AN EVALUATION OF ACCIDENT SURROGATES FOR SAFETY ANALYSIS OF RURAL HIGHWAYS

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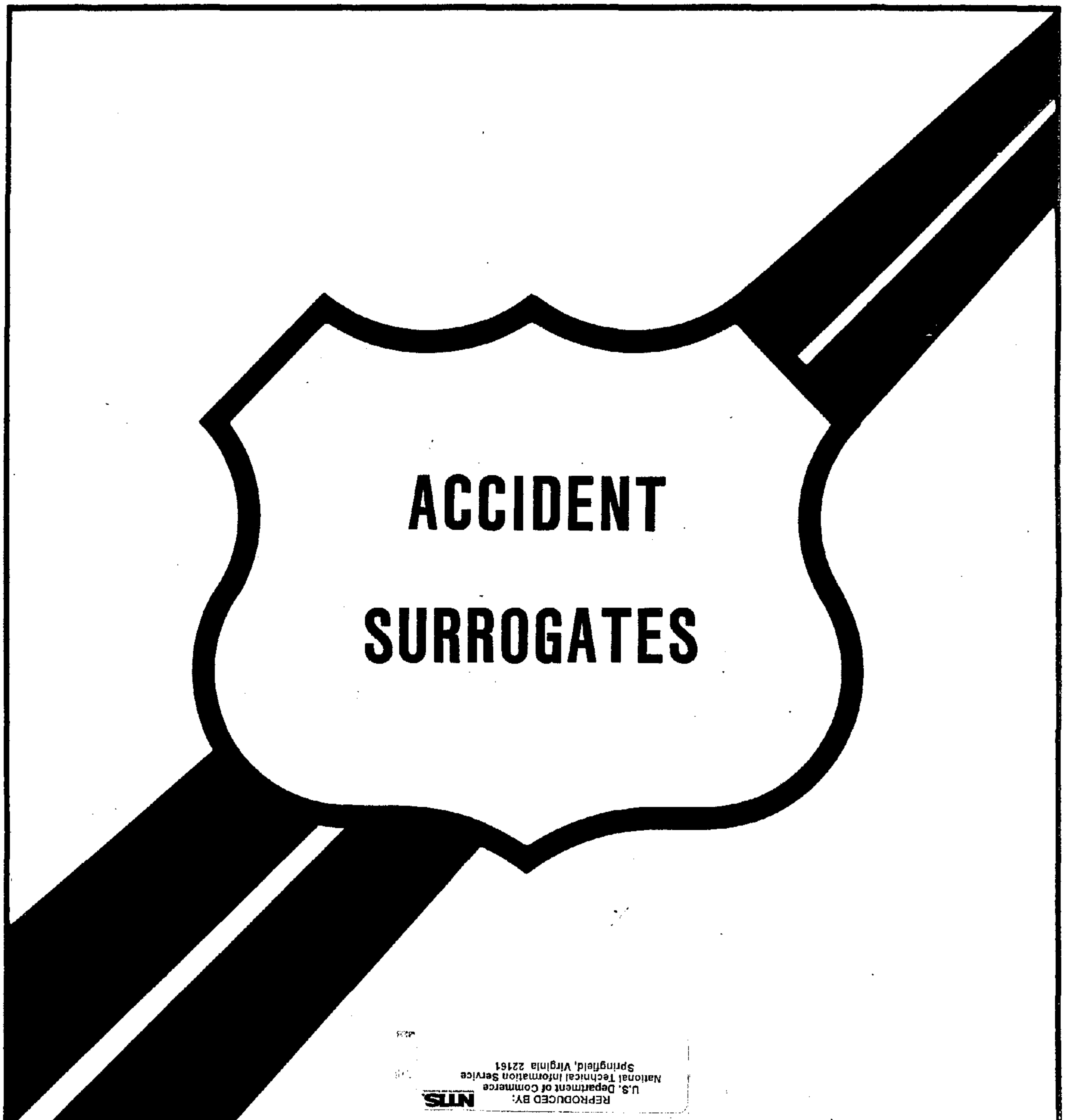

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16. Abstract

The objective of this study was to validate the use of accident surrogate measures for analyzing safety on rural highways. Emphasized were inexpensive, quickly obtained measures. They were tested for isolated horizontal curves and unsignalized intersections on 2-lane State highways.

From a literature review, 23 potential surrogates for curve accidents and 20 for intersection accidents were identified. They were measured in samples of 78 curves and 121 intersections in western New York. Predictive equations for accident rates were derived by multiple regression analysis. Degree of curvature and traffic volume were the best predictor variables for curves, while major and minor road traffic volume, minor road average stopped delay, and percent left turns were the best predictor variables for the intersections. The maximum variance in accident rates accounted for was 31 percent, but mathematical considerations suggested that stronger relationships were theoretically possible with more reliable and precise surrogate measures. Increasing reliability through sophisticated instrumentation, longer measurement periods, and other methods was recommended.

This volume is the second in a series. The other volumes are:

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NOTICE

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LIST OF ABBREVIATIONS AND SYMBOLS

acc.	=	accidents
ADT	=	average daily traffic
AADT	=	average annual daily traffic
AASHTO	=	American Association of State Highway and Transportation Officials
CC	=	change of curvature
DOT	=	Department of Transportation
FHWA	=	Federal Highway Administration
IL	=	inside lane
is. veh.	=	isolated vehicles
OL	=	outside lane
PC	=	point of curvature
PT	=	point of tangency
R	=	coefficient of multiple correlation
RMS vol	=	root-mean-square volume = $\sqrt{\text{major road volume x minor road volume}}$
veh	=	vehicles

CHAPTER ONE
INTRODUCTION

This study evaluated the use of accident surrogates as measures of safety at rural isolated curves and unsignalized intersections. It continued the work begun in a previous study, in which Goodell-Grivas, Inc. explored a large number of possible surrogates at a relatively small number of sites in Michigan (Datta, Perkins, Taylor, and Thompson, 1983). In addition, that study included a literature review of previous research bearing on accident surrogates, and a workshop of highway safety experts who identified candidate surrogate variables. The study presented here built upon the work begun by Goodell-Grivas, and it was conducted for the Federal Highway Administration (FHWA) by Calspan Corporation.

The most accepted measure of safety for a given highway location has been accident experience. However, accidents are infrequent and data need to be collected over long time periods to be reliable. This problem is greatest at many rural locations where low traffic volumes require several years to establish an accident rate. Consequently, interest has developed within the highway safety community in finding substitute measures that (a) can be quickly obtained, (b) do not require elaborate equipment, and (c) validly indicate the relative safety (accident risk) of a highway location. These measures would be "accident surrogates".

This study sought accident surrogates meeting the following criteria:

1. Relationship to Accidents. There must exist a quantified relationship between the accident experience and the accident surrogate.
2. Definition. The accident surrogates must be clearly defined, observable, and measurable.
3. Ease of Data Collection. The surrogates should be measured simply, in a short time, and at low cost.

4. Affectability. There must be a high probability that a change in the accident surrogate value will affect or reflect a change in the accident experience.

5. Reliability. The measures should be consistent when repeated over time or by different data collectors.

During the planning phase of this study, consideration was given to the types of spot locations offering the most promise for accident surrogate development. Consequently, two types were chosen:

- Isolated curves on rural two-lane roads.
- Unsignalized intersections on rural two-lane roads.

OBJECTIVES

The general objective of the study was to validate the use of accident surrogates at rural curves and unsignalized intersections, and the specific objectives were as follows:

1. To quantify the relationship between surrogate measures and accident experience.

2. To develop methods for using surrogates to:

   a. Identify and rank hazardous locations.

   b. Evaluate accident countermeasures.

   c. Review design plans.

EXPLICATING THE "ACCIDENT SURROGATES" CONCEPT

Since accidents are events, ideal surrogates would be other events which correlate with accidents over time; as accidents (or rates) increase or decrease, these events (or their rates) increase or decrease accordingly. Both accidents and surrogate events are likely to be consequences of the same hazardous causes. Preferably, the surrogate events occur sufficiently often so that a count of them over a brief time period will reflect the number of accidents (which are rare events) over a longer period of time. It is this attribute that would make such surrogates valuable, and because these surrogates are events, they may be used for before-after countermeasures evaluations at any one location. Such surrogates may also be used to compare hazardousness among locations at any one time. Traffic conflicts are a good example of this type of intended surrogate (Glauz, Bauer, and Migletz, 1985).

Ideal accident surrogates are hard to find, however. Consequently, the adopted surrogates criteria more broadly include nearly any variable that correlates with accidents, accident rates, or accident severities; some surrogates may correlate with accidents over time, while others correlate only across locations at a particular time. Thus, static measures reflecting hazardous properties of the locations could be surrogates. Unlike the event surrogates, the static ones cannot reveal whether countermeasures have been effective.

Generally, ideal surrogates would include only traffic operational variables, e.g., encroachments, conflicts, erratic maneuvers, while the broader approach permits nonoperational variables as well, e.g., degree of curvature, sight distance, edgeline width, provided that such variables correlate with accident data. These kinds of variables are related to the study objectives as follows:

- Identification of hazardous locations can use both operational (dynamic) and nonoperational (static) factors. Hazardous conditions may be created by either type or by an interaction between them; e.g., in the ratio of traffic volume to capacity.
- Evaluation of countermeasures must use operational measures, in order to reflect traffic responses to an attempted reduction of hazards.
- Design evaluations necessarily apply nonoperational surrogates, which become criteria against which to judge the design features.

Single Variables or Equations?

If there were several accident surrogates found for a type of site such as an isolated curve, each one could be used to estimate a site's relative hazardousness. More accurate estimation might be obtained, however, by using some or all of the variables in a mathematical equation that accounts for the unique contributions of each surrogate as well as for interaction among them. In this study, three equations were sought for the isolated curves and unsignalized intersections, respectively. Corresponding to the three applications, one equation would include only operational variables, another would include only nonoperational ones, and a third would include both.

Surrogates for Rates or for Frequencies?

Since accident surrogates were defined as measures to indicate accident probabilities, which in turn must be expressed in relation to exposure events, it is clear that surrogates are sought for accident rates. Just what the denominator (exposure units) for accident rates should be will be addressed empirically in reporting the results of this study.

THE STARTING POINT: PRIOR INDICATIONS OF RURAL CURVE AND UNSIGNALIZED INTERSECTION ACCIDENT SURROGATES

Since this research was to utilize the promising output from the large body of accident causation studies, the starting point for identifying accident surrogates was the existing literature. Heavy reliance was made on the literature review in the Goodell-Grivas study, although reference was also made to other literature reviews and to original studies for specific details in a few instances.

Goodell-Grivas's empirical explorations provided a foundation for this study, so their results will be discussed in some detail. In addition, a major study of rural curves by Jack Leisch and Associates will be given special attention. While not specifically seeking accident surrogates, it provided valuable information on non-operational correlates of curve accidents (Glennon, Neuman, and Leisch, 1983). It also provided a valuable critical review of previous research on curve accidents.

Rural Isolated Curves

Accident types. Goodell-Grivas provided data on the kinds of accidents found at the 25 rural curves they studied. Road departures were definitely the most frequent collision type, with head-ons and rear-ends following in that order.

To provide a broader view of the accident types to be found on curves, table 1 lists details of curve accidents in the National Crash Severity Study (NCSS), the Leisch study (Glennon et al., 1983), and a review by Smith et al. (1981). Some commonalities can be discerned. Single-vehicle accidents, especially road departures, predominated. The Leisch study found a substantial number of other collision types, but the collision mix was probably influenced by the inclusion of tangent sections beyond the extremities of curves. The proportions of head-on and rear-end collisions varied considerably across the studies.

Another prominent characteristic of rural curve accidents is their occurrence on dry pavement. It is possible that wet or icy pavements increase curve accidents, but statistically the dry conditions heavily predominate. No other condition achieves great prominence, though there are tendencies in certain directions, e.g., for curve accidents to be on level roads or downgrades. The proportions of night and day accidents may be fairly equal.

Surrogates. The Goodell-Grivas and Leisch literature reviews revealed the following variables to be related to the accident rates on curves, in one or more studies:

Table 1. Accident characteristics at rural curves.

	Proportions of Total Accidents		
Manner of Collision	NCSS[1] (1978-79)	Glennon et al., 1983	Smith et al., 1981
Road departure	65.3% (Road departure and Other single veh.)	35.4%	75% (Road departure and Other single veh.)
Other single veh.		19.0	
Head-on	13.2	7.0	18
Side, angle side	9.9	19.0	6
Rear-end	1.9	14.6	1
Sideswipe	0.2	5.3	NA
Misc. object	4.5	NA[2]	NA
Other	5.0	NA	NA
Number Vehicles			
One	71.4 %	54.4%	75%
Two	26.9	45.6 (Two and Three or more)	25 (Two and Three or more)
Three or more	1.7		
Time of Day			
Night	63.9%	39.3%	47%
Day	36.1	60.7	53
Road Condition			
Dry	70.4%	72.5%	77%
Wet	20.8	27.5 (Wet, Ice and Snow)	23 (Wet, Ice and Snow)
Ice	5.2		
Snow	3.0		
Other	0.6	NA	NA
Horizontal Alignment			
Curve right	43.4%	NA	NA
Curve left	56.6	NA	NA
Vertical Alignment			
Level	42.4%	NA	NA
Grade up	19.4	NA	NA
Grade down	32.5	NA	NA
Crest	3.4	NA	NA
Sag	2.3	NA	NA
Severity			
Fatal	NA	41.5% (Fatal and Injury)	2%
Injury	NA		43
Property Damage Only	NA	58.5	55

[1]NCSS = National Crash Severity Study

[2]NA = data not available

- Degree of curvature.
- "Isolatedness": distance from other curves.
- Access points on curve.
- Shoulder width.
- Clear zone width.
- Pavement width.
- Degree of roadside slope.
- Traffic volume.

An important point to note in the Goodell-Grivas and Leisch reviews is the near-absence of operational variables correlated with curve accidents. Only traffic volume was suggested as a possible operational accident surrogate.

Degree of curvature appears complexly related to accidents. One complication is that the relationship may be curvilinear, as accident rates have been found to increase mainly with curvatures above four degrees. Another complication is that curvature seems to interact with other variables in the following ways:

- Curvature was found positively related to accident rate at low traffic volumes, but negatively related at high volumes (Raff, 1953).
- Steep grades appear to multiply the effect of curvature on accidents, at least at low traffic volumes (Raff, 1953; Bitzel, 1957; Billion and Stohner, 1957).
- Traffic control devices seem to be effective in reducing accidents mainly on sharp curves (Taylor and Foody, 1966; Leisch, 1971).

In the Goodell-Grivas field study, 25 isolated curves had a median of 3.4 accidents over 3 years. Multiple regression analysis was used to reveal the relationships betweenpotential surrogates and accident rates (accidents per million vehicles). Unfortunately, only 16 percent of the variance in total accident rates could be accounted for, and that was by one variable: degree of curvature. With rates of specific accident types, however, the proportions of variance explained (R^2), all statistically significant ($p < .05$), were as follows:

- Road departures - 37%
- Head-ons - 31%
- Rear-ends - 16%
- Outside lane crashes - 26%

While these figures indicate only modest explanatory or predictive power, results appeared much better for analyses concentrated on particular subsets of curves, e.g., those with grades under 4 percent, or with low residential land use and speed limits above 45 mi/h (75 km/h). Those results may not be reliable, however, as they were ex post facto selections of the best results from 162 separate regression analyses.

Only a few of the many surrogate candidates provided "significant" regression relationships, and the predictor variables tended to vary by accident type. The best-appearing candidates were as follows:

Road-departure accidents

- Degree of curvature.
- Superelevation error (AASHTO-recommended minus the actual).

Rear-end accidents

- Traffic volume.
- Side slope angle.

Outside lane accidents

- Outside lane speed reduction.
- Distance to last outside lane "event".

Note that traffic volume and outside lane speed reduction (average approach speed minus speed at curve midpoint) appeared as operational surrogate variables. The analyses also suggested the rate of edgeline and centerline encroachments as weakly related to accident rates.

The Leisch study of accidents at 3,304 rural curves was actually a study of accidents in 0.62-mi (1-km) road segments containing a curve (Glennon, Neuman, and Leisch, 1983). As the average length of curve was 0.15-mi (0.24 km), the accident counts necessarily included accidents occurring elsewhere than on a curve. The dependent variable in their analyses was accidents per road segment, with a median 3-year count of 2.4 accidents.

For a first analysis of the accidents, the Leisch study used analysis of covariance to study the effects of average daily traffic (ADT), degree of curvature, length of curve, roadway width, and shoulder width. Curves in four States were studied, and "State" was also used as a predictor variable. Similar to the Goodell-Grivas results, only 19 percent of the variance in total accident rate could be accounted for. "State," degree of curvature, and their two-way interactions with other variables accounted for most of the explained variance. Unlike the Goodell-Grivas results, little success was had when using as dependent variables the single vehicle, multivehicle, night, and fatal-plus-injury accident rates.

The Leisch analysis produced more impressive-looking results when multiple discriminant analysis was used to distinguish segments at the high-accident and low-accident extremes (about 10 percent of the total sample). After beginning with 12 predictor variables, a solution using 5 of them was able to correctly classify 69 percent of the segments as "high-accident" or "low-accident" sites. The predictor variables, in descending order of discriminating power, were:

- Roadside rating (accounting for side slopes and obstacles).
- Shoulder width.
- Length of curve.
- Degree of curvature.
- Pavement skid rating.

Nearly as high a success rate (66 percent) was found by using only degree and length of curve and shoulder width as predictor variables. While the results support the importance of these variables as accident surrogates, caution is needed in interpreting the strength of the relationships. Instead of beginning with sites already identified as the low-and high-accident extremes, the normally desired application is to identify high accident sites within the total population.

Summary. Regarding possible accident surrogates, the picture is fairly consistent on some variables and inconsistent on others. Degree of curvature was consistently found related to curve accidents, and it appears to have interaction effects with other variables such as volume, grade, and the presence/absence of traffic control devices. Inconsistent results, however, were obtained with roadside variables. The Leisch study found its roadside hazard variable, which refers to side slopes and fixed objects, to be its strongest discriminator of high-accident sites. Yet Goodell-Grivas found side slope and fixed object ratings to be at best poor predictors of accidents.

Because of the varied findings, it was necessary to use careful judgment to identify the more promising and less promising accident surrogates on curves. Considered more promising were those variables either consistently found related to accidents or found strongly related in a well-executed study. Variables possessing these attributes to a lesser degree were judged accordingly. Table 2 shows our judgments of the variables studied. Note that operational variables are not among the strongest surrogate candidates.

Rural Unsignalized Intersections

Although there are an estimated 2.6 million intersections in the rural two-lane highway system in the United States (Smith et al., 1981), a limited number of investigations has been conducted to identify safety problems and relationships between accidents and geometric, environmental, and operational variables. Accident types and surrogate candidates identified in these studies are summarized below.

Accident types. Shown in table 3 are distributions of rural intersection accidents by type. There are some large differences in the percentages among the three data sources. For example, angle collisions ranged from 24.1 percent in the Smith study to 51.6 percent in the NCSS data. However, each of the sources indicate that angle and run-off-road accidents are the predominant collision types at rural intersections.

Other prominent conditions worth noting in the intersection accidents are that they include predominantly daytime accidents, they occur mostly on dry pavements, and nearly all happened at tee and cross intersections. Information on traffic controls was limited to the study by Parker and colleagues (1983) in Michigan, but that one found stop signs predominating at the crash sites.

Surrogates. In the Goodell-Grivas study, the following candidate surrogates were identified for rural unsignalized intersections:

Table 2. Candidate accident surrogates for rural isolated curves.

(As determined from literature review.)

	Operational/ Nonoperational	
	Op.	Nonop.
"Best Bets"		
Radius of curvature, especially interacting with:		•
• Traffic volume	•	
• Grade		•
• Presence/absence of traffic control devices		•
Distance from last event, outside lane		•
Moderately Promising		
Roadside hazard rating		•
Shoulder width		•
Length of curve		•
Outside-lane speed reduction	•	
Superelevation error		•
Traffic volume	•	
Lateral placement variance, outside lane	•	
Weakly Promising		
Total encroachment rate	•	
Number access points on curve		•
Shoulder type		•
Pavement width		•
Pavement skid rating		•
Pavement marking		•
Not Promising		
Average speed reduction efficiency[1]	•	
Advance sight distance		•
Distance to last event, inside lane		•
Centerline encroachment rate	•	
Edgeline encroachment rate	•	
Maximum superelevation		•
Approach alignment		•

[1]A complex variable relating actual speed reduction to "desired" speed reduction.

Table 3. Accident characteristics at rural unsignalized intersections.

Manner of Collision	Smith et al., 1981	Parker et al., 1983	NCSS[1] (1978-79)
Run-off-road	28.5%	37.5%	19.3%
Head-on	5.5	1.8	9.9
Angle	24.1	29.9	51.6
Rear-end	18.3	15.0	7.1
Sideswipe	NA[2]	10.0	0.0
Other	23.6	5.8	12.1
Number of vehicles			
Single vehicle	28.5	35.2	21.1
Multiple vehicle	71.5	64.8	78.9
Time of Day			
Day	70.1	57.3	60.3
Night	29.9	42.7	39.7
Road Condition			
Dry	75.3	64.3	72.8
Wet	19.7	20.4	18.9
Snow or ice	5.1	14.8	8.0
Other	0.0	0.6	0.3
Type of Control			
Stop	NA	78.8	NA
No control	NA	1.1	NA
Other	NA	20.1	NA
Geometry			
Tee	NA	41.9	43.9
Cross	NA	48.4	53.9
Other	NA	9.7	2.2
Alinement			
Horizontal curve	NA	51.4	15.7
Tangent	NA	48.6	84.3
Severity			
Fatal	1.6	0.8	NA
Injury	38.3	35.1	NA
Property damage only	59.6	64.1	NA

[1]NCSS = National Crash Severity Study

[2]NA = data not available

- Traffic volume.
- Approach speed.
- Sight distance.
- Traffic conflicts.

The first two were found related to rural intersection accidents in the literature review, while the second two were selected as surrogate candidates in a workshop of highway safety experts.

In the literature review conducted in this study, the following variables appeared related to intersection accidents:

- Traffic volume. Accident rates have been found related to the percent of cross traffic (Kipp, 1952), to the product of major and minor road volumes (McDonald, 1953), and to the sum of the major and minor road volumes (Heany, 1969; Stockton et al., 1981; Parker et al., 1983).

- Intersection geometry. Several studies (Staffeld, 1953; Hanna et al., 1976; Smith et al., 1981; and Parker et al., 1983) found that cross intersections have higher accident frequencies and rates than do tee intersections.

- Intersection control. Two studies found four-way stop signs to reduce accident rates (Syrek, 1955; Briglia, 1982), but Lum and Parker (1982) found no discernible effect of stop signs at rural intersections with total entering volume less than 1,000 vehicles per day (vpd).

- Turn lanes. The addition of left-turn lanes at rural intersections was found to significantly reduce accidents in studies by the California Department of Public Works (1967) and by Shaw and Michael (1968).

- Left-turn volume. Baldock (1946) found that the accident involvement per left-turn vehicle is much higher for low left-turn volumes than for high volumes.

- Illumination. Installation of lighting at rural intersections was found to substantially reduce accidents in studies by Tamburri et al. (1968), Lipinski and Wortman (1976), and by Walker and Roberts (1976). In the third study, however, illumination effects were nil below 3,500 vpd.

- Stopped delay. In an unpublished report prepared by Lieberman, King, and Goldblatt (1975), mention was made of an Australian study where increased stopped delay was associated with increased accident frequencies at intersections. There are also isolated reports such as by Dale (1974), who reported that improvements made at an intersection resulted in a reduction in stopped delay and total accidents.

- Sight distance. Three studies (Hanna et al., 1976; Wu, 1973; and David et al., 1975) indicated that intersections with no sight distance limitations have significantly lower accident and severity rates than intersections with limited sight distance.

- Fixed objects. David and Norman (1975) found that the proportion of fixed-object accidents per intersection is related to the number of fixed objects in the intersectional area. At rural intersections in Michigan, however, Parker et al. (1983) found that fixed-object accidents seldom reoccurred at the same intersection within a three-year period.

- Angle of intersection. Webb (1953) found that at signalized intersections, skewed intersections generally had fewer accidents than intersections with perpendicular roadways.

- Roadside development. McMonagle (1952) found that as the number of commercial developments within the intersectional area increased, the accident rate increased.

- Posted speed limit. Fatal and injury accident rates were found significantly higher at Michigan intersections with posted speed limits of 50 to 55 mi/h (80 to 88 km/h) than they were with rates of 40 to 45 mi/h (64 to 72 km/h) (Datta et al., 1983).

- Vertical alignment. Intersections with large differences in grades of the approach legs had higher accident rates in a study by King and Goldblatt (1975). Hanna, Flynn and Taylor (1976), however, found lower accident rates at intersections with severe grades (over five percent).

- Horizontal alignment. Webb (1955) found that signalized intersections with curved approaches had higher accident rates than those with tangent alignment.

Much of the previous safety research on rural unsignalized intersections comprised before-and-after studies to evaluate accident countermeasures, and more comprehensive studies examining the combined effects of operational and nonoperational intersection variables have been rare. One study (King and Goldblatt, 1975) used multiple regression analysis to model accident experience, but found that most of the explained variance at stop-controlled intersections was due to urban-rural differences. Other models accounted for little variance.

Perhaps the most comprehensive study on the factors contributing to rural intersection accidents is that by Parker, Flak, Tsuchiyama, Wadenstorer, and Hutcherson (1983). The dependent variables were accidents per intersection and accident per million entering vehicles, computed for 1,028 rural intersections (mostly unsignalized) in Michigan. Unsignalized intersections had an average of 2.7 accidents in 3 years. The analysis used the Automatic Interaction Detector (AID), a multivariate technique to identify variables which maximize the explained variance in the dependent variable. Nearly 48 percent of the variance in accident frequency was explained by the type of intersection control, the total entering traffic volume, and intersection geometry (tee vs. other). Only 33 percent of the variance was explained in the accident rate. Again, ADT, type of control, and intersection geometry were the key explanatory variables.

Summary. The predominant collision types at rural unsignalized intersections appear to be angle and run-off-road crashes. Also prevalent were daytime and dry-pavement accidents. Based on a review of the literature, it appears that surrogates could be developed for the total number of intersection accidents, as well as for accident rate.

While several operational and nonoperational variables have been found related to rural unsignalized intersection accidents, little previous research has been conducted especially for operational variables. No previous work was found for a number of operational variables such as approach speed and lag acceptance, and only a few studies have examined relationships between accidents and delay and turning volume.

There was substantial evidence in the studies reviewed suggesting that major and minor roadway volumes are strongly related to rural unsignalized intersection accidents. Also, type of control, intersection geometry, and the presence of illumination appeared to be promising candidates for indicating accident frequencies.

Shown in table 4 are the candidate surrogates categorized by their potential for further development.

Implications Regarding Study Objectives

Having seen what was found in previous studies bearing on accident surrogates for curves and intersections, it is important to consider the implications for the objectives of this study.

For rural curves and intersections, it is apparent that the combination of low traffic volumes and limited crash-capture area at these "spot" locations necessarily produces on the average very low accident counts, even over three years. Random variation can affect such counts considerably, making statistical analysis of surrogate candidates difficult. Necessarily, it also implies that countermeasure benefits, though real, may be hard to detect except for substantial improvements at high-accident sites. This can present a significant problem in finding sufficiently sensitive operational surrogates for measuring countermeasure benefits.

Regarding rural curves specifically, these problems seem to be reflected in the modest variance in accidents or accident rates that has been accounted for by surrogate-type variables. The Leisch study indicated that most curves differ little in their accident tendencies, and apparently only an unusual combination of factors sets off a high-accident curve from the rest. Some success was had in finding their geometric characteristics, but few operational measures appeared promising.

Previous research experience at rural intersections appears rather different from the curve experience. More variance in accident counts has been accounted for, although the key predictive factor was usually some function of the traffic flows. Thus, past research has explained intersection accidents mainly in terms of exposure.

Table 4. Candidate accident surrogates for rural unsignalized intersections.

(As determined from literature review.)

	Operational/ Nonoperational Op.	Nonop.
"Best Bets"		
Major and minor roadway volumes:		
• Percent of cross volume	•	
• Sum of major and minor volumes	•	
• Product of major and minor volumes	•	
Moderately Promising		
Intersection geometry (tee vs cross)		•
Intersection control (stop of yield sign on minor roadway)		•
Illumination (number of luminaires)		•
Presence of turn lanes		•
Weakly Promising		
Number of commercial and residential driveways		•
Horizontal alinement of major roadway		•
Sight distance from minor roadway		•
Posted speed limit		•
Angle of intersection		•
Vertical alinement		•
Left turns off the major roadway	•	
Stopped delay on minor roadway	•	
Not Promising		
Fixed objects in the intersectional area		•

CHAPTER TWO

RESEARCH DESIGN AND METHODS

THE RESEARCH DESIGN

The objectives of the study were accomplished through two main phases:

1. Developmental Phase. With data from western New York, this phase determined (a) which of the surrogate candidates were related to accident occurrence at rural isolated curves and unsignalized intersections, and (b) equations showing the relationships between the surrogates and accident rates.

2. Validation Phase. With data from Ohio and Alabama, this phase determined whether the western New York relationships may be applicable elsewhere.

Western New York was chosen as the locale for the Developmental Phase, for several reasons. It is, first, the region where Calspan is located and it thus had advantages regarding travel time and costs. Second, as will be seen in chapter 3, the geographical and topographical diversity of the region provided a variety of road conditions and environment. Third, a modern accident data system was available through the regional offices of the New York State Department of Transportation. Because that system is operative mainly for State highways, it was decided that sites on two-lane state highways would be studied.

The States of Ohio and Alabama were chosen for the Validation Phase. These two States differ geographically and climatically, and in each a useful accident data file was available to the study through the cooperation of the relevant State agencies.

Accident Time Frame. The period over which accidents were counted is three years. Although this is a commonly used period apparently stemming from May's (1964) judgment that it is optimal, a simple check on the stability of three-year counts was made determining the correlation between the accident totals at two successive three-year time periods. This was done for a small sample of road segments containing sites identified for this study, with the results shown below.

Type of Site	No. Sites	Test-Retest Correlation
Curves	28	0.8
Unsignalized intersections	30	0.5

Although the correlation for curves looks fairly good, omission of the three highest-accident sites would decrease the correlation to 0.5, i.e., there is the possibility of spurious inflation of the correlation through outliers. On the other hand, correlations increase with sample size. The Spearman-Brown Prophecy Formula (Walker and Lev, 1953) was used to estimate the test-retest reliability for a sample size increased from 30 to 100:

$$\text{Estimated } r = \frac{\left(\frac{100}{30}\right) \times 0.5}{1 + \left(\frac{100}{30}\right) - 1 \quad \times \quad 0.5}$$

$$= 0.77$$

While this result may overestimate the stability of accident counts, a three-year time period was judged sufficient for the study. That was important, because our examination of the State highway maintenance records revealed that beyond three years, the likelihood of road changes (resurfacing, sign changes, etc.) increases substantially.

ACCIDENT DEPENDENT VARIABLES

Glauz et al. (1985) argued that surrogates are more feasibly sought for accidents of specific types. This seems reasonable, for some road features are likely to produce hazards for particular kinds of accidents. At rural "spot" locations, however, accident counts tend to be so low that subdividing them would so lower reliability that the search for surrogates would be defeated. Consequently, the main dependent variables used in this study were rates of total accidents. Examination of specific accident types was limited mainly to sample descriptions.

A critical part of the data collection for this study was the determination of accident counts at the sites, and methods were adopted to enhance accuracy. Neccessarily, the methods had to accommodate the accident reporting systems of each State in the study. Since the Developmental Phase data were fundamental to the study, the accident data collection in western New York is described below. (Variations of the procedure used in Ohio and Alabama are described in appendix E.) The steps were as follows:

1. Identify road segment. The road segment in which the curve or intersection was located was identified by the roadside reference markers just beyond the established site limits. For curves, the site limits were 500 feet (150 meters) before the point of curvature and 500 feet (150 meters) after the point of tangency. For intersections, the site limits were 200 feet (60 meters) from the center of the intersection.

2. Obtain accident listing from New York Department of Transportation (DOT). The segment reference markers were provided to the New York DOT for input to the State Highway Accident Surveillance System. This automated data system generated lists of all accidents reported for the segments during the most recent 3-year period on the file.

3. Delete non-relevant accidents: office screening. From details on the computer printouts, accidents involving animals and pedestrians were eliminated as not relevant to the purposes of the study. For road segments containing a selected intersection, accidents not specified at the intersection were deleted.

4. Obtain accident reports. Copies of all police reports and motorist reports for the non-deleted accidents were obtained from the New York Department of Motor Vehicles.

5. Delete non-relevant accidents: field screening. The accident reports were taken to the study sites by the research staff, where the locations of the accidents were determined from the report details. Accidents occurring outside the site limits were deleted. If the location of an accident was uncertain, the accident was not deleted.

6. Code the accident details. Pertinent details of the accidents were coded. (See appendix A for the accident coding forms.)

POTENTIAL SURROGATES MEASURED

The results of previous research revealed that a wide variety of independent variables or potential surrogates were statistically or conceptually related to accidents. The selection of potential surrogate variables for the developmental study was based on the following criteria:

- How promising the variable appeared in the results of previous research.
- The need to include both operational and nonoperational variables appropriate for identification of hazardous locations, evaluation of countermeasures, and design plan review.
- The need to measure the variable accurately within a few hours at each site, with equipment available at most highway agencies.

Horizontal Curve Variables

The curve variables constituting the surrogate candidates are listed in table 5. Each was either measured directly on the data forms (appendix A) or derived from direct measures. Most of the derivations were straightforward, but a few less obvious ones are listed in appendix F.

The variables shown in table 5 include most of the promising candidates developed from previous investigations. The only exception is lateral placement variance, which was not selected because automated traffic data-collection

Table 5. Isolated curve surrogate candidates measured.[1]

A. Operational

Vehicles per hour: outside lane

Vehicles per hour: both lanes

AADT as per New York DOT.

AADT estimated from vehicles per hour

Average speed reduction: outside lane

Centerline encroachments per hour: outside lane

Centerline encroachments per hour: inside lane

Centerline encroachments per hour: both lanes

Edgeline encroachments per hour: outside lane

Edgeline encroachments per hour: inside lane

Edgeline encroachments per hour: both lanes

B. Nonoperational

Degree of curvature

Length of curve, ft

Salience of curve advance warnings: outside lane

Salience of curve advance warnings: inside lane

Number of within-curve warnings[2] per 1000 feet: outside lane

Number of within-curve warnings[2] per 1000 feet: inside lane

Superelevation error

Shoulder width, ft

Vertical alignment

Roadside hazardousness rating: outside lane

Roadside hazardousness rating: inside lane

Distance to last major event, mi

[1]See glossary for definitions. 1 ft = 0.30 m
[2]Chevrons, delineators, etc. 1 mi = 1.61 km

equipment, not normally available to highway engineers, is required for accurate measurement.

Although Glennon et al. (1983) found that pavement skid rating was related to curve accidents, skid resistance was not measured because the measurements require highly trained personnel and expensive equipment. The pavement rating scale developed by Glennon et al. (1980) also was not used, due to the anticipated reliability problems in judging pavement friction as a function of surface roughness and depth of asperities.

Definitions of all significant terms are given in the glossary. A few measures merit further explanation here.

- Centerline and edgeline encroachments were recorded only for isolated vehicles. Isolated vehicles were selected to examine a possible relationship between single-vehicle road departure accidents and single-vehicle encroachments, as in the experiments conducted by Pagano (1972) in Pennsylvania and Stimpson et al. (1977).
- The distance to last major event is a variable identified in the Goodell-Grivas study (Datta et al., 1983). It was defined as a highway situation that requires a driver to adjust vehicular speed or path. Examples of last events include horizontal curves, intersections of major public roads, railroad crossings, and narrow bridges.
- The estimated annual average daily traffic (AADT) volumes were derived from regression equations relating the New York DOT volumes to the recorded vehicles per hour. The purpose here was to convert the vehicles per hour into the more familiar AADT units.
- Roadside hazard ratings were determined by the data collectors for the outside and inside lanes. The rating was based on a scale used by Datta et al. (1983). The scale ranged from clear roadside with no fixed objects to numerous or continuous rigid fixed objects. It was used in lieu of the roadside hazard rating that was a promising surrogate candidate in the Leisch study (Glennon et al., 1983). Our investigation found that detailed description of the method is apparently not available, and furthermore, it requires photographs and sketches of each site.

- The salience of curve advance warnings is a derived variable based on the type and number of advance curve warning signs. The basic concept of the algorithm, shown in appendix F, is that the greater the quantity or intensity of the curve warnings, the higher is the salience.

The potential surrogates listed in table 5 were collected only during the Developmental Phase. In the Validation Phase, data collection was limited to variables related to accidents in the Developmental Phase.

Unsignalized Intersection Variables

The intersection variables constituting the surrogate candidates are listed in table 6. As with the curves, some were measured directly and some were derived from direct measures.

The variables listed in table 6 include the more promising candidates identified in previous investigations. Because only one operational variable appeared promising, some weakly promising ones were included as they were easy to measure and could be collected in a short time. Traffic conflicts were specifically excluded because they require extensive training and were being studied more extensively in other FHWA studies.

COLLECTING THE SURROGATES DATA

The data collection process included preparation of data collection forms and the field guide, selection of data collectors, training the observers, and collecting the field data. These are described below.

Data Collection Forms

The data forms (appendix A) were designed in three parts: (1) non-operational data collected by the team, (2) operational data collected by one observer, and (3) the remaining operational variables collected by the

Table 6. Unsignalized intersection surrogate candidates measured.[1]

A. Operational

Vehicles per hour, major road

Vehicles per hour, minor road

Total entering vehicles per hour

Major road AADT estimated from vehicles per hour

Left turn percent, major road

Average minor road stopped delay -- seconds per vehicle

Square root of product of major and minor road volumes -- vehicles per hour

Ratio of minor road volume to major road volume

B. Nonoperational

Geometry (tee or cross)

Type of traffic control present

Number luminaires within 200 ft of intersection

Number of turning lanes on major and minor roadway

Number of driveways within 200 ft of intersection

Sight distance from minor road, categorized

Posted speed limit, major road

Right-angle vs. skewed intersection

Major road vertical alignment, categorized

Minor road vertical alignment, categorized

Major road horizontal alignment, categorized

Minor road horizontal alignment, categorized

[1] See glossary for definitions.

other team member. The operational data forms were prepared to balance the data collection workload to prevent overloading and avoid errors. All forms were designed to permit data entry directly from the form.

Data Collectors Manual

The Ohio data were collected during July 1985 and the Alabama data were obtained during August 1985. The surrogates measured were only those related to accidents in the New York sample: traffic volume, degree of curvature, and distance to last major event. As volume was the only operational surrogate, these data were obtained for only a two-hour period or four 20-minute data collection periods at each site. Two of the data collectors from the Developmental Phase obtained the validation data. The data were recorded on forms comprising sections exerpted from the forms used in the Developmental Phase.

Selection of Data Collectors

Because this research was to develop accident surrogates that could be used by rural highway personnel, the study encompassed only those variables that were easy to collect in a short period with existing equipment, e.g., volume counter boards, radar, stopwatches, etc. In accordance with this objective, data collectors were hired with educational and experience backgrounds similar to the technical requirements of traffic technicians.

Six temporary personnel were hired for data collection. In recruiting data collectors, the minimum of a high school diploma or equivalent was required. Applicants with courses in highway and/or traffic engineering or math and science were given preference. Also, persons with experience in linear surveying, highway design or drafting, or traffic data collection were given special consideration. As it turned out, highly qualified personnel were hired for the study. Several had college degrees and a few had previous measurement experience.

Training of Data Collectors

A six-day formal training program was developed to prepare the observers for field data collection. The hired personnel and the study monitor received the training. (See appendix D for details.)

Training began with classroom lectures explaining the purposes of the research and reviewing the variables, data forms, and measuring equipment. Slightly over one day was devoted to this, after which the trainees spent nearly three days in field instruction and supervised practice in measurement. On the fifth day, the trainees were divided into three two-man permanent teams and assigned their measurement equipment. They spent the last two days of training by completing data forms at assigned sites. The forms were reviewed by the instructor and discussed with the teams to resolve any problems. After the teams had collected the surrogates data for about one month, additional training was given on how to perform the field screening of accident reports described earlier in this chapter.

Field Procedure: Developmental Phase

Collection of the nonoperational and operational surrogate variables was initiated in mid-June 1984 following the formal training period and concluded in mid-December 1984. Three two-person teams collected data at 78 curves and 121 intersections in western New York State.

Data were collected during daylight hours on weekdays, except during holiday periods and at times when weather conditions restricted visibility. A

40-hour, 5-day week was initially implemented to permit each team to collect all the field data at one site in one 8-hour day. However, as many of the sites were located throughout western New York, travel demands reduced the time that could be devoted to data collection. In September, a 10-hour workday, 4-day week was initiated to minimize the effects of travel time.

A typical day involved team members assembling at the office in the morning to pick up their equipment and site assignments. Each team would travel to an assigned site, collect the nonoperational data, then observe and record specific operational variables assigned to individual members. An attempt was made to collect four hours of operational data at each site. Operational data were collected for a 20-minute period followed by a 10-minute interval which was used to record the data on the forms, reset the counters, and for break. The data collection cycle was then repeated. At the end of the data collection period, the observers exchanged forms and reviewed their work for omissions and errors. At the end of the day, the team traveled to the office and turned in their forms for checking and coding.

When a team member was absent due to illness or other circumstances, the study monitor replaced the missing observer so data collection could proceed uninterrupted. During periods of inclement weather, the observers coded data in the office.

Equipment used to measure and record the surrogate variables was simple to operate. The equipment used for horizontal curves consisted of a 100-foot (31 m) tape, hand-held radar meter, distance measuring instrument, rule, level and stringline, counter board, and a watch. Data collectors at the intersections used only a 100-foot (31 m) tape, a counter board, rule level and stringline, stopwatch and watch.

Field Procedure: Validation Phase

Following completion of the Developmental Phase in western New York, relationships between accidents and surrogate candidates looked more promising for curves then for intersections, so efforts were concentrated on validating the curve relationships. In doing so, accident and surrogate data were collected for 40 curves in Ohio and for 41 curves in Alabama.

The Ohio data were collected during July 1985 and the Alabama data were obtained during August 1985. The surrogates measured were only those related to accidents in the New York sample: traffic volume, degree of curvature, and distance to last major event. As volume was the only operational surrogate, these data were obtained for only a two-hour period or four 20-minute data collection periods at each site. Two of the data collectors from the Developmental Phase obtained the validation data. The data were recorded on forms comprising sections excerpted from the forms used in the Developmental Phase.

Reliability of Measurement

Reliability of measurement is critical to evaluating surrogates, for potential surrogates with low reliability cannot correlate well with accident rates. This criterion was especially important in this study, where emphasis was on potential surrogates that can be measured in a few hours and without elaborate equipment. To test reliability, a subsample of eleven curves and eleven intersections was remeasured on all the potential surrogates, by a different measurement team from the first, and with several weeks between measurements. The correlations between the measures were then computed as indexes of reliability.

Table 7 shows that for the curve sites, the most reliable measurements were among the nonoperational variables. Exceptions were:

Table 7. Test-retest reliability of the curve surrogate candidates.

Operational Variables	Pearson r
Vehicles per hour: outside lane	0.77
Vehicles per hour: both lanes	0.82
Average speed reduction: outside lane	0.71
Centerline encroachments per hour: outside lane	0.68
Centerline encroachments per hour: inside lane	-0.01
Edgeline encroachments per hour: outside lane	0.76
Edgeline encroachments per hour: inside lane	0.16
Nonoperational Variables	
Degree of curvature	0.94
Length of curve	0.93
Salience of curve advance warnings: outside lane	0.95
Salience of curve advance warning: inside lane	0.83
Number of within-curve warnings per 1000 ft: outside lane	0.96
Number of within-curve warnings per 1000 ft: inside lane	0.59
Superelevation error	0.93
Shoulder width, ft	0.69
Vertical alignment	*
Roadside hazardousness rating: outside lane	0.94
Roadside hazardousness rating: inside lane	0.65
Distance to last major event	0.30
Above distance, 2 worst cases eliminated	0.95

*Variance among sites insufficient to test reliability.

(a) Within-curve warning rate, inside lane.

(b) Shoulder width, where uneven shoulders made measurement inexact.

(c) Roadside hazard rating, outside lane.

(d) Distance from outside lane last event, where ambiguities of definition created problems.

Regarding the "last event," the reliability problem was traced to disagreements between teams as to which location was the last major event at two sites. For the other sites, their measures correlated an impressive 0.95. To reduce confusion caused by low-volume intersections, the team was told to consider an intersection as a major event only if more than two vehicles enter the intersection during a 5-minute period.

Among the operational variables at curves, the test-retest correlations were fair-to-good, with the exception of the unreliable centerline and edgeline encroachment rates in the inside lane. A possible reason for the latter is that the observations were made from the outer roadside.

At the intersection sites, the picture was quite different. As table 8 shows, few of the nonoperational variables varied sufficiently among the sites to assess reliability. For example, on all the reliability test sites except one, the teams agreed that the sight distance was unrestricted. For the other variables the reliability was quite good, except for average stopped delay on the minor road.

Table 8. Test-retest reliability of the intersection surrogate candidates.

Operational Variables	Pearson r
Vehicles per hour, major road	0.91
Vehicles per hour, minor road	0.94
Total entering vehicles per hour	0.96
Left turn percent, major road	0.95
Average minor road stopped delay	0.49
Square root of product of major and minor road volumes	0.99
Ratio of minor road volume to major road volume	0.95
Nonoperational Variables	
Type of traffic control present	*
Number luminaires	*
Number of turning lanes on major and minor roadway	*
Number of driveways	0.88
Sight distance from minor road	*
Posted speed limit, major road	*
Right-angle vs. skewed intersection	0.78
Major road vertical alignment	*
Minor road vertical alignment	*
Major road horizontal alignment	0.69
Minor road horizontal alignment	*

* Variance among sites insufficient to test reliability.

CHAPTER THREE
SAMPLE DESCRIPTION

Since the nature and size of a sample can markedly influence the results of a study, this chapter describes how this study's samples were obtained, and it examines their characteristics.

SITE SELECTION CRITERIA

The following factors were considered during the formulation of the site selection criteria:

- Necessity to select a majority of sites with accident tendencies, to enhance prospects for developing accident surrogates.
- Need to reduce error variance by eliminating sites experiencing major geometric and/or operational changes in recent years.
- Desirability of minimizing operational data collection time by eliminating sites with very low traffic volumes.

Based on these considerations, site selection criteria were developed following discussions with New York State highway officials and a field review of approximately 250 miles of rural two-lane highways located in western New York. Following the field review and examination of the State highway records, it was decided to limit the sample to State roads only. Low traffic volume, nonavailability of highway records, and the difficulties of obtaining accident records were the primary reasons that local roads were eliminated from consideration.

The preliminary review revealed difficulties in finding many isolated rural curves. The definition of "isolated" used was that no other major traffic events, i.e., horizontal curves, public street intersections, railroad crossings, narrow bridges, etc., that could cause a change in vehicle speed or direction, are located within 0.25 mile (0.40 km) of the curve.

Due to insufficient numbers of curves isolated in both directions of travel, curves isolated in only one direction were included as candidates for site selection.

The criteria used to select sites are shown in tables 9 and 10.

SITE SELECTION IN WESTERN NEW YORK STATE

Since Calspan is located in a suburb of Buffalo, New York, it was appropriate for study logistics that data be collected on roadways located in the surrounding counties of western New York, which are predominantly rural.

The eight-county sampling area is shown in figure 1. Its topography ranges from the 2000-foot (610-m) Allegheny foothills in the south, through the flat-to-hilly central region, to the flat plains in the north. Farmland characterizes much of the northern two-thirds of the area, while the southern hills include a number of recreational areas, including skiing centers. Among the challenges to finding rural isolated curves is the fact that many curves in the southern counties are in winding sections, while roads in the flat northern counties have long tangent sections connected with curves of less than 2°.

Sample Sizes Sought

The targeted sample sizes were chosen to be sufficient to analyze the relationships of surrogates to accident data. Although the Accident Research Manual (Council et al., 1980) indicates there are no guidelines for determining the sample sizes needed for establishing relationships, it was decided to select sample sizes to assure that relationships within the samples would reasonably estimate the relationships within the curve and intersection populations. Evaluation of the 95 percent confidence intervals for correlations

Table 9. Site-selection criteria for rural isolated curves.

Criterion	Sample Requirement
Rural Location	Outside of city and village limits; not in residential area.
Traffic Volume	1500 vehicles per day minimum
Posted Speed Limit	45 mi/h (72 km/h) minimum
Degree of Curvature	2° minimum
Road Surface	Must be paved
Isolatedness	There must be no major events, e.g., another horizontal curve, intersections of public streets or major commercial developments, railroad grade crossings, narrow bridges, etc., within 1/4 mi (0.40 km) of the beginning or end of the subject curve, in at least one direction of travel.
Recent Changes	There must have been no major operational or physical changes within the past four years, e.g., roadway construction, resurfacing, shoulder widening, etc.

Table 10. Site-selection criteria for rural unsignalized intersections.

Criterion	Sample Requirement
Rural Location	Outside of city and village limits; not in residential area.
Traffic Volume	Major roadway: 1500 vehicles per day minimum Minor roadway: 100 vehicles per day minimum
Geometry	Must be tee (3-leg) or cross (4-leg) intersections. Y or jogged intersections were excluded.
Type of Control	Major roadway: No control Minor roadway: Stop, Yield, or no control
Major Events	There must be no major events such as another public street or major commercial development, railroad crossing, narrow bridge, or other similar feature within 1/4 mi (0.40 km) of the subject intersection. (Horizontal curves were not considered to be major events.)
Recent Changes	There must have been no major operational or physical changes within the past four years.

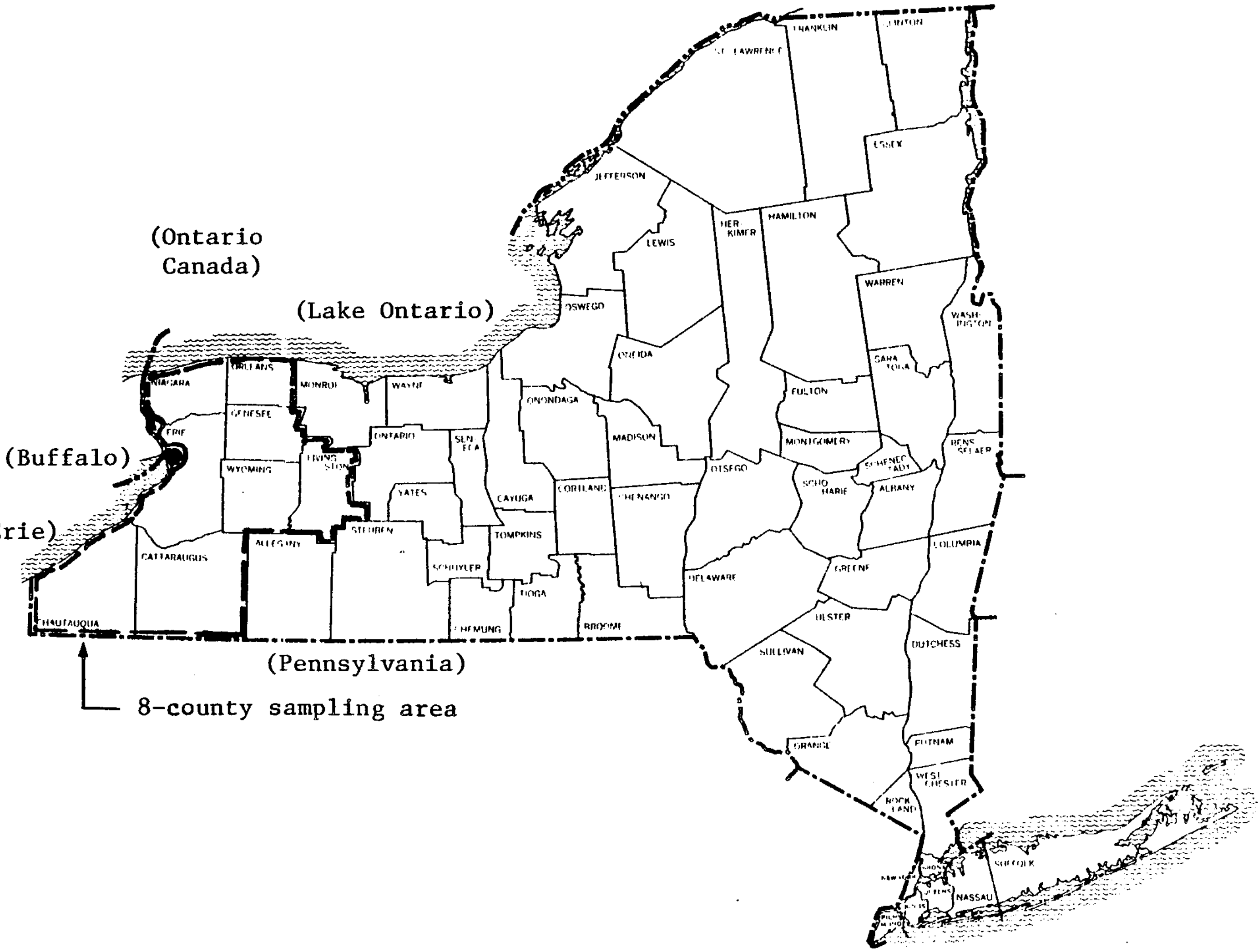

Figure 1. Sampling area within New York State.

indicated that for a population correlation of 0.8 or higher, a sample of 100 or more provides a fairly good estimate of the population parameter. Considering there would be little interest in weak relationships, and taking into account data collection costs and time limitations, sample sizes of 120 curves and 120 intersections were targeted.

Site Selection Procedure

Using the site selection criteria, a preliminary list of sites was generated by reviewing New York DOT highway maps, volume data, road construction records, and maintenance records. This work turned out to be extremely time-consuming, as it involved looking up records, translating across record systems, and occasionally resolving discrepancies among record sources. When it became apparent that the time required was prohibitive, it was decided to complete the site selections through a field review of the State highways. A review team including an experienced highway and traffic engineer examined each potential site in the eight western New York counties, over a two-week period.

In meeting the selection criteria, the curves suffered enormous attrition. Initially, 500 curves were identified in the office review, but 40 percent were eliminated by the minimum volume criterion. Another 5 percent were rejected because of the "last event" criterion. Finally, another 40 percent were eliminated in the field review because of recent construction work, insufficient curvature, close proximity to developed areas, and the close proximity of major events. The last was particularly significant, indicating that in western New York at least, isolated curves are a minority of all rural curves. With intersections, there was attrition due to recent construction, low traffic volumes, and proximity of other major events; however, finding eligible intersections was not a problem.

During the field reviews, 77 isolated curves and 138 unsignalized intersections were identified. Several additional curves were found during subsequent field trips. During data collection, several sites were eliminated from the sample due to major roadway reconstruction. The final sample in western New York consisted of 78 curves and 121 intersections.

Descriptive Statistics

The western New York sites are described in terms of their measured operational and nonoperational variables in tables 11-14, and their accident characteristics are shown in tables 15 and 16. A few aspects are worth noting.

The curves had on the average somewhat higher degrees of curvature than in the Leisch study (Glennon et al., 1983), but they were not nearly as sharp as the average 10° of curves in the Goodell-Grivas study (Datta et al., 1983). While the western New York sample is in this respect intermediate to the other studies, the differences may be reflected in the final results.

The average accident frequency of 1.7 for the western New York curves was much less than the means of 3.9 in the Leisch study and 4.5 in the Goodell-Grivas study. The Leisch study could have had higher rates because it sampled much longer road segments than this study, while the sharper curves in the Goodell-Grivas study could have effected more accidents.

Notice in table 15 that the predominant accidents at the western New York curves were road departures. All other types were infrequent, making it impractical to treat them as separate dependent variables for surrogates analysis.

Table 11. Nonoperational variable descriptors for the rural New York curve sites.

Variable	45 Curves Isolated in Both Directions			33 Curves Isolated in One Direction		
	Min.	Max.	Mean	Min.	Max.	Mean
Degree of curvature	2.1	10.3	4.7	1.5	15.2	6.1
Length of curve, PC to PT (ft)	279	1525	765	290	1835	715
Salience of advance warnings: OL	0	4	1.6	0	4	2.1
Salience of advance warnings: IL	0	4	1.7	0	5	1.6
Within-curve warnings/1000 ft: OL	0	33.1	4.2	0	41.7	8.6
Within-curve warnings/1000 ft: IL	0	33.9	4.3	0	23.2	5.4
Superelevation error (AASHTO rec. - actual)	0.01	0.07	0.04	0.01	0.07	0.04
Shoulder width (ft)	5	14	8.3	5	12	7.9
Roadside hazard rating: OL	1	6	3.6	1	6	3.8
Roadside hazard rating: IL	1	6	3.4	1	6	4.1
Distance from last event (mi): OL	0.03	1.10	0.39	0.12	0.83	0.37

Variable	Grade	45 Curves Isolated in Both Directions	33 Curves Isolated in One Direction
Vertical alignment	< 1% grade	71.1%	45.5%
	1-4% grade	20.0	30.3
	> 4% grade	8.9	24.2
		100.0%	100.0%

1 mi = 1.6 km
1 ft = 30 cm

OL = outside lane
IL = inside lane
PC = point of curvature

PT = point of tangency
AASHTO = American Assn. of State Highway and Transportation Officials

Table 12. Operational variable descriptors for the rural New York curve sites.

Variable	45 Curves Isolated in Both Directions			33 Curves Isolated in One Direction		
	Min.	Max.	Mean	Min.	Max.	Mean
Volume (veh/h): OL	25	190	109.2	18	254	97.0
Volume (veh/h): total	48	389	216.5	41	554	206.9
AADT per New York DOT	1100	6700	3302	1100	6800	3276
AADT estimated from total veh/h	1587	5120	3333	1515	6829	3234
Ave. speed reduction (mi/h): OL	-2.5	6.3	1.7	-1.6	8.9	2.3
Centerline encroachments/100 is. veh: OL	5.8	59.7	27.9	4.0	73.3	36.1
Centerline encroachments/100 is. veh: IL	0	37.3	12.5	1.4	30.6	13.4
Centerline encroachments/100 is. veh: total	6.5	36.9	20.1	11.6	32.0	21.8
Edgeline encroachments/100 is. veh: OL	0.9	27.1	11.6	0	28.6	9.9
Edgeline encroachments/100 is. veh: IL	5.9	71.4	25.6	7.0	54.0	26.4
Edgeline encroachments/100 is. veh: total	5.9	44.4	18.8	9.9	24.0	16.9

1 mi = 1.6 km
OL = outise lane
IL = inside lane
veh = vehicles
is. veh = isolated vehicles

Table 13. Nonoperational variable descriptors for the rural New York intersection sites.[1]

Variable		72 Tee Intersections	49 Cross Intersections
Traffic control	Yield sign	5.6%	4.1%
	Stop sign	93.0	95.9
	Other	1.4	0.0
No. luminaires within 200 ft	0	23.6%	18.4%
	1	75.0	75.5
	2 or more	1.4	6.1
No. turning lanes	0	98.6%	98.0%
	1 or more	1.4	2.0
No. driveways within 200 ft	0	11.1%	16.3%
	1	19.4	14.3
	2	15.3	20.4
	3 or more	54.2	49.0
Sight distance: minor road	>500 ft, 2 approaches	84.7%	91.8%
	<500 ft, 1 approach	15.3	8.2
	<500 ft, 2 approaches	0.0	0.0
Speed limit: major road	None posted	29.2%	18.4%
	55 mi/h	69.4	79.6
	Other	1.4	2.0
Intersection angle	Right angle	38.0%	39.6%
	Skewed	62.0	60.4
Vertical alignment. major road	<1% grade	79.2%	87.8%
	1-4% grade	15.3	6.1
	>4% grade	5.5	6.1
Vertical alignment minor road	<1% grade	56.3%	51.0%
	1-4% grade	29.6	30.6
	>4% grade	14.1	18.4
Horizontal alignment major road	Tangent	72.2%	89.8%
	Isolated curve	16.7	6.1
	Winding	11.1	4.1
Horizontal alignment minor road	Tangent	87.5%	85.7%
	Isolated curve	1.4	2.0
	Winding	11.1	12.3

1 ft = 30 cm   1 mi = 1.6 km

[1] Totals equal 100 percent for each variable.

Table 14. Operational variable descriptors for the rural New York intersection sites.

Variable	72 Tee Intersections			49 Cross Intersections		
	Min.	Max.	Mean	Min.	Max.	Mean
Volume (veh/h): major road	59	565	279.7	88	646	276.9
Volume (veh/h): minor road	1	82	19.1	7	131	40.2
Volume (veh/h): total entering	70	605	299	113	773	317.0
AADT per New York DOT	1300	8300	3932	1200	9900	4120
AADT estimated from veh/h: major road	1084	7818	4023	1467	8896	3986
% left turns: major road	0.1	18.5	3.5	0.6	12.6	4.4
Ave. stopped delay (s/veh): minor road	3.0	12.5	7.0	4.9	14.4	7.7
RMS vol. (veh/h)	19	188	66.8	40	287	99.0
Minor volume ÷ major volume	0.00	0.26	0.07	0.03	0.86	0.16

RMS vol = root-mean-square volume = $\sqrt{\text{major volume x minor volume}}$

Table 15. Accident characteristics at the rural New York curve sites.

Variable	45 Curves Isolated in Both Directions	33 Curves Isolated in One Direction
Mean accidents per curve	1.60	1.88
Mean accidents per million veh.	0.42	0.50
Site accident frequencies [1]		
0 accidents	24.4%	39.4%
1 accident	35.6	21.2
2 accidents	17.8	15.2
3 accidents	8.9	9.1
4 accidents	6.7	3.0
5 accidents	4.4	3.0
6+ accidents	2.2	9.1
Manner of collision [2]		
Road departure	68.1%	74.2%
Other single-vehicle	5.6	1.6
Head-on	4.2	4.8
Angle	0	0
Left-turn	2.8	1.6
Right-turn	0	0
Rear-end	6.9	1.6
Sideswipe	8.3	9.7
Other multivehicle	4.2	6.5
Number of vehicles [2]		
Single vehicle in motion	73.7%	75.8%
Multiple vehicles in motion	26.3	24.2
Time of day [2]		
Day	55.5%	50.0%
Night	44.5	50.0
Road surface condition [2]		
Dry	55.5%	41.9%
Wet, snow, ice	44.5	58.1
Severity [2]		
Fatal	0%	3.2%
Injury	51.4	54.9
Property damage only	48.6	41.9
Striking-vehicle travel lane [2]		
Inside lane	42.9%	46.8%
Outside lane	57.1	53.2

[1] 100% = all sites; [2] 100% = all accidents

Table 16. Accident characteristics at the rural New York intersection sites.

	72 Tee Intersections	49 Cross Intersections
Mean accidents per intersection	1.68	3.59
Mean accidents per million entering veh.	0.24	0.53
Site accident frequencies[1]		
0 accidents	31.9%	12.3%
1 accident	16.7	18.4
2 accidents	26.4	20.4
3 accidents	13.9	10.2
4 accidents	4.2	10.2
5 accidents	2.8	6.1
6+ accidents	4.1	22.4
Manner of collision[2]		
Road departure	31.4%	8.5%
Other single vehicle	5.8	1.7
Head-on	0.8	1.1
Angle	14.9	42.0
Left-turn	12.4	10.8
Right-turn	0.8	2.3
Rear-end	15.7	13.1
Sideswipe	13.2	13.1
Other multivehicle	5.0	7.4
Number of vehicles[2]		
Single vehicle in motion	37.2%	10.2%
Multiple vehicles in motion	62.8	89.8
Time of day		
Day	73.9%	75.9%
Night	26.1	24.1
Road surface condition[2]		
Dry	57.0%	50.0%
Wet, snow, ice	43.0	50.0
Severity[2]		
Fatal	0.8%	1.1%
Injury	40.5	50.0
Property damage only	58.7	48.9

[1] 100% = all sites; [2] 100% = all accidents

With regard to the intersections, table 13 reveals that they differed little on the following nonoperational variables:

- Traffic control.
- Number of turning lanes.
- Sight distance: Minor road.
- Vertical alignment: Major road.
- Horizontal alignment: Major and minor roads.

Lack of variation in these measures greatly limits their capability to correlate with accidents in the western New York data.

The intersection accidents (table 16) exhibited major differences between the tee and cross intersections. Road departures were more frequent at the tee intersections; such accidents usually involve vehicles from the minor road overshooting the intersection. Angle accidents were more common at the cross intersections, where multivehicle accidents predominated. Cross intersections also had twice as many accidents per site as the tee intersections. These different accident patterns are likely to be associated with different accident surrogates.

SITE SELECTION IN OTHER STATES

The curves in Alabama and Ohio were chosen in accordance with the selection criteria used in western New York, using volume data provided by each State and the results of on-site reviews. The difficulties experienced in New York in finding curves meeting the site selection criteria also surfaced in Alabama and Ohio. By searching State highways in nine counties of Ohio, a 40-curve sample was obtained there. In Alabama, a nine-county search yielded a 41-curve sample. Descriptive data are presented in the next chapter.

CHAPTER FOUR

RESULTS

To find useful equations for estimating accident rates, analyses of the western New York data proceeded through the following steps:

1. Identify denominators for accident rates. Possible exposure variables were examined for at least a positive relationship to accident frequency.

2. Examine univariate distributions of surrogate candidates. The variables were inspected for aspects requiring special treatment in analysis and for low variance which might lower relationships to accident rates.

3. Examine bivariate relationships of surrogate candidates to accident rates. Variables with little or no relationship to accident rates were eliminated, unless they were expected to contribute to interaction terms or other effects. For variables that were related to accident rates, the apparent form (rectilinear, curvilinear) was noted for further examination.

4. Perform preliminary multivariate analyses. Stepwise multiple regression was used to explore the contributions of each surrogate to accident rate variance. Potential surrogates not adding significantly to variance in accident rate were eliminated at this stage, unless their contributions in other ways were expected.

5. Do hierarchical multiple regression analysis. The remaining surrogate candidates and the form of their relationship to accident rates were examined through hierarchical regression, in which successively more complex models, including interaction effects, were tested. Complex models explaining no more accident rate variance than simpler models were eliminated.

In addition to these analyses, validation tests were performed on equations for estimating isolated curve accident rates. The tests were first made on equations from the Goodell-Grivas and Leisch studies (Datta et al., 1983; Glennon et al., 1983), and subsequently on new equations developed with western New York data. All the analyses were performed on Calspan's IBM System 370 Model 3031 computer, using programs of the Statistical Analysis System (SAS).

The results for the isolated curves and the unsignalized intersections are presented in order.

RESULTS FOR THE ISOLATED CURVES

Validation Test of the Goodell-Grivas and Leisch Curve Equations

This analysis determined whether the equations for curve hazardousness in the Goodell-Grivas and Leisch studies were valid in western New York. Procedures in those studies were replicated closely, except as noted below.

The Goodell-Grivas equations. The equations accounting for the most variance in the Goodell-Grivas study were for road departure, outside lane, head-on and rear-end accidents. Since head-on and rear-end accidents each comprised only five percent of the western New York curve accidents, however, the "best" Goodell-Grivas equations were tested only for road departure and outside lane accident rates:

$$\text{Road departure rate} = (-)\ 2.975 + 0.499\ (\text{degree of curvature}) - 18.096\ (\text{superelevation error}) \quad (1)$$

$$\text{Outside lane rate} = 0.032 + 0.595\ (\text{distance to last event}) + 0.151\ (\text{outside lane speed reduction}) \quad (2)$$

Datta et al. (1983) found the equations best only for certain types of isolated curves; e.g., the first equation was for curves with restricted sight distance in nonresidential areas. In this study, however, they were tested for application to the broader sample of western New York curves. The accident rates predicted by the equations were correlated with the actual accident rates. Squaring the correlations to indicate variance accounted for, the results were:

Road departure rate: $r^2 = 0.33$ ($p < .001$)
Outside lane rate: $r^2 = 0.01$ ($p > .5$)

Thus, the equation for road departure rate was fairly successful, though the outside lane equation was not.

The Leisch equations. The best Leisch equation for identifying hazardous curves used a roadside rating variable which could not be replicated in this study. Consequently, validity was tested for another equation found nearly as good in the Leisch study.

Similar to the procedure in the Leisch study, the curves were divided into three groups by ADT (1400-2099, 2100-3099, and 3100-4899 vpd). Within each, curves within the highest 15 percent and lowest 15 percent of accidents per kilometer were identified. For each curve, a Discriminant Factor score (D) was determined as follows:

$$D = 0.377 \text{ (degree of curvature)} + 3.209 \text{ (curve length)} - 0.220 \text{ (shoulder width)} + 0.289 \quad (3)$$

A high accident site is predicted when D is 0.36 more more. Table 17 shows that the predictions were not very accurate for western New York curves.

Implications. It may not be surprising that the Goodell-Grivas equations had limited success, since they resulted from an exploratory analysis of a small specialized curve sample. The Leisch equation, however, was based on a large, geographically diverse sample, and it ought to be widely applicable. That it did not work well for western New York curves may be due to the following:

Table 17. Application of discriminant function from Leisch study (Glennon et al., 1983)

		Accident Rate Groups			Total
		Low	Medium	High	
Discriminant factor	D≥.36	14 28.6%	27 55.1%	8 16.3%	49 100.0%
	D<.36	9 39.1%	12 52.2%	2 8.7%	23 100.0%
Total		23	39	10	72*

Chi-square = 1.23 (Not significant)

*Seven sites with ADT over 4,899 were omitted, to be comparable with the Leisch study. To increase numbers for this analysis, the data include curves isolated in one direction as well as two. Separate analysis on each group showed results to be similar.

(a) Since the Leisch equation was based on curves extremely high or low in accident counts, it may be less applicable to a broad sample of curves.

(b) The Leisch equation may apply more to road segments comprising curve and tangent sections than to curves per se.

Since the Goodell-Grivas and Leisch equations were found limited as isolated curve accident surrogates, it was decided to begin anew, starting with the most promising variables from the literature review. Using the western New York curves isolated in both directions, analysis proceeded through the steps listed at the beginning of this chapter. The resulting equations were given a tentative validation check on western New York curves isolated in only one direction, and then they were tested on Ohio and Alabama data. To maximize chances of finding valid surrogate equations, the systematic procedure outlined at the beginning of this chapter was followed.

Denominators for Curve Accident Rates

An ideal exposure measure is one which increases proportionately with accident frequency; i.e., the units represent equal opportunities for accidents at all points on the continuum. The commonly used denominators of traffic volume (ADT) and curve length were examined to see how well they met this ideal. A plot of accident frequency versus traffic volume at the "doubly isolated" curves (figure 2) reveals a wide dispersion of the data, but there appears to be a positive curvilinear relationship. While the Pearson correlation between volume and accident frequency was 0.43, the curvilinear relation suggests that an accident rate (expressed as accidents per million vehicles) would correlate positively with volume. Thus, volume could be both a denominator for curve accident rates and a predictor variable (surrogate candidate) for those rates.

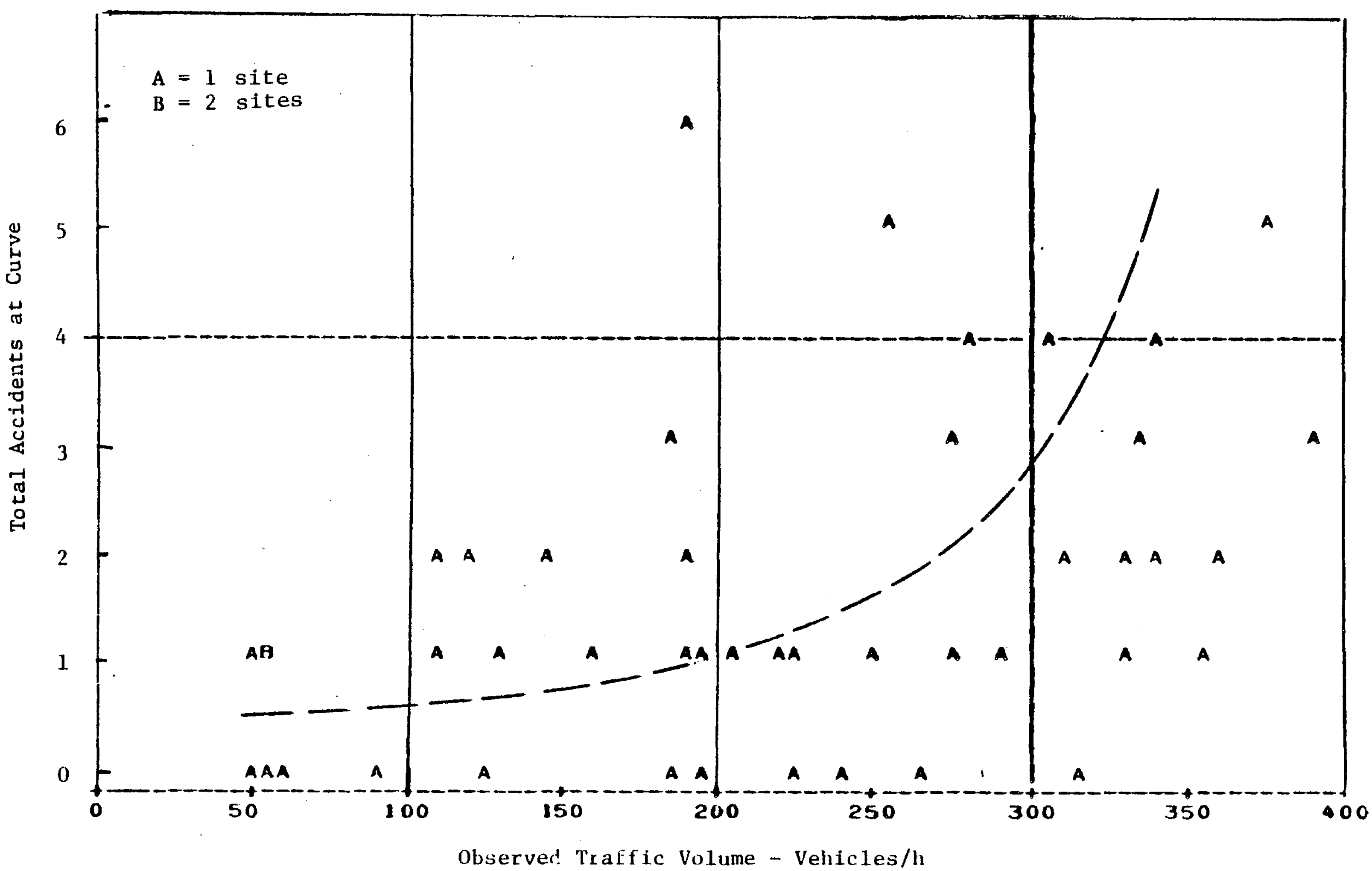

Figure 2. Accidents in relation to volume at the "doubly isolated" curves

Curve length was found generally unrelated to accident frequency. A plot of the relationships at the "doubly isolated" curves exhibited an essentially random dispersion, and the Pearson correlation was a nonsignificant - 0.02. Curve length, therefore, was not supported as an accident rate denominator. (Note that this also explains part of the failure of the Leisch equation, which included curve length).

Accidents per million vehicles were adopted as the accident rate for the curve analyses. To decide whether the rates should be based on traffic volume in the New York Department of Transportation (DOT) records or from our traffic counts at the sites, the correlations of each volume with accident frequency were compared. The New York DOT data correlated 0.17, a figure much lower than the 0.43 for our volume measures. Consequently, our volume data were accepted as more applicable to our sample.

Identifying Viable Surrogate Candidates

While low measurement reliability or low variance among curves could limit the potential usefulness of a surrogate candidate, no candidate was rejected on those criteria alone. Any candidate was considered "viable" if it exhibited a systematic, nontrivial relation to accident rates. Inspection of the data in table 18 was used for this preliminary screening, with statistical testing reserved for subsequent multivariate analyses. Table 18 was used to judge whether relationships to accident rate were monotonically increasing or decreasing, and whether they appeared to be rectilinear or curvilinear. Thirteen of the surrogate candidates exhibited an apparent relationship to accidents. The salience of advance warnings and shoulder width increased with accident rate, however, contrary to what would be expected if warning signs and wide shoulders have beneficial safety effects. (Glennon et al., [1983] found shoulder width negatively correlated with accident rate.) These relationships suggest possible countermeasure responses, e.g., adding warning signs to high-accident sites.

Table 18. Means and percents of potential surrogates within accident-rate groups: curves.

Potential Surrogates	Accidents per 10^6 Vehicles ≤ 0.09 (n = 11)	0.10-0.74 (n = 25)	≥ 0.75 (n = 9)	Rel. to Acc. Rate
Operational Variables				
Volume (veh/h): OL	80.0	117.8	121.0	*
Volume (veh/h): total	164.2	231.0	240.0	*
AADT per New York DOT	2763.6	3680.0	2911.1	
AADT est. from total veh/h	2790.7	3482.9	3579.6	*
Ave. speed reduction (mi/h): OL	1.4	1.4	2.6	*
Centerline encroach./100 is. veh: OL	29.5	24.3	35.8	*
Centerline encroach./100 is. veh: IL	15.1	11.0	13.8	
Centerline encroach./100 is. veh: total	22.6	17.4	24.6	
Edgeline encroach./100 is. veh: OL	12.5	10.4	13.9	
Edgeline encroach./100 is. veh: IL	21.4	22.9	38.3	*
Edgeline encroach./100 is. veh: total	16.8	16.8	26.7	*
Nonoperational Variables				
Degree of curvature	4.2	4.2	6.4	*
Length of curve (ft)	734.2	818.8	652.2	
Salience of advance warnings: OL	1.4	1.3	2.4	*
Salience of advance warnings: IL	1.4	1.4	2.9	*
Within-curve warnings/1000 ft: OL	4.5	4.0	4.6	
Within-curve warnings/1000 ft: IL	4.4	3.7	5.9	
Superelevation error	0.05	0.04	0.05	
Shoulder width (ft)	7.7	8.3	9.0	*
Roadside hazard rating: OL	3.6	3.6	3.3	
Roadside hazard rating: IL	3.3	3.4	3.3	
Distance from last event (mi): OL	0.6	0.4	0.3	*
% with grade ≥ 1%	36.4%	16.0%	55.6%	*

1 mi = 1.6 km

1 ft = 30 cm

OL = outside lane

IL = inside lane

veh = vehicles

is. veh = isolated vehicles

* = variable appears related to accident rate

Variables exhibiting relationships to accident rates in table 18 were carried over for subsequent multivariate analyses with three exceptions. The two veh/h variables were omitted because they were redundant with average annual daily traffic (AADT) estimated from total veh/h. (Inside and outside lane volumes correlated 0.93 and total veh/h necessarily correlated 1.00 with the estimated AADT.) The total edgeline encroachment rate was excluded because its relation to accidents was due mainly to the inside lane rate, which was included. The advance warning and shoulder width variables were carried over on the remote possibility they have some predictive value. Thus, the surrogate candidates remaining at this point were:

- AADT estimated from veh/h.
- Average speed reduction.
- Centerline encroachment rate, outside lane.
- Edgeline encroachment rate, inside lane
- Degree of curvature.
- Salience of advance warning, outside lane.
- Salience of advance warning, inside lane.
- Shoulder width.
- Distance from last event, outside lane.
- Vertical alignment (grade.)

Identifying the Best Surrogate Equations

Prior to developing predictive equations, it was necessary to choose a suitable method. While multiple regression analysis is widely used (e.g., Datta et al., 1983), some analysts argue that skewed accident data require special methods such as Poisson regression (Jorgenson, 1961; Flowers, Sparks, Litton, and Cook, 1980). On the other hand, noted authorities such as Cohen and Cohen (1983) claim that a square root transformation of the data permits use of more common regression techniques. After consulting with other statistical analysts, it was decided to use the latter approach.

[The following technical section is necessary to convey how the final accident surrogate equations were developed, but it may be skipped by the reader interested mainly in the results.]

To screen surrogate candidates having little predictive power for accident rates, stepwise multiple regression was used. In this method, the computer tests successive predictive models, starting with the one-variable model accounting for the most variance. No interactions among variables or curvilinear relationships were included at this stage. The results indicated no predictive capability for the advance warning, shoulder width, and average speed reduction variables. They were not examined further.

Hierarchical multiple regression analysis was used to perfect the predictive equations. The objective was to account for the most variance in the accident rates with the simplest model, while testing for curvilinear relationships and interaction effects among variables. In hierarchical regression, a series of equations are tested as the analyst controls the terms added at each step. The "best" equations are not automatically guaranteed, but one uses prior knowledge and a rational process to examine successive models until it seems a "point of diminishing returns" has been reached. The following rules guided the analysis:

1. Minimize complexity by testing simple models before more complex ones; do by entering linear terms before quadratics (for curvilinear relationships) and cross-products (for interactions between variables).

2. Add variables in order of causal priority so that consequences do not "steal" variance belonging to causes (Cohen and Cohen, 1983, p. 121). Applying this to the surrogates problem, traffic response variables were added after nonoperational and exposure (AADT) variables; e.g., degree of curvature was included before encroachment rates, because curvature could influence encroachments but the converse is impossible.

Statistical significance of each term entered was checked with an F-test, to indicate whether it contributed predictive ability. For the more promising equations, the "residuals" (actual accident rates minus the predicted ones) were plotted against the predicted values and inspected. This procedure is used to determine if there are abnormalities suggesting violation of assumptions or relationships meriting further investigation.

The basic variables included in the hierarchical analyses were as follows:

- Degree of curvature.
- AADT estimated from veh/h.
- Distance to last major event, outside lane
- "Key encroachments" rate (combined outside lane centerline encroachment rate and inside lane edgeline encroachment rate).

Curvilinear effects of each of these were tested, as were the following interactions:

- Degree of curvature with AADT.
- Degree of curvature with grade.
- Degree of curvature with distance to last major event in the outside lane.
- AADT with distance to last event.

The first two interactions were suggested by the literature review, while the last two were added to examine the distance to last major event more fully.

Although the number of variables and interactions tested was relatively small, the total models possible from them is large, even with the limiting rules specified above. Models tested are listed in Appendix G.

Solutions were obtained for rates of total accidents and for the most prevalent types -- road departures and outside lane accidents. In accord with the study objectives, equations including only operational or nonoperational variables were also sought.

The equations derived for western New York curves are shown in table 19. Estimation of accident rates was best achieved for total accidents and road departures, using degree of curvature, distance to last outside lane event,

Table 19. Best-fitting equations for accident rate developed from western New York data.

Total accidents per 10^6 vehicles

$$= \left[\text{AADT}\ (0.000043 \times \text{degree of curvature} - 0.00011 \times \text{distance to last outside lane event})\right]^2 \quad (4)$$

$R^2 = 0.28$ (p = .0002)

Total road departure accidents per 10^6 vehicles

$$= \left[\text{AADT}\ (0.000035 \times \text{degree of curvature} - 0.000089 \times \text{distance to last outside lane event})\right]^2 \quad (5)$$

$R^2 = 0.36$ (p = .0001)

Total outside lane accidents per 10^6 vehicles

$$= \left[0.018 \times \text{degree of curvature} + 0.000075 \times \text{AADT}\right]^2 \quad (6)$$

$R^2 = 0.09$ (p = .035)

Accident rates estimated from operational variables only:

Total accidents per 10^6 vehicles

$$= \left[0.29 + 0.0000030\ \text{AADT} \times \text{key encroachments rate}\right]^2 \quad (7)$$

$R^2 = 0.14$ (p = .01)

Road departure accidents per 10^6 vehicles

$$= \left[0.000088\ \text{AADT} + 0.0080\ \text{key encroachments rate}\right]^2 \quad (8)$$

$R^2 = 0.13$ (p = .06)

and traffic volume. Poor estimation (low R^2 values) was obtained for the outside lane accident rates and with the equations using operational variables only. Since the two best equations included only nonoperational variables and AADT, no attempt was made to find an equation with exclusively nonoperational variables.

Distance to last outside lane event was a surprising predictor variable, since the relationship to accidents was opposite to that found by Datta et al. (1983). Instead of curve "isolatedness" raising accident rates, the results seem to suggest the opposite.

For a preliminary validation test, the total-accident and road departure equations were applied to the western New York curves isolated in one direction only. The resulting R^2 values of 0.37 and 0.34 for total accidents and road departures were encouraging. Even the surprising relation between accident rate and distance to last major event was upheld. (The correlation of the two variables was -0.40 for the doubly-isolated curves, and -0.36 for curves isolated in one direction.)

Because the equations for total accidents and road departure accidents seemed moderately successful, the decision was made to collect validation data to test them.

Validating the Curve Equations

Initial examinations of the data from the validation States of Ohio and Alabama promptly revealed that distance to last major event was not related to the accident rates in either State. Not only were the correlations statistically insignificant, the Alabama one was opposite in sign to the correlations found in western New York. (The correlations were 0.0 in Ohio and + 0.25 in Alabama.) This proved that the predictive equations from western New York were not generally valid. Consequently, distance to last major event was eliminated as a predictor variable, and new equations for total accident and road departure rates were derived from the western New York data. They were applied to the Ohio and Alabama curves, with the results shown in table 20. The equations appear valid for Ohio, but they were unable to explain variations in accident rates of the Alabama curves. That is not necessarily a failure of the equations, as will be seen shortly.

Tables 21 to 23 present in detail the results when the equation for total accident rate in table 20 was used to "predict" curves with high, intermediate, and low accident rates in each of the three States studied. Although the cutting points for the three groups were arbitrarily determined, discriminating sites in this way is one of the objectives of accident surrogates. The tables help to illustrate important points about the results:

1. The equation performed modestly well. It identified more than half the high-accident-rate sites in western New York and it did not drastically misclassify curves with "high" or "low" accident rates (table 21). Its Ohio performance was less satisfactory, though extreme misclassifications were few (table 22). With the Alabama curves (table 23), none were predicted to have accident rates, and few did. Their "high" rates could easily have resulted from chance. (Note their low degrees of curvature, traffic volumes, and accident counts.) Thus, the equation seemed to function validly in Alabama.

2. Had curves with predicted high accident rates been designated for countermeasure treatment, the expenditures would have been wasted on only one "low-accident" curve in Ohio.

3. The tenuous nature of the accident rates is revealed by comparing the accident counts across columns of the tables. A difference of one or two accidents could change a curve from one category to another. This suggests the extent to which chance operates in the accident data, and why it is difficult to find strong relationships with accident surrogate candidates.

To conclude the validation data analysis, the equations for total accident rate and road departure rate were regenerated from the combined New York and Ohio data, omitting the Alabama data because of their excessive number of low accident sites (table 24).

Table 20. Best curve equations developed from western New York data after excluding "distance to last major event".

Total accidents per 10^6 vehicles

$$= \left[0.15 + 0.000026 \text{ (degree of curvature x AADT)}\right]^2 \qquad (9)$$

R^2 = 0.21 for western New York ($p < .002$)

= 0.26 for Ohio ($p < .001$)

= 0.03 for Alabama (not significant)

Total road departure accidents per 10^6 vehicles

$$= \left[0.000029 \text{ (degree of curvature x AADT)}\right]^2 \qquad (10)$$

R^2 = 0.29 for western New York ($p < .001$)

= 0.31 for Ohio ($p < .001$)

= nil for Alabama

Table 21. Curve details in relation to accident rates: New York.

Predicted Accident Rate (Eq. 9)	Actual Accident Rate (3-year Base): Low (<.06 acc/10^6 veh)			Med. (.06-.63 acc/10^6 veh)			High (>.63 acc/10^6 veh)		
	Deg.	AADT	#Acc.	Deg.	AADT	#Acc.	Deg.	AADT	#Acc.
Low (<.2 acc/10^6 veh)	2.1	3000	0	2.6	4050	1			
	3.0	3400	0	2.8	2750	1			
	4.0	2000	0	2.3	1600	1			
	3.0	1700	0	3.8	1700	1			
	4.3	1650	0	2.5	1650	1			
	5.0	1700	0						
Medium (.2-.4 acc/10^6 veh)	3.9	3600	0	3.8	4650	2	6.8	2300	2
	6.8	2400	0	2.8	4750	1	2.5	4650	4
	6.0	3100	0	3.4	3650	1	3.5	3950	3
	4.3	3800	0	4.2	3350	1	4.5	2600	2
	4.0	4350	0	4.2	3400	1	4.5	3750	5
				5.0	3100	2			
				5.8	3100	1			
				3.6	4600	3			
				5.7	3200	1			
				4.5	3950	1			
				4.0	3050	1			
				3.4	4500	1			
				5.0	2250	1			
High (>.4 acc/10^6 veh)				4.4	4300	2	5.5	4950	5
				5.5	4800	2	5.0	4250	4
				4.0	5100	3	6.0	4000	4
				5.0	4500	2	10.3	3100	6
				8.8	2450	1	7.5	3000	3
							9.5	2250	2

Table 22. Curve details in relation to accident rates: Ohio.

Predicted Accident Rate (Eq. 9)	Actual Accident Rate (3-year Base)								
	Low (<.06 acc/10^6 veh)			Med. (.06-.63 acc/10^6 veh)			High (>.63 acc/10^6 veh)		
	Deg.	AADT	#Acc.	Deg.	AADT	#Acc.	Deg.	AADT	#Acc.
Low (<.2 acc./10^6 veh.)	2.5	3150	0	2.0	3550	2	2.0	4900	4
	2.5	3050	0	2.0	4950	1	2.0	3350	4
	1.8	3100	0	2.2	3600	2			
	1.5	3250	0	2.3	3350	1			
	2.7	3300	0	2.3	3400	1			
	2.4	2900	0	2.0	4600	1			
	2.0	2500	0	2.0	4000	1			
	2.3	2600	0	2.0	3450	1			
Medium (.2-.4 acc./10^6 veh.)	4.5	2450	0	3.0	4000	1	4.0	3750	5
	3.0	4600	0	2.2	5250	2	3.5	3420	3
				6.5	2850	1	2.8	4200	3
				2.8	4200	1	4.2	4450	6
				3.7	4300	1			
				3.0	4400	1			
				3.5	5100	1			
High (>.4 acc./10^6 veh)	6.0	4750	0	8.5	3650	2	9.5	6100	15
				6.0	3600	2	11.5	2400	2
				4.0	7000	3			
				2.7	9650	5			
				6.2	4700	2			
				4.8	4600	1			

Table 23. Curve details in relation to accident rates: Alabama.

Predicted Accident Rate (Eq. 9)	Actual Accident Rate (2-year Base): Low (<.06 acc/10^6 veh)			Med. (.06-.63 acc/10^6 veh)			High (>.63 acc/10^6 veh)		
	Deg.	AADT	#Acc.	Deg.	AADT	#Acc.	Deg.	AADT	#Acc.
Low (<.2 acc./10^6 veh)	3.0	2600	0	3.0	2200	1	3.5	2000	2
	2.8	2300	0	2.0	1800	1	4.0	2600	3
	2.8	2300	0	2.3	2800	1	2.0	2100	2
	2.3	2300	0	3.0	2100	1	4.5	1900	2
	2.5	1800	0	3.3	1900	1			
	2.0	1800	0	2.0	1900	1			
	2.3	1800	0	2.0	2300	1			
	3.8	1600	0						
	4.5	1600	0						
	3.3	2600	0						
	2.0	2600	0						
	2.3	2600	0						
	2.0	2800	0						
	2.0	4200	0						
	2.3	3800	0						
	1.8	2600	0						
	2.8	1600	0						
	5.5	1800	0						
	2.2	2100	0						
	2.5	2100	0						
	3.3	2100	0						
	2.0	1900	0						
	3.5	1900	0						
	3.0	1900	0						
Medium (.2-.4 acc/10^6 veh)	6.8	2200	0	4.8	2600	1	3.5	3200	3
				3.0	3800	1			
No high accident rates predicted.									

Table 24. Best curve equations developed from combined western New York and Ohio data.

Total accidents per 10^6 vehicles

$$= \left[0.21 + 0.000021 \text{ (degree of curvature x AADT)}\right]^2 \qquad (11)$$

$R^2 = 0.23$ $(p = .0001)$

Total road departure accidents per 10^6 vehicles

$$= \left[0.000022 \text{ (degree of curvature x AADT)}\right]^2 \qquad (12)$$

$R^2 = 0.28$ $(p = .0001)$

Further Examination of Traffic Volume and Degree of Curvature

Since the best predictive equations for curve accident rates included only degree of curvature and traffic volume, these two variables were examined further to possibly reveal why they dominated as predictors. Table 25 shows that each of the variables correlated with several others, though they are mainly independent of each other. This suggests that degree of curvature and traffic volume are basic causal variables, influencing traffic responses and/or curve design, which in turn may influence accidents.

Table 26 shows the Pearson correlations of degree of curvature and traffic volume with accident rates in western New York and Ohio. (The limited Alabama sample had no significant relationships.) Degree of curvature correlated more with the road departure rates than with the total accident rates, while the reverse was true for AADT. This suggests that high degree of curvature is hazardous primarily for road departure accidents, while high volume probably increases opportunities for vehicle-vehicle collisions. This accounts for most curve accident types.

Summary of Isolated Curve Analysis

The search for isolated curve accident surrogates began by testing predictor equations from two other studies (Datta et al., 1983; Glennon et al., 1983). Only an equation by Datta et al. (1983) was supported with western New York data. That equation estimated road departure accident rates from degree of curvature and superelevation error. Subsequently, superelevation error was found unrelated to western New York curve accidents.

Further effort to find curve accident surrogates began with a list of promising variables, but most were eventually eliminated as useful surrogates. Table 27 shows that nearly all the rejected candidates had two or more fundamental weaknesses. One variable, distance to the last major event in the

Table 25. The centrality of degree of curvature and traffic volume at rural curves.

(In parentheses: Pearson correlations in western New York data.)

Higher degree of curvature is associated with . . .

- Higher centerline encroachment rates in the outside lane (r = 0.50)
- Higher edgeline encroachment rates in the inside lane (r = 0.50)
- Shorter curve length (r = -0.52)
- Higher salience of curve warnings (outside lane r = 0.46; inside line r = 0.53)
- Somewhat lower traffic volume (r = -0.19)
- Somewhat greater grade (r = 0.30)
- Somewhat higher speed reduction (r = 0.31)

Higher volume curves tend to have . . .

- Lower grades (r = -0.33)
- Lower centerline encroachment rates in the outside lane (r = -0.43)
- Somewhat higher edgeline encroachment rates in the outside lane (r = 0.28)
- Somewhat lower degree of curvature (r = -0.19)
- Somewhat longer curve length (r = 0.23)

Table 26. Correlations of curve accident surrogates with accident rates (per 10^6 vehicles).

	AADT		Degree of curvature		AADT x degree of curvature	
	With Total Acc. Rate	With Depart. Acc. Rate	With Total Acc. Rate	With Depart. Acc. Rate	With Total Acc. Rate	With Depart Acc. Rate
Western New York	0.21	0.19	0.34^{*}	0.47^{**}	0.46^{**}	0.54^{**}
Ohio	0.33^{*}	0.05	0.40^{**}	0.60^{**}	0.51^{**}	0.47^{**}

$^{*}P < 0.05$ $^{**}P < .01$

Depart. = road departure

Table 27. Attributes of variables rejected as curve accident surrogates.

Variable	Reliability Poor	Variance Low	Bivariate Relat. To Accidents: Weak/Nil	Bivariate Relat. To Accidents: Contrary	Mutivar. Rel. to Acc. Nil	Validation Support Nil
Operational Variables						
AADT per New York DOT			X			—
Ave. speed reduction: OL	(X)	X			X	—
Centerline encroachment rate: OL	(X)				X	—
Centerline encroachment rate: IL	X		X			—
Edgeline encroachment rate: OL	(X)		X			—
Edgeline encroachment rate: IL	X				X	—
Nonoperational Variables						
Length of curve			X		X	
Salience of advanced warnings: OL				X	X	—
Salience of advanced warnings: IL				X	X	—
Within-curve warnings rate: OL			X		X	—
Within-curve warnings rate: IL	X		X		X	—
Superelevation error		X	X			—
Shoulder width	(X)			X	X	—
Vertical alignment		(X)			X	—
Roadside hazard rating: OL	(X)		X			—
Roadside hazard rating: IL			X			—
Distance from last event: OL	(X)					X

OL = outside lane IL = inside lane (X) = borderline acceptability outside lane, looked promising with the western New York data, but it was rejected at the validation stage. Thus, only degree of curvature and AADT remained as valid surrogate variables. Equations (numbers 9 and 10) estimating total accident rate and road departure rates from these variables appeared valid with New York, Ohio, and Alabama data.

RESULTS FOR THE UNSIGNALIZED INTERSECTIONS

Because the accident patterns of tee and cross intersections differed substantially (see chapter three), potential accident surrogates were examined for each type of intersection.

Denominators for Intersection Accident Rates

While total entering traffic volume is a commonly used exposure measure for intersections, much more complex measures have been considered (Council, Stewart, Reinfurt, and Hunter, 1983). Examination of the relation between accident frequency and total entering volume in the western New York intersection samples revealed a tendency for the volume to increase with accidents. The linear correlations were 0.21 ($p < 0.10$) for the tee intersections and 0.59 ($p < 0.001$) for the cross intersections, with a curvilinear tendency suggested for the latter. These relationships gave modest support for using total entering volume as an exposure measure. To maintain comparability of the results, total entering volume was used as the accident rate denominator for both intersection types.

Identifying Viable Surrogate Candidates

Initial screening of the surrogate candidates was again accomplished by comparing accident rate groups. Tables 28 and 29 present results.

Table 28. Means and percentages of potential surrogates within accident-rate groups: tee intersections.

Potential Surrogates	Accidents Per 10^6 Vehicles ≤ 0.09 (n=23)	0.10-.90 (n=41)	> 0.90 (n=8)	Rel. to Acc. Rate
Operational Variables				
Volume (veh/h): major road	255.1	317.1	158.6	
Volume (veh/h): minor road	11.9	22.8	20.4	*
Volume (veh/h): total entering	267.0	339.9	178.9	
% left turns: major road	2.7	2.9	9.2	*
Ave. stopped delay (s/veh): minor road	7.4	7.2	5.0	*
RMS vol (veh/h)	49.7	78.7	55.0	
Minor volume ÷ major volume	0.05	0.07	0.14	*
Nonoperational Variables[1]				
% with stop signs	95.7%	97.6%	62.5%	
No. luminaires within 200 ft	0.65	0.78	0.88	*
No. turning lanes	0.04	0.0	0.0	
No. driveways within 200 ft	2.48	3.15	3.38	
% with sight restriction: minor road	39.1%	4.9%	0%	
% with 55 mi/h speed limit	95.7%	100.0%	100.0%	
% with skewed intersections	68.8%	58.5%	62.5%	
% with grades: major road	39.1%	12.2%	12.5%	
% with grades: minor road	47.8%	47.5%	12.5%	*
% with curve: major road	30.4%	24.4%	37.5%	
% with curve: minor road	8.7%	14.6%	12.5%	

1 mi = 1.6 km
1 ft = 30 cm

veh = vehicles
* = variable appears related to accident rate

[1]Percent figures refer to percent of sites.

Table 29. Means and percentages of potential surrogates within accident-rate groups: cross intersections.

Potential Surrogates	Accidents per 10^6 vehicles ≤0.90 (n=23)	0.10-.90 (n=41)	>0.90 (n=8)	Rel. to Acc. Rate
Operational Variables				
Volume (veh/h): major road	260.2	267.9	298.2	*
Volume (veh/h): minor road	15.5	42.1	46.2	*
Volume (veh/h): total entering	275.7	310.0	344.4	*
% left turns: major road	2.2	4.8	4.7	*
Ave. stopped delay (s/veh): minor road	8.4	7.7	7.6	
RMS vol (veh/h)	62.7	97.8	114.8	*
Minor volume ÷ major volume	0.06	0.18	0.16	
Nonoperational Variables[1]				
% with stop signs	83.3%	96.3%	100.0%	
No. luminaires within 200 ft	0.50	0.51	1.13	*
No. turning lanes	0.0	7.4%	0.0	
No. driveways within 200 ft	3.17	2.59	3.06	
% with sight restriction: minor road	0.0	11.1%	6.3%	
% with 55 mi/h speed limit	100.0%	96.3%	100.0%	
% with skewed intersections	50.0%	65.4%	56.3%	
% with grades: major road	16.7%	14.8%	6.3%	
% with grades: minor road	83.3%	51.8%	31.3%	*
% with curves: major road	0.0	11.1%	12.5%	
% with curve: minor road	0.0	22.2%	6.3	

1 mi = 1.6 km
1 ft = 30 cm

veh = vehicles
* = variable appears related to accident rate

[1]Percent figures refer to percent of sites.

Several operational measures appeared related to accident rates, although tee and cross intersections differed on specifics. The clearest relationships were exhibited with the cross intersections, where the volume measures systematically increased with accident rate.

Results were more nebulous with the nonoperational variables. The relationships of these categorical variables to the accident rate groups were examined through contingency tables, and the data have been simplified in tables 28 and 29 for illustration. Chi-square statistical tests were performed in the contingency tables, and not one relationship even approached statistical significance. The "best" of these weak relationships was with number of luminaires and vertical alignment on the minor road. The luminaires relationship contradicted expectations, because high accident sites had generally more illumination. Exploration revealed that most of the high-accident-rate sites were in just two counties where the intersections were most frequently illuminated. Consequently, number of luminaires was not considered a viable accident surrogate. With that exception, the variables noted with asterisks in tables 28 and 29 were considered viable candidates as accident surrogates.

In reviewing the viable candidates, their limitations for the study's objectives became apparent. Having at most one nonoperational surrogate would be insufficient for identifying hazardous sites, while the predominance of volume variables among the operational candidates would limit countermeasure evaluation capability.

To find clues to other characteristics of hazardous intersections, data of individual sites were reviewed. Cross intersections with high accident rates appeared to have high left-turn rates from the minor road (in contrast with the major road left-turns previously examined). Consequently, minor road left-turn rate was added to the list of variables for further investigation.

Identifying The Best Surrogate Equations

As with the analyses for isolated curves, multiple regression was used to generate equations for estimating accident rates. Square-root transformation of the actual rates was used to compensate for their skewed distributions.

Stepwise multiple regression analyses resulted in the equations shown in table 30. For both tee and cross intersections, the remaining nonoperational variable -- minor road vertical alignment -- was eliminated for its failure to add predictive power. Prominent in the equations were interactions between the major and minor road volumes. The ratio of minor to major road volumes was important to tee intersection accidents, while their product was relevant to cross intersections.

Since the interaction effects suggested by previous research had already been included, and since the predictive variables were limited to a few operational variables, further attempts at refining the predictive models were not made. The limitations of the results also led to the decision not to include a validation phase for the intersection equations in the study.

Volume Relationships as Exposure Measures

Since volume relationships appeared so prominent in the equations to estimate accident rates, and volume reflects accident opportunity, it was hypothesized that the strongest relationships might be found between the volume variables and the single accident frequencies. Multiple regression analyses were run to check on this. Since the analyses were tangential to the main objectives of the study, the results are not reported in detail. It is simply noted that among total entering volume, ratio of minor and major road volumes, RMS volume, and their quadratic terms, RMS volume was most strongly related to accident frequencies at both tee and cross inter-

Table 30. Best intersection equations developed from western New York data.

Tee intersections

Total accidents per 10^6 entering vehicles

$$= \left[0.68 - 0.054\ (\text{ave. vehicle delay, minor road}) + 2.50\ (\text{minor road vol.} \div \text{major road vol.})\right]^2 \quad (13)$$

$R^2 = 0.24$ $(p = .0001)$

Cross intersections

Total accidents per 10^6 entering vehicles

$$= \left[0.78 + 0.0022\sqrt{\text{major road vol. x minor road vol.}} - 0.0077\ (\%\ \text{left turns, minor road})\right]^2 \quad (14)$$

$R^2 = 0.25$ $(p < .002)$

sections. For tee intersections, R^2 was a modest 0.18 (P = 0.0002), but for cross intersections, the value was 0.46 (P = 0.0001). (In chapter five it will be seen that the latter value is about as high as may be expected.) An implication is that RMS volume may be a fundamental exposure measure, accounting for most accident opportunities arising from the interactions of the traffic stream in an intersection.

Summary of Unsignalized Intersection Analyses

The outstanding result in the search for intersection accident surrogates was that ultimately only operational variables were found to have predictive power for accident rates. Few of the nonoperational variables appeared to be related to accident rates, and none of their relationships came close to statistical significance. Several of the nonoperational variables were limited by minimal variation among the intersections.

Every one of the operational variables appeared related to accidents at tee or cross intersections. Major and minor road traffic volumes were important predictor variables, but their ratio was relevant to tee intersections while their product was relevant to cross intersections. Besides traffic volume, minor road delay and percent left turns from the minor road were predictive variables for the tee and cross intersections respectively.

The variables that were not accepted as accident surrogates at either tee or cross intersections are listed in table 31. The reader is reminded that the variables were rejected only as measured in this study and for the range of variation in the study sample.

Table 31. Attributes of variables rejected as intersections accident surrogates.

Variable	Reliability	Variance	Bivariate Relat. To Accidents		Multivar. Reliation To Acc.
	Poor	Low	Weak/Nil	Contrary	Nil
Operational Variables					
Minor road volume; major road volume; total entering volume	Supplanted by other volume var's.				
Percent left turns: major road					X
Nonoperational Variables					
Type of traffic control	*	X	X		
No. luminaires within 200 ft	*			X	
No. turning lanes	*	X			
No. driveways			X		
Sight distance: minor road	*	X	X		
Speed limit: major road	*	X	X		
Intersection angle			X		
Vertical alignment: major road	*		X		
Vertical alignment: minor road	*				X
Horizontal alignment: major road	(X)		X		
Horizontal alignment: minor road	*	X	X		

(X) = borderline acceptability

* = indeterminate because of low variance in reliability subsample.

CHAPTER FIVE
DISCUSSION

> The general approach used to "validate" a surrogate measure has been to compare observed accidents with the observed surrogate measure, and then to be quickly discouraged by the lack of agreement. For example, correlation coefficients of 0.4, 0.6, or even 0.8 are quickly rejected as not being large enough to adequately "estimate" or "predict" accidents. Any attempt to match surrogates with accidents in this manner is doomed to failure.
>
> Glauz, Bauer, and Migletz (1985)

Is it feasible to evaluate accident surrogates by how well they estimate or predict accident rates? We think so. If surrogates are to substitute for accident data, the two ought to agree to some extent in distinguishing more hazardous sites from less hazardous ones. Showing that extent is not too much to expect of the surrogates developer.

But as Glauz et al. suggest, if we insist on a high agreement, our efforts may be doomed to fail. We need a standard of what is acceptable. Glauz et al. compared how accidents predict future accidents with how traffic conflicts predict future accidents. That is a good idea, but our approach is slightly different from theirs. We suggest that a useful benchmark for evaluating surrogates is the reliability of accident rates. Recall that in chapter two, intersection accident counts in one 3-year period correlated 0.5 with accident counts in a following 3-year period. That means that the accident data of the first period could "explain" 25 percent (0.5^2) of the accident variance in the second period. Therein is a standard for evaluation. To be sure, our sample was very small and we do not know the test-retest correlations for accident <u>rates</u>. But with more complete data and larger samples, those correlations are readily obtained -- for curves, intersections, and other "spot" locations or road sections. Any surrogate that predicts at least as well as accident data is not a bad surrogate.

If past accident rates were known to correlate 0.5 with future accident rates at isolated curves, how would our results compare? Our curve predictive equations performed equally well, using as predictor variables only degree of curvature and AADT.

But can surrogates realistically be expected to do better? To answer this, we use a relationship originating in the statistics of measurement (Walker and Lev, 1953; Cohen and Cohen, 1983). It is as follows:

$$r^2_{xy} = r^2_{x^*y^*} \; r_{xx} \; r_{yy} \qquad (15)$$

where r_{xy} is the obtained correlation between two variables, such as surrogate X and accident rate Y

$r_{x^*y^*}$ is the "true" correlation of X and Y

r_{xx} = the reliability of X (surrogate reliability)

r_{yy} = the reliability of Y (accident rate reliability)

In relation to accident surrogates, $r_{x^*y^*}$ seems best interpreted as the correlation between the surrogate and "true" accident rate, or accident potential of a site. If the surrogate were perfect, $r_{x^*y^*}$ would be 1.0. If r_{xx} = 0.9 and r_{yy} = 0.5, and the "true" correlation is perfect, then,

$$r^2_{xy} = 1.0 \text{ X } 0.9 \text{ X } 0.5 = 0.45 = 45\%.$$

This figure provides a second standard for evaluation of surrogates, if surrogate and accident reliabilities are about as estimated. It suggests that the maximum accident rate variance we can account for with a perfect surrogate (variable or equation) is around 45 percent. If the surrogate or accident rates are less reliable then estimated, then of course the maximum is reduced.

Summarizing the discussion so far, a standard for acceptable performance of an accident surrogate is how well accident rates predict accident rates, while the maximum performance possible is limited by the reliabilities of surrogates and accident rates. Our exercise suggested that the two standards might be approximately 25 percent and 45 percent of accident variance explained, though better information on accident rate reliability is needed to have confidence in the figures.

RELIABILITY OF SURROGATES

An interesting implication of the preceding is that, in theory at least, it is possible for surrogates to estimate future accident rates better than past accident rates can. How can this be? The answer is that surrogates can be more reliable than accident rates, thereby providing a more solid basis for estimation or prediction.

A related implication is that surrogate candidates that are only as reliable as accident rates can predict no better than accident rates. Presuming they also lack a perfect "true" correlation with accident rates, they must do worse.

Considering the importance of surrogate reliability, it is illuminating to review the test-retest reliabilities of the surrogate variables entering the final predictive equations identified in chapter four:

Curves

degree of curvature:	r = 0.94
AADT (from veh/h):	r = 0.82

Intersections

RMS volume:	r =	0.99
% left turns:	r =	0.95
minor/major volume ratio	r =	0.95
ave. minor road vehicle delay	r =	0.49

All except minor road delay were among the most reliable of the surrogate candidates. Low reliability probably explains why several of the other candidates had insufficient relationships to accident rates. (And one may suspect that average vehicle delay will not be upheld as an intersection accident surrogate.) Clearly, one of the preconditions for a good surrogate is high reliability. That may argue against the use of simple measurements for some of the variables examined in this study.

For variables with fair or poor reliability, it should be recognized that the lack of reliability can be due to one or more of the following:

- Inherently unreliable or random variable.
- Poor definition of variable.
- Inadequate measurement technique.
- Unreliable measuring instrument.
- Lack of data collector skill (due to aptitude, attitude, or training).
- Data collection period too short (for operational variables).

For each of these problems except the first, remedial efforts should improve reliability.

FUTURE PROSPECTS FOR SURROGATES

Although this study produced curve surrogate equations for total accidents and road departure rates which may predict as well as accident rates themselves, better curve surrogates are desirable. Better "hit rates" are preferred for identifying hazardous sites, and operational surrogates are still needed for evaluating accident countermeasures. For design plan review, design engineers certainly need more criteria than degree of curvature and volume for safety considerations. With unsignalized intersections, the results were even more limited. Though the findings on operational measures may be useful for further surrogate development, the need for nonoperational surrogates remains.

A fundamental question raised by the results of this study is: Are better surrogates really possible? We think they probably are, provided they are not limited to just simple measurements. Some variables, especially more complex operational ones, may need more effort put into measurement technique.

If any further effort is to be put into surrogates development, what will maximize chances of success? Lessons can be learned from the theoretical points discussed above, as well as from the limitations that can now be seen in this study as well as in those that preceded it. The following are the needed aspects of surrogates development studies:

1. Demonstrate that accident rates are reliable. A prerequisite is to show that accident rates (not just frequencies) are significantly reliable at the kind of site or road section of interest. This is tantamount to showing that the accident rates are not due only to chance. The accident data should be carefully screened for errors and locational accuracy. Surrogates development should proceed only if accident rates correlate with accident rates at no lower a level than, say, $r = 0.4$.

2. Test only reliably measured surrogate candidates. This prerequisite may imply substantial preliminary effort to increase reliability of measurement for promising variables of low reliability. The standard should be high, with recommended test-retest correlations of 0.85 or above. To achieve high reliability, some surrogate candidates may

require: (a) sophisticated measuring or recording instruments; (b) extensive or improved data collector training; (c) several hours or days of data collection; and/or (d) refined operational definitions.

3. Use diversified samples. While uniformity is needed on control variables, e.g., by examining curves only on two-lane rural roads, diversity is needed in accident rates and surrogate candidates. Variance in these measures is needed for detecting relationships. Since design standards may restrict variations, samples from several States and/or State and local roads may be needed.

4. Use a large sample size. It is clear now, from this study's empirical results and the statistical considerations earlier in this chapter, that high correlations between surrogate variables and accident rates cannot be expected. To detect and estimate weaker relationships, sample sizes several times larger than in this study are needed. Confidence intervals for the Pearson correlation coefficient indicate that a sample size of at least 500 is required. (It is worth noting that previous accident causation studies used sample sizes in the 1000's; e.g., Billion and Stohner, 1957; Kihlberg and Tharp, 1968; Glennon et al., 1983.)

5. Use conservative data analysis. Extensive "churning of the data" is to be avoided, as it is likely to capitalize on chance in revealing bogus "relationships". Instead of testing large numbers of equations, e.g., for various subsets of sites and accident types, analysis guided by theory, engineering logic, and previous research is more likely to produce reliable results.

6. At rural "spot" locations, consider analyzing sites within groups. Surrogates are most needed at rural "spot" locations where low traffic volumes and small crash-capture areas result in low, less-reliable accident counts. But the very phenomenon that creates an especial need for accident surrogates at these locations also makes it difficult to detect surrogate-accident relationships. One may be tempted

to sample road segments much larger than the "spot" location, in order to capture more accident data. This is not recommended, for it may only obscure relationships. Instead it may be more feasible to collect a large sample in which each "case" is a group of sites--perhaps five per group--similar in their values of the surrogate candidates. For example, 500 curves sampled in this way would comprise a sample size of 100 curve groups. The accident data would be pooled within groups.

7. Demonstrate surrogate ability to distinguish hazardous sites. The analysis should show clearly the success rates with which the surrogates are able to distinguish hazardous sites from others. Since assessing hazardousness is one of the basic objectives of accident surrogates, comparing the indications of surrogates with the indications of accident rates is fundamental. It is most important that this be done with a validation sample of sites.

In summary, while the concept of accident surrogates has merit, for surrogates to be viable, more than very simple measures are needed. Since the developmental effort described above could command a substantial investment of resources, the preliminary checking of accident rate reliability and developing surrogate-variable reliability are essential. Only when those prerequisites are achieved should large-sample evaluation studies be made.

CHAPTER SIX

CONCLUSIONS

The following conclusions were derived from the review of previous research, the results of this study, and the discussion in chapter five.

1. While several promising accident surrogates for rural isolated curves and unsignalized intersections were identified in the research literature, simple measures of surrogates do not appear sufficient for these locations.

2. If accident surrogates are to be feasible, effort needs to be put into developing the methods of measurement; possibilities included improvement of manual techniques, better training of personnel, and more sophisticated instrumentation.

3. For rural isolated curves, degree of curvature and AADT are valid accident surrogates; however, additional surrogate variables are needed to improve predictability and to facilitate countermeasure evaluation.

4. For unsignalized intersections, evidence suggests the following accident surrogates as promising but not validated:

    (a) for tee intersections: minor road average vehicle delay, minor road AADT ÷ major road AADT;

    (b) for cross intersections: percent left turns from minor road, root-mean-square of major and minor road AADTs.

    Further work is needed to identify nonoperational surrogates, improve predictability, and establish validity.

5. For identifying and developing useful accident surrogates, studies need to do the following:

    (a) Determine accident rate reliability.

    (b) Establish highly reliable surrogate measures.

    (c) Use heterogeneous site samples, i.e., those diversified in their operational and nonoperational characteristics.

(d) Use samples sufficiently large to detect weak relationships of surrogates to accident rates. (Samples of at least 250 sites are preferable.)

(e) Use conservative data analysis, to avoid capitalizing on chance.

CHAPTER SEVEN

RECOMMENDATIONS

1. It is recommended that, instead of further attempts to develop comprehensive sets of simple surrogate measures, resources should be concentrated on a few key studies described below.

   (a) Determine reliability of accident counts and rates at rural locations. Besides providing an essential prerequisite for the development of accident surrogates, studying the reliability of accident counts and rates (accidents per exposure unit) would also provide countermeasure guidance for spot locations. Consider four possible outcomes at a specific location:

   (1) Accident frequencies and rates are reliable. This would show that the sites differ in hazardousness, suggesting that surrogates are feasible and countermeasure application to sites with high accident rates is appropriate. If the sites also differ significantly in exposure, the high-exposure sites deserve high priority.

   (2) Accident frequencies are reliable, but rates are not. The reliable frequencies would suggest that enduring site differences in exposure, e.g. in AADT, are producing enduring differences in the accident counts. The unreliable rates, however, indicate no significant site differences in site hazardousness (risk per exposure). In this case, surrogates to indicate hazardousness are not feasible, and countermeasures would reasonably be applied to these sites with the greatest exposure.

   (3) Accident rates are reliable, but frequencies are not. This would indicate that there are enduring differences in accident risk among the sites, but that exposures do not differ or they vary randomly. This suggests that surrogates are feasible, and countermeasures should be attempted at the high-risk sites.

(4) Neither accident counts nor rates are reliable. Since no consistent differences in accident experience are observed among the sites, any countermeasures should be uniformly applied to all.

(b) Evaluate traffic engineering estimates of hazardous sites. Experienced highway engineers often use on-site observations to judge whether a site is hazardous or not. They report using evidence such as skid marks, shoulder ruts, and damage to roadside furniture in making their judgments. The suggested study would use human factors techniques to determine three aspects of these judgments. First, it would determine their reliability by comparing independent ratings of site hazardousness within a sample of experienced engineers. Second, it would determine the validity of the ratings by comparing them with indications of accident rates. Third, it would determine how the judgments were made. The engineers would be asked to record the clues used in making their ratings. Among those whose ratings correlated with the accident rates, their clues would be analyzed to identify new surrogates for accident data. Positive results could then be used to develop procedures for training others to use the method.

(c) Develop improved surrogate measures. There are some variables that held promise as surrogates in the literature review, but were either not examined in this study because of measurement complexities, or their examination was limited by problems of reliability or sample variance. They should not be ruled out as accident surrogates, but their evaluation will need sophisticated measures, more developed measures, or more complex samples. Further efforts with these variables are probably best concentrated on a few at a time. The variables are:

- Roadside hazard (curves).
- Vehicle lateral placement variance (curves).
- Skid rating (curves).
- Vertical alignment (curves and intersections).
- Horizontal alignment (intersections).
- Sight distance (intersections).
- Minor road average vehicle delay (intersections).

2. Certain curve variables were rejected as surrogate candidates, but the findings suggest that further study would improve understanding of accident causes and perhaps enhance countermeasures. Studies of the following are recommended.

   (a) Edgeline and centerline encroachments. Although these variables added no predictive power to equations, including degree of curvature, encroachments may be a hazardous consequence of degree of curvature. While it would take a specially designed study to determine that, the results may suggest countermeasures.

   (b) Distance to last major event. This was one of the most promising surrogate candidates in the literature review, and it still looked promising in the western New York results. It failed the validation test, but low reliability obscured the results on this variable. With the definition of "major event" improved to raise reliability, it would be valuable to determine just how important "isolatedness" is to curve hazardousness. If it is not important, then isolated curves should not be considered a special safety problem. If it is important, countermeasures should be considered. A systematic study would examine the full range of isolatedness in relation to accidents, in both travel directions.

3. For exposure measures at intersections, it is recommended that the root-mean-square of major and minor road traffic volume (RMS volume) be further investigated. Appropriate accident rates are a recognized need for hazardous site identification and countermeasure evaluation, and results in this study suggest that RMS volume may be a feasible denominator for intersection rates. It is a variable found related to accident frequencies, it was more strongly related than total entering volume, and is simpler to use than complex exposure variables requiring additional measurements and complex equations.

GLOSSARY

This glossary gives operational definitions used in this study. The operations may differ somewhat in other studies or applications.

AADT estimated from vehicles per hour - average annual daily traffic volume estimated with equations relating measured volume at spot locations to State-recorded AADT for road sections.

encroachment, centerline and edgeline - the touching of the road centerline or edgeline by a vehicle tire; measured in this study for isolated vehicles within the limits of a curve.

entering volume - the total number of vehicles, per unit of time, entering an intersection from all approach legs.

horizontal alignment - degree of curvature, recorded as measured for isolated curves, and recorded in the following categories for intersections:

1 - tangent (straight)
2 - isolated curve
3 - winding

isolated curve - a curve in which no major event is within 1/4 mi (0.4 km) of either end (doubly isolated) or of one end only (singly isolated).

isolated vehicle - a vehicle with a forward and backward headway of 9 seconds or more to the next vehicle, in both lanes of a two-lane road.

length of curve - the distance from the point of curvature to the point of tangency (simple curves) or to the change of curvature (reverse and compound curves).

major event - a highway situation that requires a driver to adjust vehicular speed or path; e.g., horizontal curves, intersections of major public roads, railroad crossings, and narrow bridges.

outside lane accident - a curve accident in which the striking vehicle (or first vehicle to cross the centerline) was traveling in the outside lane prior to the collision.

roadside hazardousness rating - a judgment of the net hazard a roadside presents to a road-departing vehicle; rated on the following scale (adapted from Datta et al., 1983):

1 - clear, no fixed object, fairly level terrain
2 - vegetation or yielding objects, fairly level terrain, no rigid fixed objects
3 - isolated rigid fixed objects, fairly level terrain
4 - ditch through most of curve, no embankment or sideslope $>$ 3:1
5 - embankment or side slope $>$ 3:1
6 - numerous or continuous rigid fixed objects

salience of curve advance warning - the prominence or attention-getting value of all signs warning of a curve and associated hazards ahead; determined by an algorithm that weights the number and intensity of warning signs (appendix G).

sight distance from minor road - the unobstructed distances in both directions of the major road, as viewed from the minor road approaches at an intersection; recorded in the following categories:

1 - unrestricted ($>$ 500 ft [152 m]), both approaches
2 - restricted ($<$ 500 ft [152 m]), one approach
3 - restricted ($<$ 500 ft [152 m]), both approaches

speed reduction, curve - average speed 250 ft (126 m) prior to the point of curvature of the outside lane, minus the average speed at curve midpoint; determined for isolated vehicles only.

superelevation error - the recommended minimum superelevation (AASHO, 1965) minus the superelevation measured at curve midpoint; superelevation is a unitless rise-over-run ratio.

vertical alinement - percent of grade at steepest point within a curve or within 200 feet (61 m) of an intersection; recorded in categories of less than 1 percent, 1 percent-4 percent, and greater than 4-percent.

within-curve warning rate - the total number of warning devices (directional arrows, chevrons, post delineators) per 1,000 feet (305 m) of curve.

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