.

c. The number of intersections increases.
d. The indicated speed decreases.
e. The average daily traffic increases.
f. The pavement width increases.

Holbrook, L.F., "Prediction of Wet Surface Intersection Accidents from Weather and Skid Data", Transportation Research Record No. 623, 1976.

This study utilized nearly 40,000 accidents occurring at over 2,000 intersections for which a skid coefficient value was available.

A major component of this study was the development of an estimate of wet time which would reflect both seasonal and geographic considerations. This variable was developed under the assumption that precipitation in inches, as commonly reported by weather stations, is not a suitable substitute for actual wet time.

Conclusions to this study indicate that both estimated surface wet time and skid number are important variables in the determination of wet accident involvement. However, no critical skid number emerged as a point above which wet accident hazard disappeared. Instead, wet accidents appear to be a continuously decreasing function of surface friction. With a skid number of 30 or less wet accident incidence increases at a slightly increasing rate with declining surface friction.

Huelke, D.F., and Gikas, P.W., "Non-Intersectional Automobile Fatalities - A Problem in Roadway Design", Highway Research Record No. 152, 1967.

In depth analysis of 111 accident cases resulting in 146 fatalities was used to identify multiple roadside obstacles or design factors contributing to fatal accidents.

Sixty-seven of these accidents were single vehicle collisions where fatalities occurred due to trees or utility poles, bridge abutments, guardrails or posts, earth embankments, or rollovers due to ditches, slopes or embankments, or losing control on the roadway.

Ivey, D.L., Olson, R.M., Walton, N.E., Weaver, G.D., and Furr, L. Whitehurst, "Safety at Narrow Bridge Sites," NCHRP Report 203, 1979.

The primary objectives of this study were to:

1. Define the narrow bridge problem.
2. Appraise the effectiveness of current corrective measures.
3. Develop guidelines for treatment at narrow bridge sites.

Data on speed and lateral position of vehicles at 25 bridge sites of various geometric characteristics were analyzed to define the narrow bridge problem. Conclusions reached include:

1. Any bridge less than 24 ft. wide should be considered a restricted-width bridge, but not necessarily a hazardous bridge site.

2. Any bridge less than 18 ft. in width should be considered a one-lane bridge.

3. Any bridge with a width of 15 ft. or less should be considered a hazardous site.

Before and after evaluations of corrective measures at 11 bridge sites were used to determine a corrective treatment for restricted width bridges. The bridges were predominantly 24 and 26 ft. wide. The roadway had a 24 ft. paved surface width with 8 ft. paved shoulders. The basis treatment included:

1. A 4-inch edge line from the outside edge of the shoulder, tapering to the roadway pavement edge in advance of the bridge and extending across the bridge.

2. Two-foot wide diagonal shoulder markers.

3. Raised jiggle bars on every fourth diagonal shoulder marker.

4. Raised pavement markers.

5. Approach guardrail.

6. Post mounted delineators.

Analysis of accident data showed that in the 22 months prior to application of corrective measures, 20 accidents involving bridges were reported. During the 17 months following the applications, only 4 reportable accidents occurred.

A major product of the research effort was the development of the bridge safety index (BSI). The BSI utilizes 10 geometric and traffic variables in estimating the relative degree of hazard at bridge sites. No correlations between accidents and BSI values were reported in this study.

Jorgensen, Roy & Associates, Inc., and Westat Research, Inc., "Evaluation of Criteria for Safety Improvements on the Highway", Report to the Bureau of Public Roads, 1966.

The major objectives of this study were recommendations of procedures for the identification of hazardous locations on the highway and street system; development of a system for forecasting accident reduction attainable from various improvement projects; and, outline of a process for making cost-effectiveness analyses of proposed hazard reducing projects.

The study involved a review and analyses of existing procedures and practices in 21 states and 6 cities.

Conclusions and recommendations contained in this report are shown under the following major headings:

1. Identification of hazardous locations.
2. Forecasting accident reduction.
3. Cost-effectiveness methodology.
4. The highway accident records system.

Jorgensen, Roy & Associates, Inc., "Cost and Safety Effectiveness of Highway Design Elements", NCHRP Report 197, Transportation Research Board, 1978.

The objectives of this research were to identify the key geometric characteristics and combinations of characteristics of road and street design that affect accident frequencies and severity; to quantify the effects of varying the key characteristics and combinations of characteristics of accident frequencies and severity; and, to develop a methodology to be used in measuring the cost-effectiveness of the various levels of each design element.

Design elements investigated were pavement width, shoulder width, and shoulder surface type for rural two-lane highways.

No significant difference was found in the accident rate between 22-ft. and 24-ft. pavement widths. There was a measurable difference between the 18-, 20-, and 22-ft. pavements with the wider pavements

having lower accident rates. Wider shoulders and paved shoulders were also found to have lower accident rates.

Kihlberg, J.K., and Tharp, K.J., "Accident Rates as Related to Design Elements of Rural Highways", NCHRP Report No. 47, Highway Research Board, 1968.

The objective of this study was to determine the relationship of motor vehicle accidents to highway types and highway design elements.

Accident, geometric, and traffic data, furnished by 5 states, were analyzed in this study. Geometric and traffic variables included number of lanes, existence of a median, degree of access control, amount of grade, degree of curvature, number of intersections, number of structures, amount of visibility limitation, amount of commercial traffic, and traffic volume.

Results of regression analysis relating specific geometric features to accident rates are:

1. The presence of the geometric elements (curves, grades, intersections, and structures) increased the accident rate on highways. The dominant element was intersections.

2. The presence of combinations of the geometric elements generated higher accident rates than the presence of individual elements.

3. Partitioning of grade and curvature by magnitude did not show any effect due to steepness of grade of sharpness of curve. The only effect occurred when the change was from no grade (less than 4%) to a grade of 4% greater, and from no curvature (less than 4 degrees) to a curve of 4 degrees or greater.

4. There was no evidence that geometric elements affected severity rates.

Kipp, O.L., "Final Report on the Minnesota Roadside Study", Highway Research Board Bulletin No. 55, 1952.

The objective of this study was to determine the relationship or association that exists between accident occurrence and certain roadway characteristics and roadside features.

In essence, this report summarizes the findings of several studies of rural highways in Minnesota. Accident data for 1948 and 1949 were used in the analysis.

Findings reported in this paper relate accident occurrence to:

1. Type of highway (two-, four-lane, divided, etc.)
2. Length of tangent section
3. Length of tangent between curves
4. Pavement width
5. Degree of curve
6. Traffic speed and volume
7. Number of access points per mile
8. Intersection type and volume
9. Frequency of advertising signs
10. Restricted sight distance
11. Roadside development

Koziol, Jr., J.S., and Mengert, P.H., "Evaluation of Dynamic Sign Systems for Narrow Bridges", Final Report, U.S. Department of Transportation, Research and Special Programs Administration, September, 1978.

This report describes the results of a before and after study to evaluate the effectiveness of dynamic sign systems in alerting motorists to the presence of narrow bridges on two-lane rural highways. Vehicle speed and lateral placement data were gathered for each of the 4 dynamic sign systems tested as drivers approached and crossed the narrow bridge. The 4 dynamic sign systems, examined under both day and night conditions, included flashing beacons, strobe lights, and two neon message signs.

Results indicated no substantial and consistent differences between the existing (passive) and dynamic sign systems in terms of the speed lateral placement measures.

Leisch, Jack E. and Associates, "Alignment," Chapter 12, <u>Traffic Control and Roadway Elements</u>, Highway Users Federation for Safety and Mobility, Washington, D.C., 1971.

This report summarizes the findings of several studies concerning the effect of degree of curvature and frequency of curves on accidents, and the effectiveness of traffic control devices to warn motorists of a change in horizontal alignment. Data from several sources in the United States and other countries were used in one study to determine the effect of curvature on accident frequency. Results show that as the degree of curve increases from about 0.5 to 4 degrees the relative number of accidents increases from approximately 0.7 to 1.5. However, as the degree of curve increases from 4 to 11 degrees the relative number of accidents increase from approximately 1.5 to 8.

A study of the effect of curve frequency on accident rates shows accident rates decreasing as the number of horizontal curves increases from 1 to 4 per mile, regardless of the degree of curve. However, when curves are separated by one mile or more accident rates decreased from approximately 3 to 2.5 accidents/MVM on curves less than 3 degrees; increased from approximately 4 to 5 accidents/MVM on curves of 3 to 6 degrees; and increased from approximately 6 to 13 accidents/MVM on curves of 10 degrees or more.

Studies of the effectiveness of traffic control devices to aid motorists in anticipating changes in horizontal alignment show speed advisory signs and post mounted delineators to be effective in reducing accidents. A before and after study of 15 curves in California revealed a 21 percent reduction in single vehicle accidents (95 to 75) after placement of safe speed signs.

A study of 221 curves in California showed delineators mounted along the outside edge of a curve to reduce the accident rate from 1.89 to 1.33 accidents/MVM when the degree of curve was greater than 11 degrees.

Lundy, R.A., "The Effect of Ramp Type and Geometry on Accidents," Highway Research Record No. 163, 1967.

The objective of this study was to determine which geometric features are critical in ramp safety, and to classify these features according to ramp type and relative safety merits.

The study analyzed approximately 3 years of accident data on 722 freeway ramps. Accident data were converted to an accident rate which was defined as the number of ramp accidents per million vehicles using the ramp.

Correlations were found between accident rates and ramp type, relative freeway-to-ramp grades, fixed objects, speed change lane lengths, possible safe entrance speeds at on-ramp noses, and off-ramp radius. No correlation could be found between ramp accident rates and on-ramp curvature, ramp lighting, ramp traffic volumes, and the magnitude of the ramp central angle.

McCullough, B.F. and Hankins, K.D., "Skid Resistance Guidelines for Surface Improvements on Texas Highways", Highway Research Record No. 131, 1966.

The objective of this study was to establish guides for minimum coefficients of friction based on minimum design requirements, available accident information and economics.

Skid resistance and accident data were collected on 517 randomly selected sections of rural highways in Texas. Accident data included total, fatal and injury accidents.

Plots of skid resistance at 20 mph and 50 mph versus accidents per one hundred million vehicle miles for a given test section were used to establish lines of maximum accidents. Results indicate accidents increasing when skid resistance decreases below the values in a range of 0.4 to 0.5 at testing speeds of 20 mph and 0.3 to 0.35 at 50 mph.

McDonald, J.W., "Relation Between Number of Accidents and Traffic Volume at Divided Highway Intersections", Highway Research Board Bulletin No. 74, 1953.

The primary objective of this study was to determine the average relation between traffic volume and number of accidents at expressway intersections.

Traffic volume data were obtained from 150 cross or T-type unsignalized intersections, where volume at intersections was defined as the average daily entering traffic. The volumes varied on the divided highway from 4,300 to 27,200 and on the crossroads from 100 to 3,100.

All reported intersection accidents occurring between January 1, 1946 and January 1, 1951 were cataloged by type and severity. Intersection accidents were defined as those reported accidents, regardless of severity, which occurred at the intersection, or which occurred near the intersection, or which occurred near the intersection and were obviously intersection related.

Volume data were then grouped by similar volume combinations. This resulted in the formation of 24 groups with a range of from 2 to

19 intersections in each group. The arithmetic mean number of accidents per year was then computed for each group. From these data a surface was plotted to express the average volume-accident relation. The three coordinates were divided highway volume in the X direction, crossroad volume in the Y direction, and number of accidents per year in the Z direction. A curve was then fitted to the data points by the method of least squares.

Conclusions reached were:

1. Accident rates at intersections are much more sensitive to changes in crossroad volume than to changes in divided highway volume.

2. No direct relationship exists between intersection accident rates and the sum of the two entering volumes.

3. Low crossroad volume intersections have higher accident rates per crossroad vehicle than do higher crossroad volume intersections.

McGuirk, William W. and Satterly, Jr., Gilber T., "Evaluation of Factors Influencing Driveway Accidents", Transportation Research Record No. 601, 1976.

This paper identified some of the characteristics of driveway accidents and relates driveway accident occurrences to various physical and environmental features of the roadway and traffic characteristics.

Relevant data from 100 sections of urban arterial highway were analyzed. The 4-year accident history for these arterial highway sections, totaling 98.6 km in length, included 1212 driveway accidents.

Conclusions reached are that the driveway accident rate tends to decrease as the spacing between two driveways and the spacing between a driveway and an adjacent intersection increase. Other relationships between driveway accident rates and physical and environmental features of the roadway, and traffic characteristics, are described.

Mulinazzi, T.E., and Michael, H.L., "Correlation of Design Characteristics and Operational Control with Accident Rates on Urban Arterials", Engineering Bulletin of Purdue University: Proceedings 53rd Annual Road School, March, 1967.

This study was conducted to examine the relationships between design and operational controls on urban arterial highways.

Accident, volume, and geometric data were collected for 100 sections of urban arterial roadways (68 of the sections were two-lane) ranging in length from 0.254 miles to 4.167 miles. Accident data were collected for the three year period 1963 through 1965. Traffic volumes on the sections ranged from 1,200 to 32,000 vehicles per day.

Multiple linear regression analysis was used to predict the accident rate (number of accidents per 100 million vehicle miles) and the annual number of accidents per mile. In all, 26 independent variables were included in the analysis. Results indicate the following factors to have a significant effect on accident frequencies on urban roadways:

1. On-street parking
2. Traffic signals per mile
3. High volume intersections per mile
4. ADT
5. Number of heavily used driveways per mile
6. Number of intersections and driveways per mile
7. Quality of signing and pavement markings.

Mullins, G.F.H., and Keese, C.J., "Freeway Traffic Accident Analysis and Safety Study", Highway Research Board Bulletin 291, 1961.

The primary objective of this study was to determine the possible correlation between freeway accidents and specific geometric design features on urban freeways.

The study considered approximately 10,000 accident reports on 54 miles of urban freeway, covering from 2 to 5 years of data. Concentrations of accidents generally were found at major changes in vertical alignment, freeway ramps, freeway interchange elements, and fixed objects.

Although few conclusive relationships were found between accidents and specific design elements, inadequate sight distance and sight relationships (at entrance and exit ramps) appeared to be a factor in all high accident frequency locations. It was further concluded that night visibility and driver condition are significant factors in fixed object accidents.

Musick, J.V., "Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio", Highway Research Board Bulletin No. 266, 1960.

This research was conducted to determine the effect of pavement edge markings on two-lane, 20-feet wide or wider, rural highways in Ohio on accidents.

A controlled before and after study utilized data from 9 pairs of sections. Each pair included a test section (pavement edge marked) and a control section (pavement not edge marked). Test sections and control sections were located as nearly as possible adjacent to each other and were selected so that the geometric design characteristics, culture surrounding each of the sections, and volume and character of traffic were similar in nature.

Accident data for the before period included all reported accidents on the sections for 1956. The after period was the first full 12-month period following application of edge markings. Accident data included type of collision, light condition and pavement condition, number of fatalities, and number of injuries.

Results of statistical analysis show that:

1. The use of pavement edge markings resulted in a significant reduction in fatality and injury-causing accidents.

2. Accidents at intersections, alleys, and driveways were significantly reduced, but accidents between access points showed no significant change.

3. The only type of collision to show a significant change was angle collisions which were associated with access points.

4. There was no significant change in day accidents; night accidents were reduced but the change was marginal.

Perkins, E.T., "Relationship of Accident Rate to Highway Shoulder Width," Highway Research Board Bulletin No. 151, 1957.

Analysis of data from two-lane rural highways in Connecticut was conducted to determine the relationship between accident rate and shoulder width.

Results showed no definite relationship between accident rate and shoulder width (shoulder width varied from 0 to 10 feet, however, the majority of data contained 4 to 9 feet wide shoulders). The same was true of the relationship between accident rate and pavement width.

Pigman, J.G., Agent, K.R., Mayes, J.G., and Zegeer, C.V., "Optimal Highway Safety Improvement Investments by Dynamic Programming," Kentucky Department of Transportation, Division of Research, November, 1974.

The objective of this study was to develop or adopt appropriate dynamic programming methods that would assist in establishing optimal budgeting procedures for various highway programs.

A dynamic programming procedure was developed in this study which selects the optimal combination of safety improvement projects for a given budget. Sixty-one projects, each with one or more alternatives, were evaluated. The input consisted of the designated budget for the safety improvement program, the improvement cost, and the benefit derived from each improvement.

Benefit and cost values were assigned to various improvements based on analysis of data from approximately 300 spot locations improved in Kentucky since 1968. Each improvement was studied to determine the accident reduction (or increase) associated with each at various location types. The study includes benefits (percent total accident reduction) and costs for 38 safety improvements applicable to general highway sections, horizontal curves, and intersections.

Priest, R.V., "Statistical Relationship Between Traffic Volume, Median Width, and Accident Frequency On Divided Highway Grade Intersections," Highway Research News No. 13, June, 1964.

This study analyzed traffic volume and median width data from 316 divided highway grade intersections to determine the relationship between these data and accident frequency.

Accident data were obtained for the period January 1, 1958 through December 31, 1960. In the total of 975 accidents investigated, the number at any one intersection ranged from 1 to 8.

Traffic volumes on the divided highway varied from 2,840 to 25,400 ADT and on the crossroad from less than 100 to 5,270 ADT. The divided highway and crossroad volumes were then coded in steps of 500 to 200 ADT, respectively. Since the code numbers were directly proportional to actual volumes, they were mutliplied together to obtain relative exposure index values.

The method of least squares was then employed to determine the relationship between median width, exposure index and accident frequency. Conclusions reached show that:

1. Accident frequency is more sensitive to crossroad traffic volumes than to divided highway traffic volumes.

2. Accident frequency increases with increases in relative exposure index.

3. Accident frequency is inversely proportional to median width, for constant values of exposure index.

4. There is marked association between exposure index, median width, and accident frequency.

Prisk, C.W., "How Access Control Affects Accident Experience", Public Roads, Vol. 29, No. 11, December, 1957.

Data supplied by 27 state highway departments were used to illustrate the effect of type of access control (full, partial or none) on accident experience in urban, suburban, and rural environments.

The data include a total of 47,000 accidents occurring on 2,093 miles of highway study sections, and were assembled from records for various years, 1949 through 1955. In all cases, the data show both accident frequency and rate increasing as access control changes from full control to no control.

Raff, M.S., "Interstate Highway - Accident Study", Highway Research Board Bulletin No. 74, 1953.

The purpose of this study was to determine how accident rates on main rural highways were affected by design features and use characteristics. Fifteen states provided information covering one year's accident experience on about 5,000 miles of highway.

The basic technique involved dividing the study routes into a large number of short, homogeneous sections, which could then be combined so as to group the sections according to any factors whose effects were of interest. An accident rate, based on vehicle-miles or other suitable units, was computed for each group. Variables studied included distance restrictions, percentage of intersection traffic on the minor road, and many others.

Conclusions reached in this study are:

1. On most types of highway sections the accident rate increased with increasing traffic volume except at extremely high volume sections. However, at two-lane curves and intersections accident rates decreased with increasing volume.

2. Sharp curves had higher accident rates than flat curves for roads carrying the same amount of traffic.

3. Wide pavements and shoulders encourage safety on two-lane curves. However, on two-lane tangents there was no consistent effect.

4. The percentage of total traffic on the crossroad proved to be extremely important at intersections.

5. At bridges and underpasses pavements on the structure several feet wider than the approach pavements were found to be safer.

6. A number of roadway features found to have no consistent effect on accident rates include grades, frequency of curves, and the percentages of commercial and night traffic.

Research Triangle Institute, "Speed and Accidents: Volume I," Final Report, June, 1970.

The major objective of this project was to gather and analyze accident and speed data that would quantitatively define the relationship between speed (primarily speed deviation of accident involved vehicles) and the frequency of occurrence of corresponding motor vehicle accidents.

All state highways and county roads in Monroe County, Indiana, with a speed limit of 40 mph or over - or where the mean speed was 40 or more mph - were included in the study. This involved approximately 70 miles of state roads on which 200 accident investigations were completed during the 13 months of active investigation (December, 1968 through December, 1969).

A major conclusion from this study is that the likelihood of being involved in an accident is increased by a factor of about 10 if one is driving at speeds which deviate considerably (approximately 15 mph) from the mean speed of the traffic. This conclusion is dependent on how finely one can subdivide the range of speed deviation values. The likelihood of involvement varied from about 6 to 21 accidents per million vehicle miles for the high-speed deviations compared to about unity for the low-speed deviations.

Rizenbergs, R.L., Burchett, J.L., and Warren, L.A., "Relation of Accidents and Pavement Friction on Rural, Two-Lane Roads," Transportation Research Record No. 633, 1977.

The primary objective of this study was to discern a relationship between accident experience and pavement friction for principal two-lane rural roads in Kentucky.

Friction measurements were made on 1,460 miles of rural two-lane roads. Traffic volume data (the average of the 1969 and 1971 AADT values) and accident data were also obtained for each test section. All accidents reported during 1969, 1970, and 1971 were analyzed. Accidents for the 3-year period totaled 8,481; of these, 1,844 occurred during wet pavement conditions.

Multiple regression analyses were performed with the ratio of wet-to-dry-pavement accident rates and wet-pavement accident rates as the dependent variables and skid number, AADT, pavement width, and access points per kilometer as the independent variables. Results of the analyses indicate:

1. On rural two-lane roads, ratio of wet- to dry-pavement accidents correlated best with pavement friction.

2. The ratio of wet- to dry-pavement accidents decreased rapidly as the skid number increased to approximately 40; further increases in skid number beyond this point resulted in only a slight reduction in the ratio of wet- to dry-pavement accidents.

3. Stratification of the data into two AADT groups (650 to 2,700 vpd and 2,701 to 8,400 vpd) showed that the critical skid numbers were higher for the low volume roads than for the high volume roads.

Schoppert, D.W., "Predicting Traffic Accidents From Roadway Elements on Rural Two-Lane Highways with Gravel Shoulders," Highway Research Board Bulletin No. 158, 1957.

This study is based on accident, geometric, and traffic volume data from 1,374 miles of two-lane rural highways with gravel shoulders. The accident histories of these sections during the 3-year period from January 1, 1952 to December 31, 1954 were used together with ADT for the year 1953. Geometric variables included lane width, shoulder width, number of commercial driveways, number of residential driveways, number of intersections, and percent of the highway with less than 1,500-ft. sight distance.

Data were analyzed through use of multiple correlation techniques. The first step in the analysis was to group the data by ADT and subdivide the various highway sections according to their location. Thus, seven ADT groups were obtained for sections in western Oregon and two were obtained for sections in eastern Oregon.

The more important conclusions drawn from the findings of this study are as follows:

1. Motor accidents are directly related to vehicle volumes and certain physical features of the highway. This relationship is strong enough in the higher ADT ranges to make possible reasonably accurate predictions of total accidents on the basis of known physical features.

2. Access to the highway through driveways or intersections is directly related to accidents at all ADT levels.

3. Although highway design elements such as lane width, shoulder width, and sight distance restrictions are related to accidents, they do not ordinarily serve as good predictors of the number of accidents.

4. The number of accidents increases with the number of situations presenting a change in conditions, and therefore requiring a decision on the part of the motor vehicle operator.

Shaw, R.B., and Michael, H.L., "Evaluation of Delays and Accidents at Intersections to Warrant Construction Of A Median Lane," Highway Research Record No. 257, 1968.

The objective of this study was to evaluate the conditions under which the construction, maintenance, and interest costs for a median lane would be warranted at suburban and rural approaches to an intersection.

The study involved analysis of delay times and accident rates by through vehicles caused by left-turning vehicles at three right-angle intersections which had median lanes, and at eight right-angle intersections which did not. Delay time incurred by a through vehicle caused by a left-turning vehicle was determined at the eleven study intersections during daylight-weekday hours; 6 a.m. to 6 p.m., Monday through Friday. Accident rates for each intersection approach were calculated from accident data for daylight-weekday hours at the eleven study sites for the period January 1, 1961 through August 31, 1965. The accident analysis was limited to those accidents caused by left-turning vehicles which could have been prevented with the installation of a median lane. Accident types included were:

1. Accidents involving a left-turning vehicle with opposing traffic.

2. Sideswipe overtaking accidents involving a left-turning vehicle.

3. Rear-end accidents that probably resulted from a left-turn movement.

Results of multiple linear regression analysis show substantial reductions in the number of accidents attributed to left-turning vehicles and negligible delay times to through vehicles at intersection approaches which had median lanes. Further, equations were developed to predict delay times and accident rates for the weekday-daylight hours for through traffic at suburban and rural intersections that resulted from left-turning vehicles and the absence of median lanes.

Slatterly, Gilbert T., and Cleveland, Donald E., "Traffic Volume," Chapter 2, Traffic Control and Roadway Elements, Highway Users Federation for Safety and Mobility, Washington, D.C., 1969.

The purpose of this document was to synthesize the current state-of-the-art concerning the effect of traffic volume on accidents. Although study results are not entirely consistent, two studies of 1941 data for 15 states show that for rural two-lane tangent sections, the accident rate increases with increasing volume up to about 8,000 to 9,000 vehicles per day, and then decreases at volume above 9,000. Other studies conclude that there is no volume above which accident rates decrease.

A possible explanation for conflicting results is that studies of the 1941 data utilized unequal segment lengths, which tends to

influence the outcome of the analysis, whereas, the other studies utilized data from equal segment lengths.

The synthesis concludes that accident rates on all types of rural roads increases exponentially with increasing traffic volume.

Stockton, W.R., Mounce, J.M. and Walton, N.E., "Guidelines for the Application of Selected Signs and Markings on Low Volume Rural Roads", A presentation at the 55th Annual Meeting of the Transportation Research Board, January, 1976.

The purpose of this study was to ascertain actual needs for signs and markings as they relate to economy and safety on low volume rural roads (less than 400 ADT). These evaluations were based on recent research and on probability of conflict analysis regarding the needs for signing and marking at intersections, horizontal curves, and sections of inadequate passing sight distance.

The research revealed that more efficient intersection control can be attained from the careful application of STOP signs and cross-road warning signs based on approach speed, sight distance, and combined intersecting volumes.

It was found that the treatment of horizontal curves can be made more efficient through the application of more stringent guidelines without adversely affecting safety.

Striping of "no-passing" zones was found to be very inefficient in most instances, as the probability of conflict in these situations is virtually nil; guidelines for alternative treatments is presented.

Stohner, W.R., "Relation of Highway Accidents to Shoulder Width on Two-Lane Rural Highways in New York State", Proceedings, 35th Annual Meeting of HRB, 1956.

The primary objective of this study was to determine the relation between shoulder width and the number of accidents/MVM of travel. Other variables investigated included pavement width, year of construction or reconstruction, and traffic volume.

Stover, V.G., Adkins, W.G., and Goodknight, J.C., "Guidelines for Medial and Marginal Access Control on Major Roadway", NCHRP Report 93, Highway Research Board, 1970.

The purpose of this study was to develop guides for selecting the degree of access control, and for selecting the type, location, and width of median and median openings, and the design and frequency of entrances to be associated with the degree of access control.

Guidelines developed in this study were based on information available in the literature, data obtained from several highway departments, counties, cities, selected private developers and other agencies.

The report identifies current highway practice and road user costs (including accident costs) in addition to several other factors relevant to access control. Guidelines for degree of access control and for the provisions of direct access driveways are provided.

Taylor, W.C., and Foody, T.J., "Ohio Curve Delineation Program - An Analysis", Traffic Engineering, June, 1966.

The purpose of this study was to determine the parameters to be used in establishing warrants for curve delineation, with effectiveness of delineation defined in terms of accident reduction.

Variables included in this study were degree of curve, total central angle and their interaction. Results of a two-year before and after study involving 557 curves used as test sections and 357 curves used as control sections showed central angle to provide a better measure of delineation effectiveness than degree of curve. It was further determined that degree of curve alone was not a sufficient parameter for establishing delineation warrants.

Taylor, J.I., and McGee, H.W., "Improving Traffic Operations and Safety at Exit Gore Areas," NCHRP Report 145, Transportation Research Board, 1973.

This project was concerned with the problem of erratic maneuvers, such as backing-up and stopping in the gore area. Specifically, it attempted to determine factors which cause motorists to make erratic maneuvers at gore areas, and to determine remedial devices which could be employed to reduce the occurrence of erratic maneuvers at those sites.

The project analyzed "before" erratic maneuver rates at 9 sites to determine causative factors for those maneuvers. Remedial measures (minor signing changes, markings, reflective delineators, etc.)

were installed at 8 sites and evaluated on the basis of reduction in erratic maneuvers can be reduced at existing sites through the application of standard traffic control devices.

A number of findings relating accident experience to geometric design, delineation, and driver population are presented in this report. The report also includes numerous findings pertaining to geometric design elements, traffic characteristics, human factors, signing, and delineation.

Recommendations concerning changes in traffic control measures and design criteria were developed through analysis of case studies included in this project.

Taylor, J.I., McGee, H.W., Seguin, E.L., and Hostetter, R.S., "Roadway Delineation Systems, NCHRP Report 130, Highway Research Board, 1972.

Primary objectives of this study include:

1. Determination of the driver's delineation requirements under various traffic, weather, geometric, and illumination conditions.

2. Establishing techniques for determining the effectiveness and detrimental side effects of delineation treatments.

3. Testing the more promising delineation treatments.

4. Developing practical criteria for the selection of delineation treatments.

The study concentrated on delineation of rural two-lane roads. Laboratory and field studies were conducted to develop and evaluate concepts basic to all delineation treatments and to evaluate the effectiveness of specific treatments or systems as specific situations. Studies included the use of post delineators and/or raised pavement markers at horizontal curves, the use of colored pavements, variation in centerline marking patterns, and variations in color and spacing of past delineators at stop approaches. These studies were used to develop recommendations for the application of various treatments at those situations.

Analysis of accident data was undertaken to determine the relative number of accidents in which poor delineation was a probable factor, and those in which poor delineation was a possible factor. Only order-of-magnitude results were reported in that it was not

possible to determine direct relationships between reported accidents and the various delineation treatments.

Webb, G.M., "The Relation Between Accidents and Traffic Volumes At Signalized Intersections", Proceedings, Institute of Traffic Engineers, 1955.

The purpose of this study was to find a method by which accidents at two-phase signalized intersections could be estimated with reasonable accuracy.

Data were collected and analyzed for approach speed, intersection geometry, character of roadside development, advance warning of signals, and traffic volume at 97 signalized intersection. Of the 97 intersections, 23 were classified as urban, 60 as semiurban, and 14 as rural.

A minimum of one year's accident data for each study site were investigated. It should be noted that all rear-end accidents occurring on the minor road were eliminated from the analysis due to the minor road (often a country road) not being included in the state accident record system. Thus, the formulas developed in this study cannot be used to estimate total number of accidents at an intersection.

Graphs showing average number of accidents per year as a function of ADT on the state highway and ADT on the crossroad were developed for the urban, semiurban, and rural environments. The method of least squares was used to develop equations to express the accident frequency - traffic volume relationships.

Conclusions reached in this study also show that approach speed, intersection geometry, roadside development, and sight distance influence accident occurrence.

Zegeer, C.V., "Effectiveness of Green-Extension Systems at High Speed Intersections," Research Report No. 472, Kentucky Bureau of Highways, May, 1977.

The Kentucky Bureau of Highways Division of Research undertook a study to determine the effectiveness of green-extension systems (GES) for reducing the dilemma-zone problem for drivers when approaching a traffic signal at high speed intersections.

A green-extension system's function is to detect an approaching vehicle within a certain prescribed zone and extend the green phase for this approaching vehicle in order to prevent the vehicle from having to stop abruptly to avoid running a red light.

Findings of the study were:

1. At three green-extension sites where before-and-after studies were made a 54-percent reduction in total accidents and a 75-percent reduction in rear-end accidents was shown after GES installation.

2. At the two sites where before-and-after conflict, volume, delay, and speed data were collected, a 62-percent reduction in yellow-phase conflicts was found and conflicts overall decreased significantly at both sites. No significant change was found in vehicle delay.

Other results were:

1. A direct correlation was found between traffic conflicts and traffic volumes.

2. Restricted sight distance was found to be a major concern at high-speed intersections.

3. Average speed increased only slightly after GES installation.

4. Non-stopping vehicles decreased almost 5 percent after GES installation.

5. On side streets, there was no significant change found in number of cars stopped or in total delay.

6. Benefit-to-cost ratios ranged from 6 to 70, depending on the number of rear-end accidents per year on the mainline.

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APPENDIX B
Workshop Participants

The workshop was conducted on March 6, 7, and 8, 1979, in Southfield, Michigan and was attended by thirteen participants with backgrounds in traffic engineering, highway safety research, and highway safety administration. The workshop participants and their affiliations included:

1. William Baker - Federal Highway Administration
2. Davey Warren - Federal Highway Administration
3. Charles Nemmers - Federal Highway Administration
4. David Merchant - Federal Highway Administration
5. Donald Orne - Michigan Department of Transportation
6. Earl Williams - Tennessee Department of Transportation
7. Willa Mylroie - Washington Department of Transportation
8. Charles Zegeer - Goodell-Grivas, Inc. (formerly Kentucky DOT)
9. Donald Robbins - City of San Diego, California
10. Harvey Friedson - City of Tempe, Arizona
11. Daniel Brame - City of Orlando, Florida
12. David Brown - Auburn University
13. Robert Hostetter - Institute for Research

APPENDIX C

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Urban Undivided Tangent Section	Information*	Pavement Marking (Lane Lines, Edgelining, Marking Visibility, No Passing Zone Markings)	1
		Delineators (Delineator Type, Frequency of Delineators)	4
		Signing (Posted Speed, No Passing Zone Signs)	2
		Lighting (Street Lighting)	3
	Human Factor	Geometry (Cross Sectional Change, Decision Sight Distance)	1
		Distractions	3
		Information Overload	2
		% Non-Local Traffic	4
	Vehicle Control	Pavement (Pavement Surface, Maintenance Characteritics, Skid Resistance, Drainage)	1
		Weather (Amount of Rain/Fog, Amount of Snow/Ice)	3
		Geometrics (Lane Width)	2

*Indicates index(es) rates as most important by workshop panel.

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Urban Undivided Tangent Section (Cont'd)	Congestion	Access (Frequency of Access Points, Frequency of Intersections)	2
		Traffic (Traffic Volumes, V/C Ratio, Traffic Mix, Peaking Characteristics)	1
		Speed Distribution	5
		Land Use	4
		Number of Lanes	3
		Side Friction (Parking Turn-Over Rate, Pedestrian Volumes)	6
	Recovery*	Roadside (Shoulder Width, Shoulder Composition, Lateral Clearance, Roadside Slope Angle)	4
		Obstructions (Frequency of Roadside Appurtenances, Parked Vehicles, Lateral Clearance, Barriers Curb and Gutter)	2
		Pavement (Pavement Surface, Maintenance Characteristics, Skid Resistance, Lane Width)	3 3
		Vehicle Speed	1

*Indicates index(es) rates as most important by workshop panel.

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Rural Undivided Winding Section	Information*	Alignment (Horizontal Alignment, Passing Sight Distance)	1
		Signing (Posted Speed, No Passing, Zone Signs Type of Advance Warning Signs)	3
		Pavement Marking (Lane Lines, Edgelining, Marking Visibility, No Passing Zone Markings)	2
		Delineators (Delineator Type, Frequency of Delineators)	4
	Human Factor	Distractions (Visual Clutter, Distracting Views)	2
		Geometrics (Cross-Sectional Change, Major Design Speed Change)	1
		% Non-Local Traffic	4
		Glare (Sun, Headlights)	3
	Vehicle Control*	Pavement (Skid Resistance, Superelevation, Pavement Surface, Lane Width, Maintenance Characteristics)	1
		Shoulders (Shoulder Width, Shoulder Composition)	2
		Weather (Amount of Snow/Ice, Amount of Rain/Fog)	3

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Rural Undivided Winding Section (Cont'd)	Congestion	Access (Frequency of Access Points, Frequency of Intersecting Roads)	2
		Geometrics (Number of Lanes)	3
		Traffic (Traffic Volume, V/C Ratio, Traffic Mix, Turning Volumes)	1
		Speed Distribution	4
		Land Use	5
	Recovery*	Roadside (Shoulder Width, Shoulder Composition, Roadside Slope Angle)	1
		Pavement (Lane Width, Maintenance Characteristics, Skid Resistance)	3
		Obstructions (Roadside Appurtenances, Barrier)	4
		Vehicle Speed	3

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Rural Isolated Horizontal Curve	Information*	Signing (Advisory Speed Panel, Type of Advance Warning Signs, No Passing Zone Signs)	1
		Delineators (Frequency of Delineators, Type of Delineators)	4
		Pavement Marking (Edge-lining, Lane Lines, Marking Visibility, No Passing Zone Marking)	3
		Geometrics (Degree of Curvature, Horizontal Sight Distance, Vertical Sight Distance, Central Angle)	2
	Human Factor	Distractions (Visual Clutter)	3
		Geometrics (Major Design Speed Change, Distance Since Last Curve, Directional Cues)	1
		Driver Task Overload	2
		% Non-Local Traffic	4
	Vehicle Control	Geometrics (Superelevation, Type of Curve, i.e., Constant, Compound, Cross-Sectional Design, Pavement-Shoulder Drop Off, Degree of Curve)	1
		Pavement (Skid Resistance, Maintenance Characteristics, Lane Width)	3

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Rural Isolated Horizontal Curve (Cont'd)	Vehicle Control (Cont'd)	Weather (Amount of Snow/ Ice, Amount of Rain/ Fog)	4
		Vehicle Speed	2
		Shoulder Composition	5
	Congestion	Access (Frequency of Access Points)	2
		Traffic (Traffic Volume, V/C Ratio, Traffic Mix)	1
		Land Use	5
		Geometrics (Number of Lanes, Shoulder Width)	3
		Speed Distribution	4
	Recovery	Geometrics (Lane Width, Number of Lanes)	4
		Roadside Shoulder Width, Shoulder Composition, Road-side Slope Angle)	3
		Obstructions (Guardrail, Clear Zone, Barrier)	2
		Median (Median Treatment, Median Width)	6
		Vehicle Speed	1
		Skid Resistance	5

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Lane Drop	Information*	Pavement Marking (Channelization, Lane Lines, Edgelining, Marking Visibility)	2
		Signing (Posted Speed, Lane Drop Signs)	1
		Delineators (Delineator Type, Frequency of Delineators)	3
	Human Factor*	Driver Task Overload	2
		Distractions (Visual Clutter)	4
		% Non-Local Traffic	3
		Unanticipated Lane Drop Locations	1
	Vehicle Control	Weather (Amount of Rain/Fog, Amount of Snow/Ice	2
		Taper Design	1
	Congestion	Traffic (V/C Ratio, Traffic Mix)	1
	Recovery	Pavement (Number of Lanes, Skid Resistance, Maintenance)	5
		Obstructions (Roadside Appurtenances, Barrier)	4
		Vehicle Speed	2
		Shoulder (Shoulder Width, Shoulder Composition	3
		Taper Length	1

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Narrow Bridge	Information*	Pavement Marking (Channelization, Lane Lines, Edgelining, Marking Visibility, No Passing Zone Markings)	2
		Signing (No Passing Zone Signs)	1
		Delineators (Delineator Type, Frequency of Delineators)	3
	Human Factor*	Distraction (Visual Clutter)	2
		Geometrics (Change in Shoulder Width, Sight Distance on Approach Transition Design)	1
		% Non-Local Traffic	3
	Vehicle Control	Channelization	2
		Weather (Amount of Rain/Fog, Amount of Snow/Ice)	
		Bridge Deck Surface Type	1
	Congestion	Traffic (Traffic Volume, Traffic Mix)	2
		Side Friction (Pedestrian Volumes, Bicycle Volumes)	1
		Lane Width	3

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Narrow Bridge (Cont'd)	Recovery	Geometrics (Lane Width, Bridge Deck Width, Bridge Length)	2
		Vehicle Speed	1
		Pavement (Skid Resistance, Roadway Condition)	3

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Exit Gore Area	Information*	Pavement Marking (Channelization, Lane Lines, Edgelining, Marking Visibility)	2
		Signing (Guide Signs, Exit Signs)	1
		Delineators (Delineator Type, Frequency of Delineators)	3
	Human Factor	Distraction (Visual Clutter)	2
		Geometrics (Major Design Speed Change, Unusual Geometric, Sight Distance to Ramp)	1
		% Non-Local Traffic	3
	Vehicle Control*	Alignment (Horizontal Alignment, Vertical Alignment)	2
		Deceleration Lane Deceleration Lane Length, Deceleration Lane Taper Design)	1
		Speed (Design Speed, Change in Design Speed)	3
		Weather (Amount of Rain/Fog, Amount of Snow/Ice)	5
		Pavement (Skid Resistance, Construction Joints, Rate of Change in Superelevation)	4

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Exit Gore Area (Cont'd)	Congestion	Traffic (V/C Ratio, Traffic Mix)	1
		Capacity of Receiving Intersections	2
	Recovery*	Shoulder (Shoulder Width, Shoulder Composition)	4
		Obstructions (Fixed Objects in Gore)	1
		Pavement (Maintenance Characteristics, Skid Resistance)	5
		Design of Recovery Area	3
		Vehicle Speed	2

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Urban Unsignal-ized Intersection	Information*	Pavement Marking (Chan-nelization, Lane Lines, Marking Visibility)	3
		Signing (Street Name Signs)	2
		Control (Pedestrian Control, Parking Regulations)	1
	Human Factor	Distractions (Visual Clutter)	3
		Channelization (Un-expected Lane Assignment)	2
		% Non-Local Traffic	4
		Sight Distance	1
	Vehicle Control	Laneage (Left-Turn Lane, Right-Turn Lane)	2
		Sight Distance (Stopping Sight Distance, Cross Traffic Sight Distance)	1
		Weather (Amount of Rain/Fog, Amount of Snow/Ice)	7
		Curb Radius	4
		Skid Resistance	5
		Demographic Character-istics (Population)	6
		On-Street Parking	3

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Urban Unsignalized Intersection (Cont'd)	Congestion*	Traffic (Traffic Volume, V/C Ratio, Peak Hour Factor, Available Gaps, Traffic Mix)	1
		Control (Intersection Control, Pedestrian Control, Parking Regulation)	2
		Bus Stop Location	4
		Side Friction (Parking Turn-Over Rate, Pedestrian Volumes)	3
		Land Use	5
	Recovery	Vehicle Speed	1-2
		Skid Resistance	4
		Geometrics (Number of Lanes, Curb and Gutter)	1-2
		On-Street Parking	3

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Rural Unsignal-ized Intersection	Information*	Pavement Marking (Chan-nelization, Lane Lines Marking Visibility)	3
		Signing (Road Name Signs)	2
		Control (Intersection Control)	1
	Human Factor	Distractions (Visual Clutter)	3
		Sight Distance	1
		Channelization (Unexpected Lane Assignment)	2
		% Non-Local Traffic	4
	Vehicle Control*	Laneage (Left-Turn Lane, Right-Turn Lane)	2
		Sight Distance (Stopping Sight Distance, Cross Traffic Sight Distance)	1
		Weather (Amount of Rain/ Fog, Amount of Snow/Ice)	4
		On-Road Parking	3
	Congestion	Traffic (Traffic Volume, V/C Ratio, Peak Hour Factor, Cap Availability)	1
		Control (Intersection Control)	2
		Land Use	3
		Pedestrian Volumes	4

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Rural Unsignalized Intersection (Cont'd)	Recovery	Vehicle Speed	1
		Pavement Condition	4
		Skid Resistance	3
		Obstructions (Roadside Appurtenances, Guardrail)	2
		Number of Lanes	

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Rural Undivided Tangent Section	Information*	Pavement Marking (Lane Marking, Edgelining, Marking Visibility, No Passing Zone Markings)	1
		Signing (Posted Speed, Advisory Speed Signs, Signage, No Passing Zone Signs)	2
		Delineators (Delineator Type, Frequency of Delineators)	3
		Land Use	4
	Human Factor	Geometry (Cross-Sectional Change, Length of Tangent)	1
		% Non-Local Traffic	3
		Distractions (Inattentiveness, Roadside Distractions)	2
	Vehicle Control*	Weather (Amount of Rain/ Fog, Amount of Snow/ Ice)	3
		Pavement (Skid Resistance, Lane Width, Maintenance Characteristics, Pavement Surface, Drainage, Shoulder-Pavement Separation)	1
		Vehicle Speed	2
	Congestion	Access (Frequency of Access Points, Frequency of Intersections)	2
		Geometrics (Number of Lanes, Shoulder Width)	3

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Rural Undivided Tangent Section (Cont'd)	Congestion (Cont'd)	Side Friction (Pedestrian Volumes, Parking Turn-Over Rate)	4
		Land Use	6
		Speed Distribution	5
	Recovery*	Shoulders (Shoulder Width, Shoulder Composition)	1
		Obstructions (Roadside Appurtenances, Barriers, Ditch Design, Roadside Slope Angle)	2
		Pavement (Lane Width, Maintenance Characteristics, Pavement Surface)	3
		Vehicle Speed	4

Summary of Factor Ranking Results

Situation	Index	Category/Factors	Category Rank
Rural Signalized Intersection	Information*	Control (Intersection Control, Control Strategy, Signal Display)	1
		Pavement Marking (Channelization, Lane Marking, Marking Visibility)	3
		Signing (RTOR-NRTOR Signs, Road Name Signs, Posted Speed)	2
		Lighting (Roadway Lighting)	4
	Human Factor*	Geometrics (Channelization, Sight Distance)	1
		Distractions (Unexpected Lane Assignment, Visual Clutter, Distance Since Last Controlled Intersection)	2
		% Non-Local Traffic	3
	Vehicle Control	Lane Assignment (Left-Turn Lane, Right-Turn Lane)	2
		Geometry (Stopping Sight Distance, Cross-Traffic Sight Distance)	1
		Weather (Amount of Rain/Fog, Amount of Snow/Ice)	3
	Congestion	Access (Land Use Type, Frequency of Access Points)	2

Summary of Factor Ranking Results (Cont'd)

Situation	Index	Category/Factors	Category Rank
Rural Signalized Intersection (Cont'd)	Congestion (Cont'd)	Traffic (Traffic Volume, V/C Ratio, Peak Hour Factor, Traffic Mix, Left-Turn Volume, Crossing Volume)	1
		Vehicle Speed	3
		Pedestrian Volume	4
	Recovery	Shoulders (Shoulder Width, Shoulder Composition)	3
		Obstructions (Frequency of Appurtenances)	4
		Pavement (Number of Lanes, Skid Resistance)	2
		Vehicle Speed	1

APPENDIX D

Summary of limited field data analysis results.

Situation: Lane Drops

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accident Frequency	. None Identified	. Posted Speed Limit . Posted Speed Limit - Sight Distance
Rear-End Accident Frequency	. None Identified	. None Identified
Sideswipe Accident Frequency	. ADT	. None Identified

Summary of limited field data analysis results (cont'd)

Situation: Rural Undivided Winding Sections

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accidents Per Mile	. Percent Trucks . Average Tangent Length	. Advisory Speed Limit . Peak Hour V/C Ratio
Run-Off-Road Accidents Per Mile	. Average Tangent Length . Posted Speed Limit . Advisory Speed Limit . Percent Trucks . Percent Trucks - Lane Width	. None Identified
Opposing Direction Accidents Per Mile	. Average Tangent Length	. ADT . Peak Hour V/C Ratio . Percent Trucks . Average Tangent Length - Posted Speed Limit
Rear-End Accidents Per Mile	. Percent Trucks . Percent Trucks - Lane Width	. Curves Per Mile . Lane Width . Posted Speed Limit . Advisory Speed Limit

Summary of limited field data analysis results (cont'd)

Situation: Rural Isolated Curves

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accident Frequency	. Distance Since Last Curve	. Speed Reduction Efficiency
Run-Off-Road Accident Frequency	. None Identified	. Distance Since Last Curve . Posted Speed Limit . Shoulder Width . Superelevation - Distance Since Last Curve - Non-Rigid Fixed Object
Opposing Direction Accident Frequency	. Posted Speed Limit . Posted Speed Limit - Erratic Maneuver Rate	. Distance Since Last Curve . Shoulder Width
Fixed Object Accident Frequency	. None Identified	. Distance Since Last Curve

Summary of limited field data analysis results (cont'd)

Situation: Urban Undivided Tangents (Two-Lane)

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accidents/Mile	. ADT . Total Access Points Per Mile . Non-Rigid Fixed Objects Per Mile . Total Access Points Per Mile - ADT - Non-Rigid Objects Per Mile	. Commercial Driveways Per Mile . Total Fixed Objects Per Mile
Rear End Accidents/Mile	. ADT . Total Access Points Per Mile . ADT - Percent Midblock Turns - Speed Changes Per Mile - Total Access Points Per Mile	. Peak Hour V/C Ratio
Fixed Object Accidents Per Mile	. None Identified	. None Identified
Driveway Accidents/Mile	. ADT . Peak Hour V/C Ratio . Total Access Points Per Mile . Percent Midblock Turns . Total Fixed Objects Per Mile . Non-Rigid Fixed Objects Per Mile . Rigid Fixed Objects Per Mile . Percent Midblock Turns - Total Access Points Per Mile - ADT	. Speed Changes/Mile . Percent Midblock Turns . Commercial Driveways Per Mile

Summary of limited field data analysis results (cont'd)

Situation: Urban Undivided Tangents (Four-Five Lane Combined)

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accidents/Mile	. Not Tested	. Not Tested
Rear-End Accidents/Mile	. Not Tested	. Not Tested
Fixed Object Accidents Per Mile	. Rigid Fixed Objects Per Mile . Peak Hour V/C Ratio . Percent Midblock Turns - Rigid Fixed Objects Per Mile	. ADT . Total Fixed Objects Per Mile . Percent Midblock Turns . Intersections/Mile . Residential Driveways Per Mile
Driveway Accidents/Mile	. Not Tested	. Not Tested

Summary of limited field data analysis results (cont'd)

Situation: Urban Undivided Tangents (Four-Lane)

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accidents/Mile	. None Identified	. None Identified
Rear-End Accidents/Mile	. None Identified	. None Identified
Fixed Object Accidents Per Mile	. None Identified	. Percent Midblock Turns
Driveway Accidents/Mile	. None Identified	. None Identified

Summary of limited field data analysis results (cont'd)

Situation: Urban Undivided Tangents (Five-Lane)

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accidents/Mile	. None Identified	. Peak Hour V/C Ratio
Rear-End Accidents/Mile	. None Identified	. Intersections/Mile
Fixed Object Accidents Per Mile	. None Identified	. ADT . Peak Hour V/C Ratio
Driveway Accidents/Mile	. None Identified	. Peak Hour V/C Ratio . Intersections/Mile

Summary of limited field data analysis results (cont'd)

Situation: Rural Signalized Intersection

ACCIDENT MEASURE	IDENTIFIED SURROGATES	
	STRONG POTENTIAL	OTHER POTENTIAL
Total Accident Frequency	. None Identified	. Peak Hour Approach Volume . AAV/AAS . AAV/AAS - Percent Trucks
Right Angle Accident Frequency	. Percent Trucks . Percent Trucks - Percent Vehicles in Pace	. None Identified
Rear-End Accident Frequency	. Peak Hour Approach Volume - Percent Left-Turns	. Peak Hour Approach Volume . AAV/AAS . Percent Left-Turns
Opposing Left-Turn Accident Frequency	. Peak Hour Approach Volume	. AAV/AAS - Percent Trucks . AAV/AAS

APPENDIX E

Definitions of Selected Candidate Surrogates

Average (intersection) approach speed - The average value of the speed distribution of vehicles approaching an intersection taken at a point 1,200 feet from the intersection. Speed distributions are based on 50 to 100 vehicles on each intersection approach.

Distance since last traffic event - The distance, measured in miles, from the highway situation under study (curves, intersections, etc.) to a previous highway situation that requires the driver to adjust vehicular speed or path. The distance is measured for each direction of travel. Examples of events are curves, railroad crossings, stop or yield sign, traffic signal, lane drop or add, etc.

Driveway accidents - Reported accidents in which at least one vehicle is entering or exiting a driveway.

Encroachment rate - The number of vehicles observed where a vehicle tire touches either the centerline or leaves the paved surface within the limits of the curve defined by the point of curvature and point of tangency per 100 vehicles (measured directionally).

Erratic maneuver rate - Total number of signal violations, severe braking maneuvers, and abrupt lane changes (due to other vehicles or traffic control devices) per 100 approach vehicles.

Fixed object measure on curves - Rating of the probability of striking a fixed object and sustaining severe damage (or injury) given that a vehicle leaves the paved surface (measured for ranges of 0-10 feet and 10-20 feet for inside and outside lane roadside environments). The rating is:

0 - Clear, no fixed objects, level terrain, recovery without incident highly probable.

1 - Vegetation or yielding objects, no rigid fixed objects, low probability of serious injury.

2 - Isolated rigid fixed objects on level terrain, avoidance of primary fixed object implies high probability of recovery without incident.

3 - Embankment with or without ditch, high probability of overturn.

4 - Continuous rigid fixed objects.

Inside lane accidents - Reported traffic accidnts involving one or more vehicles travelling on the inside lane of a curve. Examples are rear-end accidents, run-off-road accidents and fixed object accidents.

Opposite direction accidents - Reported traffic accidents involving two vehicles travelling in opposing directions. Examples are head-on accidents, opposing sideswipe accidents.

Opposing left-turn accidents - Reported accidents at intersections involving two vehicles; one travelling straight through the intersection, the other turning or in the process of turning left.

Outside lane accidents - Reported traffic accidents involving one or more vehicles travelling on the outside lane of a curve. Examples are rear-end accidents, run-off-road accidents, fixed object accidents.

Percent trucks - The number of trucks observed per 100 vehicles.

Sideslope angle - Feet measured horizontally for each foot measured vertically (downslope is positive, embankment is negative).

Signal violation rate - The observed number of red and amber phase violations per 100 approach vehicles.

Speed changes - The number of speed variations of 3 miles per hour or greater, measured at 5 second intervals while traversing a section of highway.

Speed differential - The difference in the average value of the speed distribution measured at two points (each direction of travel is measured separately). For curves, speed differential is defined as:

- average speed at 250 feet in advance of point of curvature (PC) minus average speed at the PC.
- average speed at the PC minus the average speed at the curve midpoint.
- average speed at 250 feet in advance of the PC minus the speed at the curve midpoint.

Speed reduction efficiency - The ratio of the difference in actual speed reduction (average approach speed minus average speed at the curve midpoint) to the desired speed reduction (average approach speed minus the maximum permissible speed of the curve based on the friction factor).

Superelevation error - The minimum required rate of superelevation (determined by degree of curvature, design speed, coefficient of friction) minus the actual superelevation measured in the field (measured in inches per foot).

Table F-1. Non-operational data collected at rural isolated curves.

Site #	Average Annual ADT	Degree of Curve	Grade %	Distance to Last Event Outside (Miles)	Distance to Last Event Inside (Miles)	Side Slopes (x:1)		Fixed Object Rating				Shoulder Width		Lane Superelevation ("/')	
								Inside		Outside					
						Inside	Outside	0-10	10-20	0-10	10-20	Inside	Outside	Inside	Outside
1	1803	5	2	0.35	1.50	-2	1	0	1	0	0	8	4	0.72	0.63
2	1803	8	2	0.30	1.50	1	3	4	1	0	2	7	5	0.79	0.13
3	8720	9	0	0.40	0.30	4	10	0	0	0	1	8	10	0.90	0.42
4	3899	10	0	0.60	0.30	10	1	0	4	0	3	7	9	0.90	0.40
5	3358	10	1	1.00	1.00	-2	1	1	1	1	4	3	5	0.58	0.52
6	7954	10	3	1.20	0.30	1	1	3	4	3	4	5	4	0.42	0.50
7	7954	17	3	0.30	0.30	-1	2	0	4	0	1	6	8	1.60	0.92
8	1815	11	5	0.40	0.30	-1	10	1	2	0	1	5	7	1.16	0.86
9	1815	20	1	0.30	0.25	10	2	1	4	0	4	4	6	1.59	0.54
10	2204	11	1	0.45	0.25	3	1	1	4	1	4	5	5	0.64	0.52
11	6011	15	1	0.30	0.50	-2	10	1	4	0	0	5	11	0.73	0.73
12	3800	7	0	0.30	0.50	9	5	0	0	0	0	9	10	0.00	0.00
13	4815	24	2	0.40	0.40	8	10	0	4	3	4	8	7	1.25	0.79
14	4700	8	5	0.50	0.40	-1	10	1	4	4	4	5	4	0.94	0.46
15	2866	7	2	3.00	0.40	3	2	1	4	1	4	7	7	0.79	0.83
16	2866	5	1	0.25	0.40	1	1	0	4	0	1	7	10	0.40	0.42
17	3010	6	2	0.50	1.50	-2	-1	0	2	0	2	10	6	0.29	0.92
18	3378	20	2	0.50	0.30	10	10	0	4	1	4	1	10	1.58	1.71
19	1082	5	0	0.30	0.55	2	1	0	0	0	2	7	8	0.92	0.92
20	3148	8	4	1.25	0.80	-4	2	1	4	0	4	6	7	1.61	1.86
21	1729	10	0	0.20	0.30	1	1	1	4	1	4	6	7	0.92	0.25
22	1536	13	4	3.00	0.75	-1	1	1	4	3	2	2	7	1.13	1.33
23	2214	6	0	0.30	1.10	1	1	1	4	0	4	9	8	0.67	0.83
24	1313	5	1	0.20	0.35	10	2	0	0	0	4	10	9	0.38	0.88
25	1082	8	0	0.80	0.55	10	6	0	4	0	1	9	9	0.92	0.67

Table F-2. Operational data collected at rural isolated curves.

Site #	Total Encroachment Rate	Inside Encroachment Rate	Outside Encroachment Rate	Speed Differential: Outside Approach P.C.	Speed Differential: Outside P.C. Midpoint	Speed Differential: Inside Approach P.C.	Speed Differential: Inside P.C. Midpoint	Encroachment Rate-Outside Centerline	Encroachment Rate-Outside Edgeline	Encroachment Rate-Inside Centerline	Encroachment Rate-Inside Edgeline
1	33.6	46.2	20.9	1.1	-2.5	-0.3	1.0	19.1	1.7	25.6	20.6
2	24.9	17.7	30.2	1.3	-0.7	1.4	0.2	29.2	1.0	1.4	16.3
3	5.3	1.6	7.9	0.6	1.1	2.9	2.0	7.7	0.3	0.5	1.1
4	13.4	5.4	18.9	2.3	1.5	-4.3	1.1	18.9	0.0	1.0	4.4
5	41.8	23.4	59.2	-0.1	0.8	-0.5	1.2	55.5	3.7	3.9	19.5
6	18.0	21.2	13.9	0.4	-0.5	0.1	-2.5	8.7	5.2	4.2	17.0
7	16.3	16.8	15.6	1.9	1.1	4.8	0.1	10.7	4.9	4.9	11.9
8	86.7	81.4	96.6	0.7	2.8	3.5	0.3	86.5	10.1	18.6	62.7
9	65.0	54.2	72.7	1.9	-0.3	3.4	3.2	63.1	9.6	32.4	21.9
10	36.2	45.9	25.2	2.4	2.9	3.6	3.0	0.0	25.2	45.4	0.4
11	41.9	44.4	40.8	0.9	1.9	0.8	3.5	26.4	14.4	11.1	33.3
12	26.2	21.5	31.3	2.1	-1.2	2.3	-0.7	11.9	19.4	4.7	16.9
13	40.2	37.7	42.3	3.4	4.2	2.7	3.5	7.3	35.0	20.2	17.5
14	44.6	43.6	45.2	1.8	1.6	1.5	-1.9	42.9	2.4	3.4	40.2
15	30.2	19.8	39.7	-0.6	1.3	-0.8	-1.6	34.6	5.0	11.7	8.0
16	55.2	33.3	76.2	1.9	0.0	0.8	0.3	49.5	26.7	17.7	15.6
17	58.8	75.4	42.1	1.9	-0.7	1.7	2.0	32.6	9.5	19.4	56.0
18	50.8	79.2	25.7	4.9	4.3	5.2	4.6	12.7	13.1	70.4	8.8
19	63.0	59.3	67.8	1.8	1.2	0.9	-1.8	39.2	28.6	14.6	44.7
20	34.8	49.7	25.0	3.0	1.2	2.4	1.6	0.5	24.5	49.7	0.0
21	57.3	60.9	53.8	0.2	1.1	-1.5	0.2	37.1	16.7	31.3	29.6
22	53.0	47.6	58.8	3.4	0.9	3.6	3.0	37.3	21.5	14.8	32.8
23	54.3	48.2	60.8	1.0	2.2	1.7	-0.6	32.8	27.9	39.1	9.1
24	78.7	83.6	72.2	1.3	-2.8	0.4	0.6	54.8	17.5	80.0	3.6
25	16.4	27.6	5.6	1.9	0.4	2.9	-1.3	3.1	2.5	26.3	1.3

Table F-3. Accident data collected at rural isolated curves.

Site Number	Three Year Frequency	Total Rate (per MV)	Rear End Rate (per MV)	Opposite Direction Rate (per MV)	Run-off-Road Rate (per MV)	Inner Lane Rate (per MV)	Outer Lane Rate (per MV)
1.	0	0.00	0.00	0.00	0.00	0.00	0.00
2.	0	0.00	0.00	0.00	0.00	0.00	0.00
3.	9	1.15	0.31	0.31	0.52	1.04	1.88
4.	5	1.17	0.23	0.00	0.94	1.40	1.40
5.	0	0.00	0.00	0.00	0.00	0.00	0.00
6.	10	1.15	0.34	0.11	0.57	0.68	2.52
7.	10	1.15	0.23	0.34	0.57	1.60	1.60
8.	1	0.50	0.00	0.00	0.50	0.00	1.00
9.	7	3.52	0.00	0.50	3.02	7.04	1.00
10.	0	0.00	0.00	0.00	0.00	0.00	0.00
11.	11	1.67	0.15	0.15	0.91	2.74	1.22
12.	2	0.48	0.00	0.00	0.48	0.96	0.00
13.	15	2.84	0.00	0.38	2.09	3.80	1.52
14.	6	1.17	0.19	0.00	0.58	1.16	0.78
15.	3	0.96	0.00	0.32	0.64	1.28	0.64
16.	3	0.96	0.00	0.64	0.32	1.92	1.28
17.	2	0.61	0.00	0.30	0.00	0.60	0.60
18.	7	1.89	0.27	0.54	1.08	1.08	3.78
19.	6	5.06	0.00	0.00	1.69	8.44	1.68
20.	3	0.87	0.00	0.29	0.29	1.16	0.58
21.	4	2.11	0.00	0.00	1.06	4.22	1.06
22.	5	2.97	0.00	0.59	1.78	2.38	4.76
23.	3	2.06	0.82	0.00	1.24	0.00	2.48
24.	0	0.00	0.00	0.00	0.00	0.00	0.00
25.	0	0.00	0.00	0.00	0.00	0.00	0.00

Table F-4. Non-operational data collected at rural signalized intersections.

Site	ADT North	ADT East	ADT South	ADT West	Cycle Length (Sec.)	Percent Green N-S	Percent Green E-W	Percent Amber N-S	Percent Amber E-W	Percent Red N-S	Percent Red E-W	DSLE (North)	DSLE (East)	DSLE (South)	DSLE (West)
1	5516	500	5441	500	60	57	23	10	7	33	70	1.00	0.40	0.70	1.10
2	8346	3940	5516	3940	60	55	23	7	7	38	70	0.60	0.40	1.00	1.00
3	2290	5136	902	5685	60	28	58	7	7	65	35	0.10	0.50	0.90	0.70
4	5964	3366	5248	3389	60	50	33	8	8	42	58	1.00	0.70	0.80	0.75
5	2772	1276	5094	1276	50	42	42	8	8	50	50	2.00	1.50	0.20	0.70
6	5319	3969	6229	2228	60	53	32	9	8	40	60	0.60	1.00	1.00	0.60
7	5706	3888	7022	3096	60	57	27	8	8	35	65	0.70	0.25	0.50	0.30
8	7228	4472	7784	5136	60	40	33	10	8	52	58	0.80	2.90	0.35	0.20
9	7784	2142	4672	2142	60	63	22	7	8	30	70	0.50	0.20	0.20	2.10
10	3168	3544	3430	3592	60	37	50	7	7	57	43	0.50	0.50	1.50	0.50
11	4536	8547	5188	7305	70	33	50	7	7	60	43	1.70	0.65	0.25	1.25
12	5188	262	6116	1132	60	63	23	7	7	30	70	0.25	0.15	0.15	1.25
13	1374	6029	2970	6048	70	24	63	6	7	70	30	3.00	1.00	2.00	0.85
14	6729	6454	3938	5379	70	46	39	6	6	49	56	1.00	0.20	0.20	0.95
15	4842	2120	4670	4336	60	53	31	6	8	38	61	1.00	1.00	0.80	0.80
16	3475	10946	6729	10056	60	38	43	7	7	55	50	1.00	0.25	1.00	1.00
17	6290	3932	5644	4719	60	48	37	7	7	45	57	1.00	0.45	1.05	1.00
18	378	4360	2456	5354	60	31	51	8	8	60	40	0.60	0.45	2.00	1.00
19	7198	9605	8409	9913	80	41	49	5	5	54	46	1.00	1.00	1.00	1.00

Table F-5. Operational data collected at rural signalized intersections.

Site	Approach Speed (North)	Approach Speed (East)	Approach Speed (South)	Approach Speed (West)	Percent Trucks N-S	Percent Trucks E-W	Percent Left Turn (North)	Percent Right Turn (North)	Percent Left Turn (East)	Percent Right Turn (East)	Percent Left Turn (South)	Percent Right Turn (South)	Percent Left Turn (West)	Percent Right Turn (West)	Erratic Maneuver Rate Total	Erratic Maneuver Rate (North)	Erratic Maneuver Rate (East)	Erratic Maneuver Rate (South)	Erratic Maneuver Rate (West)	Signal Violation Rate
1	45.9	36.2	42.4	38.4	6.1	5.5	5.5	24.4	41.6	38.7	33.0	2.9	8.2	22.5	0.94	2.25	1.25	0.25	0.00	0.75
2	39.9	37.9	41.8	37.5	5.5	5.8	13.0	16.4	17.1	27.6	22.1	11.9	12.9	25.8	1.56	0.50	0.25	0.75	4.75	1.38
3	25.9	38.2	39.6	37.2	9.9	6.6	29.9	15.2	6.6	4.0	14.4	30.5	9.2	12.4	0.84	0.25	0.61	0.47	2.00	0.77
4	42.1	40.3	39.4	40.9	5.0	5.9	15.5	26.4	31.3	21.9	20.1	11.2	11.8	29.8	0.70	1.54	0.00	0.67	0.67	0.00
5	42.7	40.2	43.4	41.1	4.8	5.5	8.9	1.8	4.3	58.7	34.9	3.1	20.8	21.9	0.58	0.75	0.50	0.60	0.50	0.32
6	38.0	36.6	40.8	31.5	3.9	3.6	5.5	19.3	42.2	24.6	13.7	14.2	29.8	11.2	1.19	1.75	2.00	0.00	0.70	0.56
7	42.6	41.3	41.0	40.9	6.9	8.7	11.0	5.9	11.1	19.9	10.3	2.9	9.8	24.7	0.67	0.60	1.00	0.25	0.67	0.40
8	37.0	38.3	38.0	37.2	6.0	6.5	4.5	17.4	20.3	20.7	15.5	12.2	25.3	8.4	0.50	0.00	1.00	0.40	0.60	0.15
9	44.0	42.0	48.0	40.0	6.4	7.4	1.9	18.2	37.3	25.0	7.6	7.6	31.5	4.5	1.15	1.20	1.60	1.20	0.60	0.55
10	43.2	39.3	39.8	37.7	6.9	6.6	14.2	25.8	15.5	23.6	25.8	27.1	34.5	10.3	0.83	0.75	1.07	0.75	0.75	0.70
11	39.9	37.4	31.8	41.2	4.1	16.8	16.5	27.3	11.8	28.7	38.5	12.2	11.8	28.7	1.19	1.00	1.25	1.00	1.50	0.69
12	31.5	16.0	30.3	28.0	4.3	4.3	4.5	2.2	21.9	34.2	4.2	13.4	48.4	9.4	0.73	0.75	1.00	0.00	0.00	0.64
13	38.9	44.2	38.6	46.5	16.2	7.2	9.3	34.9	5.9	11.9	33.3	32.3	8.3	3.6	1.20	0.00	0.75	3.00	0.43	0.45
14	38.1	36.2	38.8	41.1	3.5	3.4	15.5	34.2	37.2	6.3	12.4	9.2	5.8	33.0	0.94	3.25	0.25	0.00	0.25	0.81
15	37.2	37.3	40.2	37.8	3.7	4.4	26.5	7.1	12.7	7.3	4.3	21.9	16.6	41.2	0.44	^ 00	0.50	0.50	0.75	0.38
16	37.0	34.1	35.7	38.2	3.6	2.9	20.5	18.5	5.8	17.2	23.2	33.0	18.3	10.2	0.81	0.50	1.25	1.00	0.50	0.44
17	41.2	39.8	39.3	40.3	5.4	4.8	5.3	6.1	9.6	28.9	13.6	4.7	9.1	20.3	1.42	0.60	1.25	1.75	2.46	1.05
18	37.1	40.8	34.8	38.3	6.1	5.7	30.9	66.0	9.8	10.3	24.2	35.3	12.6	9.2	1.04	1.16	0.28	1.00	1.60	0.42
19	37.9	35.3	35.5	39.8	6.0	4.5	19.5	10.7	7.4	17.0	14.5	21.6	10.1	7.0	0.75	1.00	1.20	0.60	0.20	0.40

Table F-6. Accident data collected at rural signalized intersections.

Site	Total Accident Frequency	Total Accident Rate	Rear End Accident Rate	Opposing Left Turn Accident Rate	Right Angle Accident Rate	Driveway Accident Rate	Other Accident Rate	Injury Accident Rate	Property Damage Accident Rate	Rear End Rate (North)	Rear End Rate (East)	Rear End Rate (South)	Rear End Rate (West)	APP Accident Rate (North)	APP Accident Rate (East)	APP Accident Rate (South)	APP Accident Rate (West)
1	20.0	1.53	0.92	0.38	0.00	0.00	0.23	0.69	0.84	0.83	0.00	0.84	0.00	0.99	0.00	1.17	1.83
2	90.0	3.78	1.09	0.84	0.76	0.71	0.38	0.84	2.94	0.66	1.62	0.83	0.70	2.84	2.32	2.98	2.09
3	39.0	2.54	0.46	0.39	0.98	0.39	0.33	1.04	1.50	0.00	0.36	0.00	0.48	1.99	2.49	1.01	0.96
4	37.0	1.88	0.30	0.20	0.91	0.36	0.10	0.56	1.32	0.15	0.00	0.00	0.81	1.38	0.54	0.52	1.35
5	30.0	2.63	0.35	0.09	1.58	0.18	0.44	0.88	1.75	0.66	0.00	0.36	0.00	2.97	2.86	0.36	2.15
6	37.9	1.90	0.41	0.57	0.51	0.21	0.21	0.66	1.24	0.17	0.46	0.44	0.82	0.69	0.46	1.76	0.82
7	41.0	1.90	0.65	0.23	0.56	0.28	0.19	0.60	1.30	0.48	0.00	0.91	0.88	0.96	0.70	1.30	1.77
8	93.0	3.45	0.93	0.74	0.93	0.30	0.56	0.71	2.74	0.25	1.02	0.82	0.53	1.52	2.45	2.35	1.96
9	35.0	1.91	0.44	0.16	1.15	0.11	0.05	0.76	1.15	0.12	1.71	0.00	0.43	0.47	2.98	0.59	1.71
10	20.0	1.33	0.13	0.20	0.86	0.07	0.07	0.73	0.60	0.00	0.26	0.27	0.00	0.00	0.52	2.13	0.00
11	90.0	3.21	0.75	0.71	1.11	0.18	0.46	1.35	1.86	0.81	0.32	0.18	0.88	1.81	1.28	1.23	1.88
12	16.0	1.15	0.22	0.22	0.22	0.14	0.36	0.43	0.72	0.18	0.00	0.15	0.00	0.88	3.49	0.15	2.42
13	31.0	1.77	0.44	0.22	0.39	0.55	0.17	0.22	1.06	0.00	0.30	0.31	0.45	0.00	1.82	1.84	1.36
14	49.0	1.99	0.45	0.77	0.65	0.00	0.12	0.73	1.26	0.54	0.28	0.23	0.00	1.22	0.71	0.93	0.51
15	19.0	1.09	0.29	0.23	0.46	0.00	0.11	0.58	0.51	0.38	0.43	0.20	0.21	0.38	0.43	0.20	1.05
16	106.0	3.10	0.88	0.61	0.82	0.29	0.50	0.91	2.19	1.31	0.83	0.95	0.73	2.63	1.75	1.76	1.54
17	27.0	1.20	0.49	0.31	0.36	0.00	0.04	0.36	0.84	0.29	0.46	0.81	0.97	1.31	0.70	1.62	0.39
18	20.0	1.46	0.29	0.36	0.44	0.22	0.15	0.44	1.02	0.00	0.00	0.74	0.34	7.25	0.42	1.49	0.85
19	55.0	1.43	0.52	0.31	0.34	0.16	0.10	0.47	0.96	0.38	0.29	0.43	0.74	0.76	1.15	1.19	1.11

Table F-7. Non-operational data collected at urban undivided tangents.

Site	Length	No. of Driveways	No. of Commercial Driveways	No. of Residential Driveways	No. of Unsignalized Int.	No. of Signalized Int.	No. of Signs (Total)	No. of Regulatory Signs	No. of Warning Signs	No. of Information Signs	Capacity
1	0.76	47	3	44	5	0	13	6	0	7	3278
2	0.69	48	25	23	5	2	27	16	4	7	3312
3	0.86	34	7	27	8	0	14	5	1	8	3900
4	0.56	16	4	12	9	1	20	4	6	10	3960
5	0.89	17	2	15	3	0	12	5	2	5	3920
6	0.89	14	4	10	8	0	15	3	3	9	3920
7	0.90	28	0	28	4	0	10	3	2	5	3960
8	0.64	11	1	10	4	0	9	6	0	3	3722
9	0.84	34	0	34	4	0	13	2	6	5	3960
10	0.85	28	5	23	7	0	24	6	1	17	3920
11	0.86	25	8	17	11	0	22	8	0	14	3960
12	0.79	2	2	0	11	0	16	8	0	8	3312
13	0.67	6	2	4	5	0	13	5	3	5	3344
14	0.72	14	8	6	3	1	28	16	8	4	3449
15	0.67	13	1	12	9	0	17	7	1	9	3414
16	0.67	21	5	16	3	0	11	3	2	6	3484
17	0.81	31	4	27	4	0	14	1	7	6	3722
18	0.85	45	7	38	7	1	56	40	7	9	3207
19	0.91	19	3	16	5	1	26	11	9	6	3207
20	0.82	29	0	29	6	0	15	9	0	6	353
21	0.87	28	0	28	3	0	19	10	2	7	3722
22	0.80	34	0	34	3	0	12	9	1	2	3647
23	0.91	24	1	23	7	0	22	9	4	9	3800
24	0.63	24	0	24	3	0	11	8	0	3	3379
25	0.70	19	1	18	7	0	13	4	1	8	3278
26	0.80	20	2	18	5	0	23	9	6	8	3572
27	0.75	33	4	29	0	4	30	19	5	6	3379
28	0.65	7	5	2	4	1	11	5	3	3	3449
29	0.80	59	4	55	8	3	38	24	3	11	3346
30	0.63	19	1	18	7	0	12	2	4	6	3684

Table F-8. Operational data collected at urban undivided tangents.

Site	1977 Volume	Speed Changes	Percent Total Turns	Percent Trucks
1	14670	2.75	4	3
2	15747	8.75	13	2
3	18474	2.75	13	2
4	18847	4.50	12	1
5	16797	7.25	2	2
6	13801	3.25	7	2
7	4150	1.50	4	1
8	4650	1.25	4	1
9	3750	2.00	4	1
10	5050	2.75	10	2
11	20150	5.25	15	1
12	16650	3.25	12	2
13	17700	7.50	14	5
14	18742	4.50	15	2
15	18413	2.50	11	3
16	13025	3.75	12	1
17	11421	4.25	18	1
18	17200	5.50	7	1
19	12300	3.00	4	1
20	19826	1.25	6	6
21	19035	4.00	16	1
22	11280	3.50	13	5
23	9800	1.75	16	3
24	14491	1.75	11	4
25	15292	1.00	13	3
26	15633	2.25	26	5
27	12936	3.75	13	4
28	20200	3.50	12	2
29	23150	6.20	10	1
30	13350	1.50	18	2

Table F-9. Accident data collected at urban undivided tangents.

Site	Total Frequency	Total Rate	Rear End Rate	Opposite Direction Rate	Driveway Rate	Angle Rate	Fixed Object Rate	Other Rate
1	36	2.95	1.47	0.41	0.41	0.00	0.33	0.33
2	6	0.50	0.34	0.08	0.08	0.00	0.00	0.00
3	59	3.22	1.78	0.52	0.34	0.11	0.40	0.06
4	59	5.11	2.16	0.52	1.21	0.17	0.43	0.61
5	32	1.95	1.16	0.37	0.00	0.12	0.12	0.18
6	39	2.90	2.08	0.22	0.00	0.30	0.30	0.00
7	9	2.20	0.24	0.00	0.00	0.00	1.96	0.00
8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	7	2.03	0.29	0.29	0.00	0.58	0.58	0.29
10	9	1.91	0.43	0.00	0.43	0.00	0.43	0.64
11	71	3.74	1.11	0.69	0.21	1.42	0.11	0.21
12	60	4.17	1.67	0.76	0.14	1.25	0.21	0.14
13	3	0.23	0.00	0.00	0.00	0.00	0.15	0.08
14	48	3.25	0.95	1.08	0.61	0.14	0.27	0.20
15	52	3.85	2.15	0.37	0.15	0.37	0.59	0.22
16	16	1.67	0.63	0.31	0.21	0.21	0.00	0.31
17	23	2.27	0.99	0.10	0.20	0.00	0.49	0.49
18	37	2.31	1.00	0.19	0.50	0.19	0.19	0.25
19	35	2.85	0.81	1.14	0.08	0.08	0.73	0.00
20	39	2.19	0.84	0.34	0.28	0.00	0.45	0.28
21	15	0.83	0.33	0.06	0.17	0.00	0.17	0.11
22	31	3.14	0.81	0.10	0.51	0.20	1.32	0.20
23	20	2.05	0.61	0.31	0.00	0.00	0.82	0.31
24	31	3.10	1.70	0.40	0.20	0.30	0.40	0.10
25	24	2.05	0.85	0.51	0.34	0.26	0.09	0.00
26	24	1.75	0.22	0.73	0.22	0.15	0.07	0.37
27	49	4.60	2.07	0.47	1.04	0.19	0.38	0.47
28	24	1.67	1.04	0.14	0.07	0.21	0.14	0.07
29	43	2.12	1.33	0.10	0.05	0.44	0.05	0.15
30	27	2.93	1.19	0.54	0.22	0.33	0.65	0.00

Table G-1. Linear regression results for rural isolated curves - All sites.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Degree of Curve, $V10^{+++}$ Total Encroachment Rate, $V17^{+}$ Fixed Objects Within 10' of Inside Lane, $V65^{+}$	Speed Differential, $V38^{++}$ (Outside Lane Speed Reduction) Total Encroachment Rate, $V17^{+}$ Average Speed Reduction Efficiency, $V66^{+}$	Degree of Curve, $V10^{+++}$
	V02 = 0.2459 + 0.09734 V10 R^2 = 0.16	-	V02 = 0.2459 + 0.0973 V10 R^2 = 0.16
Rear-End Accident Rate (accidents/MV), V03	ADT, $V09^{+++}$	-	ADT, $V09^{+++}$
	V03 = -0.01661 + 0.00003482 V09 R^2 = 0.16	-	V03 = -0.01661 + 0.000034827 V09 R^2 = 0.16
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, $V41^{+++}$ (Inside Lane Speed Reduction)	Speed Differential, $V41^{+++}$ (Inside Lane Speed Reduction)	Degree of Curve, $V10^{+++}$ Fixed Objects Within 10' of Inside Lane, $V65^{++}$
	V04 = 0.09008 + 0.03685 V41 R^2 = 0.31	V04 = 0.09008 + 0.03685 V41 R^2 = 0.31	V04 = -0.02809 + 0.02005 V10 R^2 = 0.22

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-1. Linear regression results for rural isolated curves - All sites (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Degree of Curve, $V10^{+++}$ Total Encroachment Rate, $V17^{++}$	Speed Differential, $V38^{++}$ (Outside Lane Speed Reduction) Total Encroachment Rate, $V17^{+}$	Degree of Curve, $V10^{+++}$
	$V05 = -0.1987 + 0.09011\ V10$ $R^2 = 0.37$	-	$V05 = -0.1987 + 0.09011\ V10$ $R^2 = 0.37$
Inside Lane Accident Rate (accidents/MV), V07	Degree of Curve, $V10^{+}$	-	Degree of Curve, $V10^{+}$
	-	-	-
Outside Lane Accident Rate (accidents/MV), V08	Speed Differential, $V38^{+++}$ (Outside Lane Speed Reduction) Distance to Last Event, Outside Lane, $V13^{++}$	Speed Differential, $V38^{+++}$	Degree of Curve, $V10^{++}$ Distance to Last Event, Outside Lane, $V13^{++}$
	$V08 = 0.2807 + 0.1246\ V38$ $R^2 = 0.26$	$V08 = 0.1280 + 0.04531\ V38$ $R^2 = 0.26$	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-2. Linear regression results for rural isolated curves - Group A.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Total Encroachment Rate, V17++ Fixed Objects Within 10' of Inside Lane, V65++ Degree of Curve, V10++	Total Encroachment Rate, V17++ Speed Differential, V38+ (Outside Lane Speed Reduction) Average Speed Reduction Efficiency, V66+	Fixed Objects Within 10' of Inside Lane, V65++ Degree of Curve, V10++
	-	-	-
Rear-End Accident Rate (accidents/MV), V03	Percent Grade, V12+	-	Percent Grade, V12+
	-	-	-
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, V41++ (Inside Lane Speed Reduction)	Speed Differential, V41++ (Inside Lane Speed Reduction)	-
		-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-2. Linear regression results for rural isolated curves - Group A (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Degree of Curve, V10^{+++} Total Encroachment Rate, V17^{++}	Speed Differential, V38^{+} (Outside Lane Speed Reduction) Total Encroachment Rate, V17^{+}	Degree of Curve, V10^{+++}
	$V05 = -0.3234 + 0.1104\ V10$ $R^2 = 0.43$	-	$V05 = -0.3234 + 0.1104\ V10$ $R^2 = 0.43$
Inside Lane Accident Rate (accidents/MV), V07	Fixed Objects Within 10' of Inside Lane, V65^{++}	-	Fixed Objects Within 10' of Inside Lane, V65^{++}
	-	-	-
Outside Lane Accident Rate (accidents/MV), V08	Encroachment Rate, V33^{+++} (Outside Edge) Distance to Last Event, V13^{+++} (Outside Lane)	Encroachment Rate, V33^{+++} (Outside Edge)	Distance to Last Event, V13^{++}
	$V08 = 0.2027 + 0.02517\ V33$ $R^2 = 0.26$ $V08 = -0.01907 + 0.2884\ V13 + 0.02487\ V33$ $R^2=0.43$	$V08 = 0.2027 + 0.02517\ V33$ $R^2 = 0.26$	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-3. Linear regression results for rural isolated curves- Group B.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Degree of Curve, V10++ Fixed Objects Within 10' of Inside Lane, V65+ Total Encroachment Rate, V17+	Speed Differential, V38+ (Outside Lane Speed Reduction) Total Encroachment Rate, V17+ Avg. Speed Reduction Efficiency, V66+	Degree of Curve, V10++ Fixed Objects Within 10' of Inside Lane, V65+
	-	-	-
Rear-End Accident Rate (accidents/MV), V03	ADT, V09+++ Side Slope Angle, V63+++	Total Encroachment Rate, V17+++	ADT, V09+++ Side Slope Angle, V63+++
	$V03 = -0.07421 + 0.00004292\ V09 \quad R^2 = 0.65$ $V03 = -0.1026 + 0.00004184\ V09 + 0.0001284\ V63 \quad R^2 = 0.74$	$V03 = 0.1854 + -0.002679\ V17 \quad R^2 = 0.22$	$V03 = -0.07421 + 0.00004292\ V09 \quad R^2 = 0.65$ $V03 = -0.1026 + 0.00004184\ V09 + 0.0001284\ V63 \quad R^2 = 0.74$
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, V41+++	Speed Differential, V41+++	Degree of Curve, V10+++ Fixed Objects Within 10' of Inside Lane, V65++ Superelevation Error, V69+
	$V04 = 0.09346 + 0.03122\ V41 \quad R^2 = 0.25$	$V04 = 0.09346 + 0.03122\ V41 \quad R^2 = 0.25$	$V04 = -0.04376 + 0.01950\ V10 \quad R^2 = 0.24$

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-3. Linear regression results for rural isolated curves - Group B (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Degree of Curve, V10+++	-	Degree of Curve, V10+++ Fixed Objects Within 10' of Inside Lane, V65+
	V05 = -0.2715 + 0.09112 V10 R^2 = 0.41	-	V05 = -0.2715 + 0.09112 V10 R^2 = 041
Inside Lane Accident Rate (accidents/MV), V07	Encroachment Rate, V35+ (Inside Edgeline) Fixed Objects Within 10' of Inside Edge, V65+ Degree of Curve, V10+	Encroachment Rate, V35+	Fixed Object Within 10' of Inside Lane, V65+
		-	-
Outside Lane Accident Rate (accidents/MV), V08	Speed Differential, V38+++ ADT, V09+++	Speed Differential, V38+++	Supererror Outside, V68+++ ADT, V09++
	V08 = 0.2507 + 0.1001 V38 R^2 = 0.29 V08 = -0.05656 + 0.00009189 V09 + 0.09241 V38 R^2=0.47	V08 = 0.2507 + 0.1001 V38 R^2 = 0.29	V08 = 0.3402 + 0.1435 V68 R^2 = 0.25

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-4. Linear regression results for rural isolated curves - Group C.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Degree of Curve, V10+	-	Degree of Curve, V10+
	-	-	-
Rear-End Accident Rate (accidents/MV), V03	ADT, V09++	-	ADT, V09++
	-	-	-
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, V41+++	Speed Differential, V41+++	Degree of Curve, V10+++ Fixed Objects Within 10' of Inside Lane, V65++
	V04 = 0.1060 + 0.03524 V41 R^2 = 0.29	V04 = 0.1060 + 0.03524 V41 R^2 = 0.29	V04 = -0.05281 + 0.02438 V10 R^2 = 0.24

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-4. Linear regression results for rural isolated curves.- Group C (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Degree of Curve, V10+++	-	Degree of Curve, V10+++
	$V05 = -0.08511 + 0.08649\ V10$, $R^2 = 0.29$	-	$V05 = -0.08511 + 0.08649\ V10$, $R^2 = 0.29$
Inside Lane Accident Rate (accidents/MV), V07	-	-	-
	-	-	-
Outside Lane Accident Rate (accidents/MV), V08	Speed Differential, V38+++ Distance to Last Event, V13+++ (Outside Lane)	Speed Differential, V38+++	Degree of Curve, V10+++ Distance to Last Event Outside Lane, V13++
	$V08 = 0.3181 + 0.1506\ V38$, $R^2 = 0.32$ $V08 = 0.1183 + 0.3159\ V13 + 0.1458\ V38$, $R^2 = 0.49$	$V08 = 0.3181 + 0.1506\ V38$, $R^2 = 0.32$	$V08 = 0.07005 + 0.06129\ V10$, $R^2 = 0.20$

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-5. Linear regression results for rural isolated curves - Group D.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Speed Differential, V38+++	Speed Differential, V38+++ Total Encroachment Rate, V17++	Degree of Curve, V10+
	V02 = 0.6218 + 0.2491 V38 R^2 = 0.27	V02 = 0.6218 + 0.2491 V38 R^2 = 0.27	-
Rear-End Accident Rate (accidents/MV), V03	ADT, V09+	-	ADT, V09+
	-	-	-
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, V41+++	Speed Differential, V41+++	Degree of Curve, V10+++ Percent Grade, V12+
	V04 = 0.07042 + 0.05088 V41 R^2 = 0.52	V04 = 0.07042 + 0.05088 V41 R^2 = 0.52	V04 = -0.03708 + 0.02105 V10 R^2 = 0.24

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-5. Linear regression results for rural isolated curves - Group D (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Speed Differential, V38+++	Speed Differential, V38+++	Degree of Curve, V10+++
	V05 = 0.2571 + 0.1640 V38 R^2 = 0.44	V05 = 0.2571 + 0.1640 V38 R^2 = 0.44	V05 = 0.008064 + 0.06777 V10 R^2 = 0.29
Inside Lane Accident Rate (accidents/MV), V07	Encroachment Rate, V35++ (Inside Edgeline) Distance to Last Event, V14++ (Inside Lane)	Encroachment Rate, V35++ (Inside Edgeline)	Distance to Last Event, V14++ (Inside Lane)
		-	-
Outside Lane Accident Rate (accidents/MV), V08	Speed Differential, V38+++ Distance to Last Event, V13+++ (Outside Lane)	Speed Differential, V38+++	Distance to Last Event, V13+++ (Outside Lane) Degree of Curve, V10+++
	V08 = 0.2606 + 0.1485 V38 R^2 = 0.35 V08 = -0.002142 + 0.4825 V13 + 0.1292 V38 R^2 = 0.57	V08 = 0.2606 + 0.1485 V38 R^2 = 0.35	V08 = 0.2649 + 0.5704 V13 R^2 = 0.31 V08 = -0.1845 + 0.05030 V10 + 0.5078 V13 R^2 = 0.46

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-6. Linear regression results for rural isolated curves - Group E.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Total Encroachment Rate, V17+	Total Encroachment Rate, V17+	-
	-	-	-
Rear-End Accident Rate (accidents/MV), V03	Percent Grade, V12+	-	Percent Grade, V12+
	-	-	-
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, V41+ (Inside Lane)	Speed Differential, V41+ (Inside Lane)	-
	-	-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-6. Linear regression results for rural isolated curves - Group E (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Degree of Curve, V10^{+++} Superelevation Error, V69^{+++}	-	Degree of Curve, V10^{+++}
	V05 = -0.4043 + 0.1372 V10 R^2 = 0.42 V05 = -2.975 + 0.4985 V10 + -1.508 V69 R^2 = 0.68	-	V05 = -0.4043 + 0.1372 V10 R^2 = 0.42
Inside Lane Accident Rate (accidents/MV), V07	Fixed Objects Within 10' of Inside Lane, V65^{+}	-	Fixed Objects Within 10' of Inside Lane, V65^{+}
	-	-	-
Outside Lane Accident Rate (accidents/MV), V08	Encroachment Rate, V33^{+++} (Outside Edgeline) Distance to Last Event Outside Lane, V13^{+++}	Encroachment Rate, V33^{++} (Outside Edgeline)	Distance to Last Event Outside Lane, V13^{++}
	V08 = 0.01978 + 0.3186 V13 + 0.02708 V33 R^2 = 0.50	-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-7. Linear regression results for rural isolated curves - Group F.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	-	-	-
	-	-	-
Rear-End Accident Rate (accidents/MV), V03	ADT, V09+++	Total Encroachment Rate, V17+++	ADT, V09+++
	V03 = -0.06900 + 0.00004595 V09 R^2 = 0.72	V03 = 0.2233 + -0.003155 V17 R^2 = 0.32	V03 = -0.06900 + 0.00004595 V09 R^2 = 0.72
Opposite Direction Accident Rate (accidents/MV), V04	Degree of Curve, V10+++ Fixed Objects Within 10' of Inside Lane, V65++	Speed Differential, V41++	Degree of Curve, V10+++ Fixed Objects Within 10' of Inside Lane, V65++
	V04 = -0.06353 + 0.02286 V10 R^2 = 0.24	-	V04 = -0.06353 + 0.02286 V10 R^2 = 0.24

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-7. Linear regression results for rural isolated curves - Group F (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Degree of Curve, V10+++	-	Degree of Curve, V10+++
	V05 = -0.1280 + 0.08420 V10 R^2 = 0.30	-	V05 = -0.1280 + 0.08420 V10 R^2 = 0.30
Inside Lane Accident Rate (accidents/MV), V07	Percent Grade, V12+	-	Percent Grade, V12+
		-	
Outside Lane Accident Rate (accidents/MV), V08	Speed Differential, V38+++ (Outside Lane Speed Reduction) ADT, V09+++	Speed Differential, V38+++	Supererror, V68++ ADT, V09+
	V08 = 0.2959 + 0.1160 V38 R^2 = 0.34 V08 = 0.1615 + 0.00009103 V09 + 0.1125 V38 R^2 = 0.52	V08 = 0.2959 + 0.1160 V38 R^2 = 0.34	V08 = 0.3542 + 0.1961 V68 R^2 = 0.30

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-8. Linear regression results for rural isolated curves - Group G.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Speed Differential, V38++ (Outside Lane Speed Reduction)	Speed Differential, V38++ (Outside Lane Speed Reduction)	-
	-	-	-
Rear-End Accident Rate (accidents/MV), V03	ADT, V09+++	Total Encroachment Rate, V17+	ADT, V09+++
	$V03 = -0.06651 + 0.00004250\ V09$, $R^2 = 0.54$	-	$V03 = -0.06651 + 0.00004250\ V09$, $R^2 = 0.54$
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, V41+++ (Inside Lane Speed Reduction)	Speed Differential, V41+++ (Inside Lane Speed Reduction)	Degree of Curve, V10+++
	$V04 = 0.07441 + 0.04438\ V41$, $R^2 = 0.45$	$V04 = 0.07441 + 0.04438\ V41$, $R^2 = 0.45$	$V04 = -0.05455 + 0.01983\ V10$, $R^2 = 0.25$

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-8. Linear regression results for rural isolated curves - Group G (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Speed Differential, V38+++ (Outside Lane Speed Reduction)	Speed Differential, V38+++ (Outside Lane Speed Reduction)	Degree of Curve, V10+++
	V05 = 0.2528 + 0.1446 V38 R^2 = 0.44	V05 = 0.2528 + 0.1446 V38 R^2 = 0.44	V05 = -0.05137 + 0.06557 V10 R^2 = 0.34
Inside Lane Accident Rate (accidents/MV), V07	Encroachment Rate Inside Edgeline, V35+++	Encroachment Rate Inside Edgeline, V35+++	-
	V07 = 0.08331 + 0.03765 V35 R^2 = 0.26	V07 = 0.08331 + 0.03765 V35 R^2 = 0.26	-
Outside Lane Accident Rate (accidents/MV), V08	Speed Differential, V38+++ (Outside Lane Speed Reduction) ADT, V09++	Speed Differential, V38+++ (Outside Lane Speed Reduction)	Degree of Curve, V10+++
	V08 = 0.2094 + 0.1221 V38 R^2 = 0.43	V08 = 0.2094 + 0.1221 V38 R^2 = 0.43	V08 = -0.05503 + 0.05613 V10 R^2 = 0.34

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-9. Linear regression results for rural isolated curves - Group H.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate (accidents/MV), V02	Speed Differential, V38++ (Outside Lane Speed Reduction)	Speed Differential, V38++ (Outside Lane Speed Reduction)	-
	-	-	-
Rear-End Accident Rate (accidents/MV), V03	-	-	-
	-	-	-
Opposite Direction Accident Rate (accidents/MV), V04	Speed Differential, V41+++ (Inside Lane Speed Reduction)	Speed Differential, V41+++ (Inside Lane Speed Reduction)	Degree of Curve, V10++
	V04 = 0.07633 + 0.04688 V41 R^2 = 0.43	V04 = 0.07633 + 0.04688 V41 R^2 = 0.43	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-9. Linear regression results for rural isolated curves - Group H (Con't.).

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Run-Off-Road Accident Rate (accidents/MV), V05	Speed Differential, V38++ (Outside Lane Speed Reduction)	Speed Differential, V38++ (Outside Lane Speed Reduction)	-
	V05 = 0.3682 + 0.1355 V38 R^2 = 0.36	V05 = 0.3682 + 0.1355 V38 R^2 = 0.36	-
Inside Lane Accident Rate (accidents/MV), V07	-	-	-
	-	-	-
Outside Lane Accident Rate (accidents/MV), V08	Distance to Last Event Outside Lane, V13+++ Speed Differential, V38+++ (Outside Lane Speed Reduction)	Speed Differential, V38+++ (Outside Lane Speed Reduction) Encroachment Rate Outside Edgeline, V33++	Distance to Last Event Outside Lane, V13+++ Degree of Curve, V10+++
	V08 = 0.3061 + 0.7143 V13 R^2 = 0.51	V08 = 0.2977 + 0.1847 V38 R = 0.47	V08 = 0.3061 + 0.7143 V13 R^2 = 0.51
	V08 = 0.03227 + 0.5949 V13 + 0.1510 V38 R^2 = 0.81		V08 = -0.2379 + 0.06758 V10 + 0.5879 V13 R^2 = 0.68

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-10. Linear regression results for rural signalized intersections - All sites.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate, V10 (accidents/MV)	Total Approach Volume, V57^{+}	-	Total Approach Volume, 57^{+}
	-	-	-
Rear End Accident Rate, V11 (accidents/MV)	Total Approach Volume, V57^{+++} Signal Violation Rate, V56^{+}	-	Total Approach Volume, V57^{+++}
	V11 = 0.1539 + 0.00001962 V57 R^2 = 0.23	-	V11 = 0.1539 + 0.00001962 V57 R^2 = 0.23
Opposing Left Turn Accident Rate, V12 (accidents/MV)	Total Approach Volume, V57^{+++} Signal Violation Rate, V56^{+++}	Signal Violation Rate, V56^{++}	Total Approach Volume, V57^{+++}
	V12 = 0.05474 + 0.00001800 V57 R^2 = 0.26 V12 = -0.1273 + 0.3064 V56 + 0.00001836 V57 R^2 = 0.42	-	V12 = 0.05474 + 0.00001800 V57 R^2 = 0.26
Right Angle Accident Rate, V13 (accidents/MV)	Cycle Length, V26^{+}	-	Cycle Length, V26^{+}
	-	-	-
Driveway Accident Rate, V14 (accidents/MV)	Average Percent Trucks, V60^{++}	Average Percent Trucks, V60^{++}	-
	-	-	-
Injury Accident Rate, V16 (accidents/MV)	-	-	-
	-	-	-
Property Damage Only Accident Rate, V17 (accidents/MV)	Total Approach Volume, V57^{++}	-	Total Approach Volume, V57^{++}
	-	-	-
Rear End Accident Rate North, V18 (accidents/MV)	Percent Trucks N-S, V41^{+++}	Percent Trucks N-S, V41^{+++}	-
	V18 = 0.7178 + -0.05625 V41 R^2 = 0.21	V18 = 0.7178 + -0.05625 V41 R^2 = 0.21	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-10. Linear regression results for rural signalized intersections - All sites. (Continued)

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Approach Accident Rate North, V22 (accidents/MV)	Percent Right Turn (North) V44+++ Percent Left Turn (North), V43+	Percent Right Turn (North) V44+++ Percent Left Turn (North), V43+	-
	V22 = 0.4055 + 0.05915 V44 $R^2 = 0.30$	V22 = 0.4055 + 0.05915 V44 $R^2 = 0.30$	-
Rear End Accident Rate East, V19 (accidents/MV)	Percent Red E-W, V32+	-	Percent Red E-W, V32+
	-	-	-
Approach Accident East East, V23 (accidents/MV)	Approach Speed East, V38+	Approach Speed East, V38+	-
	-	-	-
Rear End Accident Rate South, V20 (accidents/MV)	Percent Amber N-S, V29+	-	Percent Amber N-S, V29+
	-	-	-
Approach Accident Rate South, V24 (accidents/MV)	DSLE South, V35+++	-	DSLE South, V35+++
	V24 = 0.7829 + 0.6221 V35 $R^2 = 0.22$	-	V24 = 0.7829 + 0.6221 V35 $R^2 = 0.22$
Rear End Accident Rate West, V21 (accidents/MV)	Erratic Maneuver Rate West, V55++	Erratic Maneuver Rate West, V55++	-
	-	-	-
Approach Accident Rate West, V25 (accidents/MV)	Percent Green E-W, V28+++	-	Percent Green E-W, V28+++
	V25 = 2.180 + -0.02144 V28 $R^2 = 0.17$	-	V25 = 2.180 + -0.02144 V28 $R^2 = 0.17$

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-11. Linear regression results for rural signalized intersections - Group A.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate, V10 (accidents/MV)	ADT, V57+	-	-
	-	-	-
Rear End Accident Rate, V11 (accidents/MV)	ADT, V57+	-	-
	-	-	-
Opposing Left Turn Accident Rate, V12 (accidents/MV)	ADT, V57+	-	-
	-	-	-
Right Angle Accident Rate, V13 (accidents/MV)	-	-	-
	-	-	-
Driveway Accident Rate, V14 (accidents/MV)	Percent Trucks, V60+++ Signal Violation Rate, V56+++	Percent Trucks, V60+++ Signal Violation Rate, V56+++	-
	$V14 = -0.03461 + 0.03541\ V60$, $R^2 = 0.29$ $V14 = 0.1475 + -0.3329\ V56 + 0.03690\ V60$, $R^2=0.53$	$V14 = -0.03461 + 0.03541\ V60$, $R^2 = 0.29$ $V14 = 0.1475 + -0.3329\ V56 + 0.03690\ V60$, $R^2=0.53$	-
Injury Accident Rate, V16 (accidents/MV)	Percent Trucks, V60+	Percent Trucks, V60+	-
	-	-	-
Property Damage Only Accident Rate, V17 (accidents/MV)	ADT, V57+++	-	-
	$V17 = 0.4885 + 0.00003422\ V57$, $R^2 = 0.27$	-	-
Rear End Accident Rate North, V18 (accidents/MV)	Percent Trucks N-S, V41++	Percent Trucks N-S, V41++	-
	-	-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-11. Linear regression results for rural signalized intersections - Group A. (Continued)

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Approach Accident Rate North, V22 (accidents/MV)	Percent Right Turn North, V44^{+++}	Percent Right Turn North, V44^{+++} Percent Left Turn North, V43^{+++}	Percent Green N-S, V27^{++} Percent Amber N-S, V29^{++}
	$V22 = -0.2941 + 0.07782\ V44$ $R^2 = 0.47$	$V22 = -0.2941 + 0.07782\ V44$ $R^2 = 0.47$	-
Rear End Accident Rate East, V19 (accidents/MV)	Erratic Maneuver Rate East, V53^{++}	Erratic Maneuver Rate East, V53^{++}	-
	-	-	-
Approach Accident Rate East, V23 (accidents/MV)	Approach Speed East, V38^{++}	Approach Speed East, V38^{++}	DSLE East, V35^{+}
	-	-	-
Rear End Accident Rate, South, V20 (accidents/MV)	DSLE South, V35^{+}	-	DSLE South, V35^{+}
	-	-	-
Approach Accident Rate, South, V24 (accidents/MV)	DSLE South, V35^{+++} Percent Left Turn South, V47^{++}	Percent Left Turn South, V47^{+++}	DSLE South, V35^{+++}
	$V24 = 0.5563 + 0.6823\ V35$ $R^2 = 0.44$	$V24 = 0.5360 + 0.03377\ V47$ $R^2 = 0.35$	$V24 = 0.5563 + 0.6823\ V35$ $R^2 = 0.44$
Rear End Accident Rate West, V21 (accidents/MV)	Erratic Maneuver Rate West, V55^{++}	Erratic Maneuver Rate West, V55^{++}	-
	-	-	-
Approach Accident Rate West, V25	DSLE West, V36^{+++} Erratic Maneuver Rate West, V55^{+}	Erratic Maneuver Rate West, V55^{+}	DSLE West, V36^{+++}
	$V25 = 0.2190 + 0.9761\ V36$ $R^2 = 0.33$	-	$V25 = 0.2190 + 0.9761\ V36$ $R^2 = 0.33$

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-12. Linear regression results for rural signalized intersections - Group B.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate, V10 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate, V11 (accidents/MV)	Signal Violation Rate, V56^{+}	Signal Violation Rate, V56^{+}	-
	-	-	-
Opposing Left Turn Accident Rate, V12 (accidents/MV)	ADT, V57^{++} Signal Violation Rate, V56^{++}	Signal Violation Rate, V56^{++}	-
	-	-	-
Right Angle Accident Rate, V13 (accidents/MV)	Cycle Length, V26^{++}	Approach Speed, V59^{++}	Cycle Length, V26^{++}
	-	-	-
Driveway Accident Rate, V14 (accidents/MV)	Total Erratic Manuever Rate, V51^{+++}	Total Erratic Manuever Rate, V51^{+++}	-
	$V14 = -0.1145 + 0.3915\ V51$ $R^2 = 0.34$	$V14 = -0.1145 + 0.3915\ V51$ $R^2 = 0.34$	-
Injury Accident Rate, V16 (accidents/MV)	Approach Speed, V59^{+++} Cycle Length, V26^{+}	Approach Speed, V59^{+++}	-
	$V16 = -1.429 + 0.06671\ V26$ $R^2 = 0.42$	$V16 = -1.429 + 0.06671\ V26$ $R^2 = 0.42$	-
Property Damage Only Accident Rate, V17 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate North, V18 (accidents/MV)	Percent Trucks N-S, V41^{+}	Percent Trucks N-S, V41^{+}	-
	-	-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-12. Linear regression results for rural signalized intersections - Group B. (Continued)

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Approach Accident Rate North, V22 (accidents/MV)	Percent Right Turn North, V44+++	Percent Right Turn North, V44+++	-
	V22 = 0.4406 + 0.06652 V44 R^2 = 0.37	V22 = 0.4406 + 0.06652 V44 R^2 = 0.37	-
Rear End Accident East, V19 (accidents/MV)	-	-	-
	-	-	-
Approach Accident East, V23 (accidents/MV)	Percent Right Turn East, V46++	Percent Right Turn East, V46++	-
	-	-	-
Rear End Accident Rate South, V20 (accidents/MV)	Percent Left Turn South, V47+	Percent Left Turn South, V47+	-
	-	-	-
Approach Accident Rate South, V24 (accidents/MV)	DSLE South, V35+	-	DSLE South, V35+
	-	-	-
Rear End Accident Rate West, V21 (accidents/MV)	-	-	-
	-	-	-
Approach Accident Rate West, V25 (accidents/MV)	Percent Left Turn West, V49+++ Cycle Length, V26+	Percent Left Turn West, V49+++	Cycle Length, V26+++ Percent Green E-W, V28+ Percent Red West, V32+
	V25 = 1.061 + 0.02871 V49 R^2 = 0.37	V25 = 1.061 + 0.02871 V49 R^2 = 0.37	V25 = 4.288 + -0.04370 V26 R^2 = 0.32

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-13. Linear regression results for rural signalized intersections - Group C.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate, V10 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate, V11 (accidents/MV)	ADT, V57++	Signal Violation Rate, V56++	ADT, V57++
	-	-	-
Opposing Left Turn Accident Rate, V12 (accidents/MV)	Signal Violation Rate, V56+++ Percent Trucks, V60+++	Signal Violation Rate, V56+++ Percent Trucks, V60+++ Approach Speed, V59++	-
	V12 = 0.1450 + 0.4044 V56, $R^2 = 0.3536$ V12 = 0.5895 + 0.4101 V56 + -0.08015 V60, $R^2 = 0.63$	V12 = 0.1450 + 0.4044 V56, $R^2 = 0.3536$ V12 = 0.5895 + 0.4101 V56 + -0.08015 V60, $R^2 = 0.63$	-
Right Angle Accident Rate, V13 (accidents/MV)	Cycle Length, V26+++	Approach Speed, V59+	Cycle Length, V26+++
	V13 = 2.683 + -0.03120 V26, $R^2 = 0.38$	-	V13 = 2.683 + -0.03120 V26, $R^2 = 0.38$
Driveway Accident Rate, V14 (accidents/MV)	-	-	-
	-	-	-
Injury Accident Rate, V16 (accidents/MV)	Cycle Length, V26++	-	Cycle Length, V26++
	-	-	-
Property Damage Only Accident Rate, V17 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate North, V18 (accidents/MV)	Percent Trucks N-S, V41+++	Percent Trucks N-S, V41+++	DSLE North, V18++
	V18 = 1.063 + -0.1227 V41, $R^2 = 0.32$	V18 = 1.063 + -0.1227 V41, $R^2 = 0.32$	

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-13. Linear regression results for rural signalized intersections - Group C. (Continued)

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Approach Accident Rate North, V22 (accidents/MV)	Percent Right Turn North, V44+++ Percent Amber N-S, V29+++ Percent Left Turn N, V43+++ Percent Right Turn N, V44++	Percent Right Turn North, V44+++	Percent Amber N-S, V29+++ Percent Green N-S, V27++
	V22 = 0.4185 + 0.07194 V44 R^2 = 0.40 V22 = -5.685 + 0.8104 V29 + 0.1133 V43 R^2 = 0.67	V22 = 0.4185 + 0.07194 V44 R^2 = 0.40	V22 = -4.567 + 0.8863 V29 R^2 = 0.38
Rear End Accident Rate East, V19 (accidents/MV)	Percent Red E-W, V32+++	-	Percent Red E-W, V32+++
	V19 = -1.122 + 0.02983 V32 R^2 = 0.33	-	V19 = -1.122 + 0.02983 V32 R^2 = 0.33
Approach Accident Rate East, V23 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate South, V20 (accidents/MV)	Approach Speed South, V39+	Approach Speed South, V39+	-
	-	-	-
Approach Accident Rate South, V24 (accidents/MV)	DSLE South, V35+++	-	DSLE South, V35+++
	V24 = 0.6838 + 0.7710 V35 R^2 = 0.31	-	V24 = 0.6838 + 0.7710 V35 R^2 = 0.31
Rear End Accident Rate West, V21 (accidents/MV)	-	-	-
	-	-	-
Approach Accident Rate West, V25 (accidents/MV)	Percent Green E-W, V28++	-	Percent Green E-W, V28++
	-	-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-14. Linear regression results for rural signalized intersections - Group D.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate, V10 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate, V11 (accidents/MV)	ADT, V57+++	Signal Violation Rate, V56+	ADT, V57+++
	V11 = 0.1169 + 0.00002142 V57 R^2 = 0.31	-	V11 = 0.1169 + 0.00002142 V57 R^2 = 0.31
Opposing Left Turn Accident Rate, V12 (accidents/MV)	Approach Speed, V59+++ Signal Violation Rate, V56+++	Approach Speed, V59+++ Signal Violation Rate, V56+++	-
	V12 = 3.302 + -0.07329 V59 R^2 = 0.38 V12 = 3.077 + 0.3404 V56 -0.07217 V59 R^2=0.60	V12 = 3.302 + -0.07329 V59 R^2 = 0.38 V12 = 3.077 + 0.3404 V56 -0.07217 V59 R^2=0.60	-
Right Angle Accident Rate, V13 (accidents/MV)	Percent Left Turn, V61+++ Cycle Length, V26++	Percent Left Turn, V61+++	Cycle Length, V26++
	V13 = -0.2691 + 0.06326 V26 R^2 = 0.34	V13 = -0.2691 + 0.06326 V26 R^2 = 0.34	-
Driveway Accident Rate, V14 (accidents/MV)	Percent Trucks, V60+	Percent Trucks, V60+	-
	-	-	-
Injury Accident Rate, V16 (accidents/MV)	-	-	-
	-	-	-
Property Damage Only Accident Rate, V17 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate North, V18 (accidents/MV)	Percent Trucks N-S, V41++	Percent Trucks N-S, V41++	-
	-	-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-14. Linear regression results for rural signalized intersections - Group D. (Continued)

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Approach Accident Rate North, V22 (accidents/MV)	Percent Right Turn North, V44+++	Percent Right Turn North, V44+++	Percent Amber N-S, V29+
	$V22 = 0.4677 + 0.06515\ V44$, $R^2 = 0.36$	$V22 = 0.4677 + 0.06515\ V44$, $R^2 = 0.36$	-
Rear End Accident Rate East, V19 (accidents/MV)	Percent Red E-W, V32+++ Erratic Maneuver Rate East, V53+	Percent Left Turn East, V45+ Erratic Maneuver Rate East, V53+	Percent Red E-W, V32+++
	$V19 = -0.9336 + 0.02707\ V32$, $R^2 = 0.30$	-	$V19 = -0.9336 + 0.02707\ V32$, $R^2 = 0.30$
Approach Accident Rate East, V23 (accidents/MV)	Percent Right Turn East, V46+++	Percent Right Turn East, V46+++	-
	$V23 = 0.5669 + 0.04039\ V46$, $R^2 = 0.33$	$V23 = 0.5669 + 0.04039\ V46$, $R^2 = 0.33$	-
Rear End Accident Rate South, V20 (accidents/MV)	-	-	-
	-	-	-
Approach Accident Rate South, V24 (accidents/MV)	-	-	-
	-	-	-
Rear End Accident Rate West, V21 (accidents/MV)	-	-	-
	-	-	-
Approach Accident Rate West, V25 (accidents/MV)	Percent Left Turn West, V49++ Percent Trucks E-W, V42++	Percent Left Turn West, V49++ Percent Trucks E-W, V42++	-
	-	-	-

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

Table G-15. Linear regression results for urban undivided tangents.

Dependent Variable	Operational and Non-Operational Variables	Operational Variables Only	Non-Operational Variables Only
Total Accident Rate, V12 (accidents/MVM)	No. Unsignalized Intersections per Mile, V37+++	-	No. Unsignalized Intersections per Mile, V37+++
	V12 = 1.5675 + 0.1209 V37 R^2 = 0.13	-	V12 = 1.5675 + 0.1209 V39 R^2 = 0.13
Rear-End Accident Rate, V13 (accidents/MVM)	Volume to Capacity Ratio, V33+++ No. Unsignalized Intersections per Mile, V37++ No. Signalized Intersections per Mile, V38++	Volume to Capacity Ratio, V33+++ No. Unsignalized Intersections per Mile, V37++ No. Signalized Intersections per Mile, V38++	Volume to Capacity Ratio, V33+++ No. Unsignalized Intersections per Mile, V37++ No. Signalized Intersections per Mile, V38++
	V13 = 0.3206 + 1.6740 V33 R^2 = 0.15	V13 = 0.3206 + 1.6740 V33 R^2 = 0.15	V13 = 0.3206 + 1.6740 V33 R^2 = 0.15
Opposite Direction Accident Rate, V14 (accidents/MVM)	No. Warning Signs per Mile, V41++ No. Driveways per Mile, V34++ Volume to Capacity Ratio, V33++	Volume to Capacity Ratio, V33+	No. Warning Signs per Mile, V41++ No. Driveways per Mile, V34++ Volume to Capacity Ratio, V33++
	-	-	-
Driveway Accident Rate, V15 (accidents/MVM)	-	-	-
	-	-	-
Angle Accident Rate, V16 (accidents/MVM)	-	-	-
	-	-	-
Fixed Object Accident Rate, V17 (accidents/MVM)	Volume to Capacity Ratio, V33+++ No. Commercial Driveway per Mile, V35+	Volume to Capacity Ratio, V33+++	No. Commercial Driveway per Mile, V35+
	V17 = 0.9673 - 1.3946 V33 R^2 = 0.25	V17 = 0.9673 - 1.3946 V33 R^2 = 0.25	

+++ Meets all significance tests at 0.05 level. ++ Meets all tests at 0.10 level. + Meets all tests at 0.20 level.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.