AN EVALUATION OF ACCIDENT SURROGATES FOR SAFETY ANALYSIS OF RURAL HIGHWAYS

Vol. I: Executive Summary

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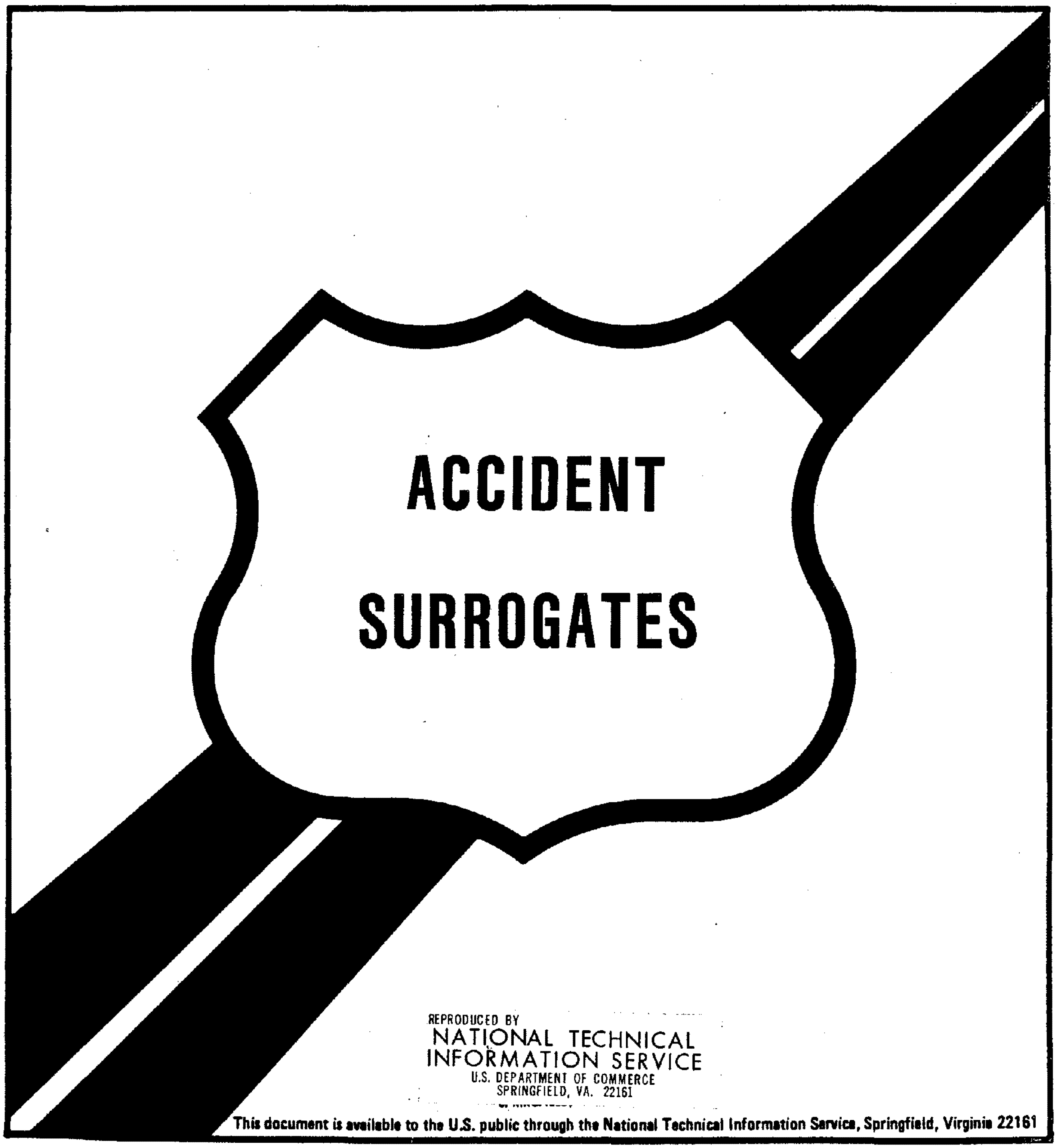

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16. Abstract

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.

The most promising surrogate variables were identified from the work of previous investigators, and 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.

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INTRODUCTION AND RESULTS SUMMARY

This study evaluated the use of accident surrogates as measures of safety at isolated horizontal curves and unsignalized intersections on rural 2-lane roads. It continued the work begun in a previous study, in which Goodell-Grivas, Inc. explored 30 possible surrogates at 25 isolated curves in Michigan (Datta, Perkins, Taylor, and Thompson, 1983). This study further examined the validity of the accident surrogate concept by using data from New York, Alabama, and Ohio.

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 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 measure should be consistent when repeated over time or by different data collectors.

During the planning of the study, it was decided that the types of spot locations offering the most promise for accident surrogate development were isolated curves and unsignalized intersections on rural 2-lane roads. Sites on State highways were studied to take advantage of automated accident data systems.

The study's objectives were as follows:

1. To quantify the relationship between surrogate measures and accident experience at rural isolated curves and unsignalized intersections.

2. To develop methods for using surrogates to:

   a. Identify and rank hazardous locations.

   b. Evaluate accident countermeasures.

   c. Review design plans for safety.

For evaluating countermeasures, operational surrogates (i.e., traffic response variables) are needed to detect effects of the countermeasures. For reviewing design plans, however, only nonoperational surrogates such as measures of road geometry, control devices, etc., are relevant. For identifying hazardous sites, both surrogate types would be applicable. Consequently, this study examined operational and nonoperational surrogate candidates.

SUMMARY OF RESULTS

1. For rural isolated curves, the best accident surrogate variables found were average annual daily traffic (AADT) and degree of curvature. Equations including these variables were derived using multiple regression analysis, and they were able to estimate accidents per million vehicles with 21-31 percent of the variance in accident rate explained.

No satisfactory equations comprising exclusively operational surrogates were found.

2. For rural nonsignalized intersections, the best surrogate variables were as follows:

- For cross intersections: major road volume, minor road volume, and percent left turns from the minor road.
- For tee intersections: major road volume, minor road volume, and minor road average stopped delay per vehicle.

Equations estimating accidents per million entering vehicles accounted for about 25 percent of the variance in accident rate, for each intersection type.

No nonoperational surrogate candidates were related to accident rates at the unsignalized intersections.

3. An exploratory analysis of 6 years of accident data for subsamples of 28 curves and 30 intersections indicated that the first 3-years' accident frequency could predict the second 3-years' accident frequency with around 25 percent of the variance explained. These results suggest that the isolated curve and unsignalized intersection accident surrogates may predict future accident experience about as well as past accident experience does.

4. An analysis of the mathematics of accident-surrogate relationships indicates a theoretical potential for surrogates to do better than past accident experience. To realize the potential, however, measures more sophisticated and/or time-consuming than used in this study seem needed.

PROCEDURE

ISOLATED CURVES

Figure 1 shows schematically the procedure in studying accident surrogates for the isolated curves. The main components are discussed next.

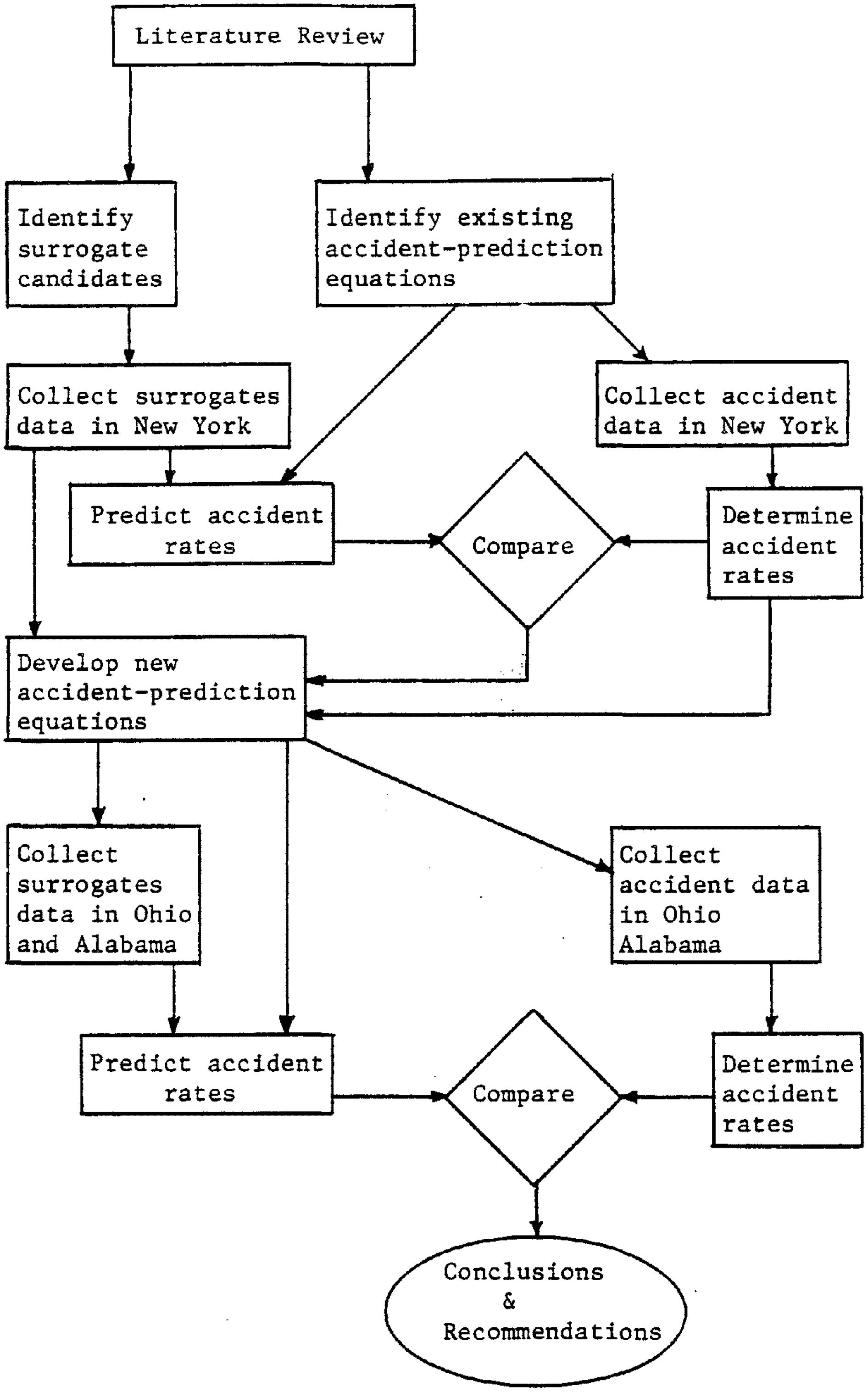

Figure 1. Schematic diagram of procedure for evaluating isolated curve accident surrogates.

Literature review. This review concentrated on the Goodell-Grivas study and a major study of rural curve hazardousness by Jack Leisch and Associates (Glennon, Neuman, and Leisch, 1983). Each report reviewed previous research literature, and from both the following were identified:

- Variables whose relationships to curve accidents suggested them as accident surrogates candidates.
- Multivariate equations developed by Goodell-Grivas and Leisch for estimating/predicting site accident experience from some of the surrogate candidates.

Data Collection. Selected for study were surrogate candidates which could be measured in a few hours with equipment available at most highway agencies. The variables and their methods of measurement are shown in tables 1 and 2.

The primary sampling area was eight western New York counties in proximity to Calspan. Sites selected were curves outside of city and village limits, on 2-lane State highways, with a minimum volume of 1,500 vehicles per day, with a minimum curvature of 2 degrees, with no major operational or physical changes in the past 4 years, and which were "isolated" by at least 1/4 mi (0.40 km) from the "last major event" (a highway feature requiring a driver to adjust vehicular speed or path). Only 78 such curves were found on State highways in the 8-county sampling area.

The field measurements were made by three 2-person teams, who received 6 days of training. Excluding travel time, about 4-6 hours per site were spent in measuring the potential surrogates, and most of the time was spent in recording the operational variables. Measurement reliability was checked by having a subsample of 11 curves remeasured by a team different from the first and determining correlations (Pearson r) between the two measurement sets. The surrogate measures varied greatly in reliability, and about half the correlations were 0.80 or higher. The less reliable measures were discussed with the teams to clarify any confusions.

Table 1. Isolated curve operational surrogate candidates.

vehicles per hour, outside lane - from on-site vehicle count over 4-5 hours, using a Denominator single-bank tally board and watch.

vehicles per hour, both lanes - measurement method as above.

AADT as per State - average annual daily traffic obtained from State records for the road segment including the curve.

AADT estimated from vehicles per hour - the observed vehicles per hour converted to AADT, using a regression equation quantifying the relation between observed vehicles per hour and State AADT.

average speed reduction, outside lane - the 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 all isolated vehicles (vehicles with forward and backward headway of 9 sec or more to next vehicle) during 3-4 hours of on-site measurement with a Kustom Radar Model No. HR4.

centerline encroachments per hour, outside lane - from 4-5 hours of on-site visual observation; counted every time the road centerline is touched by an isolated vehicle (vehicle with forward and backward headway of 9 sec or more to the next vehicle).

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

(the five items above:) Measurement methods as above.

Table 2. Isolated curve nonoperational surrogate candidates.

degree of curvature - on-site measurement of the middle ordinate between a 62-ft (18.6-m) chord and road outside edgeline; the ordinate in inches (1 in = 2.54 cm) is numerically equivalent to the curvature in degrees.

length of curve - the distance from the point of curvature to the point of tangency (simple curves) or to the change in curvature (reverse and compound curves); measured with a Transwave Distance Measuring Instrument Model No. NK-1201.

salience of curve advance warning, outside lane - the prominence of all outside-lane signs warning of a curve ahead; on an on-site count of warning signs and determined from an algorithm that weights the number and intensity of the signs.

salience of curve advance warnings, inside lane - measurement method as above.

within-curve warning rate, outside lane - the total number of directional arrows, chevrons, and post delineators per 1,000 ft (305 m) of curve.

within-curve warning rate, inside lane - measurement method as above.

superelevation error - the recommended minimum superelevation (AASHO, 1965) minus the superelevation measured at curve midpoint; measured on-site with a line-level and ruler.

shoulder width - the average of five or more measurements taken at each side of the roadway within the curve.

vertical alignment - the maximum grade of the roadway within the curve, measured on-site with a line-level and ruler.

roadside hazardousness rating, outside lane - an on-site rating using the following scale:

1 - clear, no fixed object, fairly level terrain

2 - vegetation or yielding objects, fairly level terrain

3 - isolated rigid fixed objects, fairly level terrain

4 - ditch through most of curve, no embankment or side slope 3:1

5 - embankment or sideslope 3:1

6 - numerous or continuous rigid fixed objects

roadside hazardousness rating, inside lane - measurement method as above.

distance to last major event, outside lane - distance from the point of curvature/tangency to the nearest highway feature requiring a driver to adjust vehicle speed or path; measured with a Transwave Distance Measuring Instrument Model No. NK-1201.

Site accident records for the previous 3 years were obtained from the New York State Department of Transportation. Screened out were all animal and pedestrian accidents and accidents outside the site limits of 500 feet (150 meters) before the point of curvature to 500 feet (150 meters) after the point of tangency.

Equation testing and development. The analysis began with a check of the Goodell Grivas and Leisch equations for estimating site hazardousness, and after that, an effort was made to see if improvements could be made on the equations. Beginning with the most promising variables from the literature review, the analysis proceeded through the following steps:

1. Determine denominator for the accident rate.
2. Examine the statistical properties of the variables to note special statistical treatments needed.
3. Examine the bivariate relation between each surrogate candidate and accident rate.
4. Using multiple regression analysis, test various multivariate equations for predicting/estimating accident rates from surrogate variables.

All the analyses were performed on Calspan's IBM System /370 Model 3031 computer, using the SAS statistical analysis program package.

The best equations found predicted total accident rate and road-departure accident rate (per million vehicles) from degree of curvature, AADT, and distance to last major event in the outside lane. Consequently, it was decided to validate the equations with data from two other States.

Validation tests. State highways in Ohio and Alabama were chosen for the validation testing. These two States differ geographically and climatically, and in both useful State accident data files were available to the study. Totals of 40 isolated curves in Ohio and 41 isolated curves in

Alabama were sampled, and at each the degree of curvature, AADT, and the distance to last major event was measured. Measurement procedures were exactly as in the western New York phase.

Initial examinations of the data from Ohio and Alabama revealed that distance to last major event was not related to the accident rates in either State. 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 Alabama and Ohio curves, with the outcomes as presented in the results section.

UNSIGNALIZED INTERSECTIONS

Figure 2 shows schematically the process in studying accident surrogates for the unsignalized intersections. The procedures were basically the same as with the isolated curves, except as noted below.

Literature review. While the Goodell-Grivas study suggested possible accident surrogates for unsignalized intersections, it did not attempt to develop surrogate measures or equations for that kind of site. No study developed multivariate accident-prediction equations, though many studies examined the relation of one or more variables to accident experience at unsignalized intersections. Consequently, those studies are examined to see which variables offered the most promise as accident surrogates.

Data collection. The potential accident surrogates selected for study are shown in tables 3 and 4. Data were collected at western New York unsignalized intersections outside of city and village limits, on 2-lane State highways, with minimum traffic volumes of 1,500 vehicles per day on the major roadway and 100 vehicles per day on the minor roadway, with tee (3-leg) or cross (4-leg) geometry, with no major operational or physical changes in the past 4 years, and with no major event within

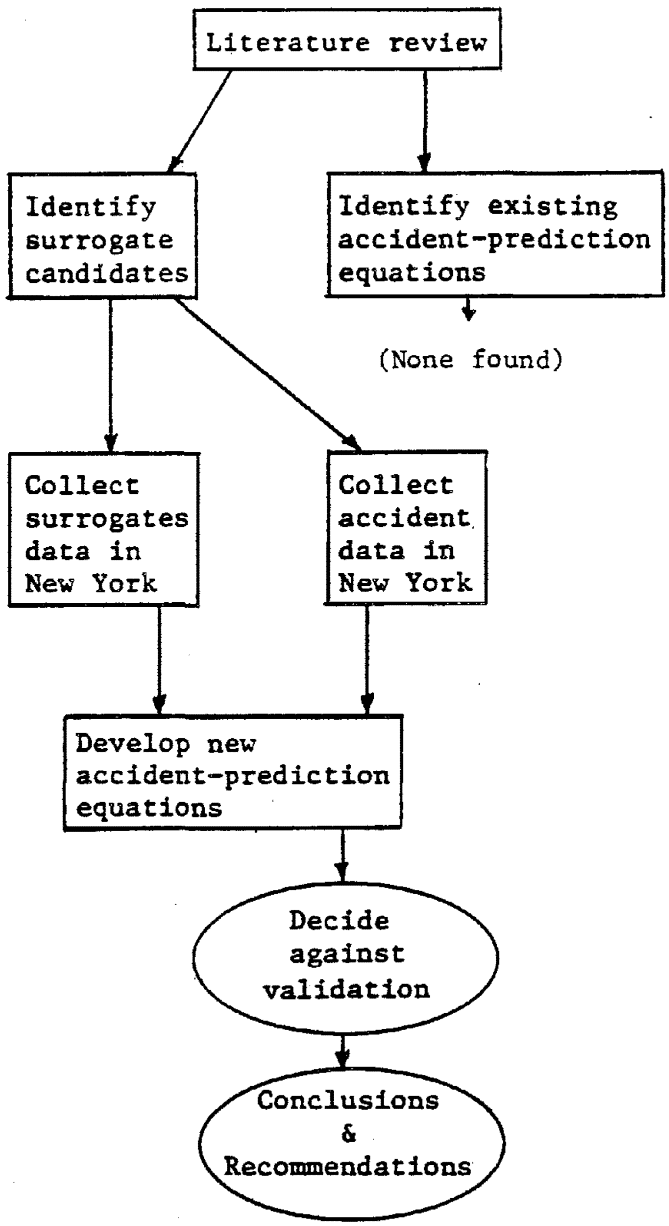

Figure 2. Schematic diagram of procedure for evaluating unsignalized intersection accident surrogates.

1/4 mi (0.40 km). There was no difficulty in identifying a sample of 121 such intersections in the 8-county sampling area.

Table 3. Unsignalized intersection operational surrogate candidates.

vehicles per hour, major road - from on-site vehicle count over 4-5 hours, using a Denominator 4-bank tally board and watch.

vehicles per hour, minor road - measurement method as above.

major road AADT estimated from vehicles per hour - the observed major road vehicles per hour converted to AADT, using a regression equation quantifying the relation between observed vehicles per hour and State AADT.

left turn percent, major road - from 4-5-hour on-site count of major road volume and number of vehicles turning left from major road; recorded on a Denominator 4-bank tally board.

left turn percent, minor road - measurement method as above.

average minor road stopped delay - from on-site measures of the stopped time of every stopping vehicle during 3-4-hour period, using stopwatch.

The data were collected by the same personnel who performed the curve field work. Measurement reliability was checked by re-collecting data at 11 intersections and correlating the first-time and second-time measurements. Most correlations exceeded 0.85. For eight nonoperational variables, however, there was insufficient data variance to test reliability; i.e., the sites were so similar that the teams' ability to distinguish variations was not sufficiently tested.

The intersection accident data were processed in a way similar to the curves. Animal and pedestrian accidents were excluded, as were all accidents occurring beyond 200 ft (60 m) from the center of each intersection.

Equation development. Since no previously developed predictive equations were identified in the literature review, the analysis developed new multivariate equations for estimating/predicting intersection accidents (per million entering vehicles) from the surrogate candidate variables. Tee intersections were examined separately from the cross intersections because their different accident patterns suggested that the accident surrogates

Table 4. Unsignalized intersection nonoperational surrogate candidates.

geometry (tee or cross) - recorded at site.

type of traffic control - on-site record of whether intersection had stop sign, yield sign, no sign, or other form of control.

number of luminaires within 200 ft (60 m) of intersection - from on-site count.

number of turning lanes on major and minor roadway - from on-site count.

number of driveways within 200 ft (60 m) of intersection - from on-site count of private and commercial driveways.

sight distance from minor road - on-site recording of whether sight distance was less than 500 ft (152 m) in neither direction, one direction, or both directions of the major roadway.

posted speed limit, major road - speed limit, if posted, within 2-3 mi (3.2-4.8 km) of the intersection.

right-angle vs. skewed intersection - on-site recording of whether the intersection angles are 90 degree or otherwise.

vertical alignment, major road - the maximum grade of the major road within 200 ft (61 m) of the intersection, measured on-site with a line-level and ruler.

vertical alignment, minor road - measured as above.

horizontal alignment, major road - the type of horizontal curvature, recorded as tangent, isolated curve, or winding.

horizontal alignment, minor road - recorded as above.

might differ also. (The cross intersection accident rates were double those of the tee intersections, and angle accidents predominated at the former while road departures were more common at the latter.)

While equations for estimating/predicting intersection accident rates were developed, only operational variables--predominantly traffic volume variables--were identified as useful accident surrogates. This led to the decision not to perform validation tests for the intersections, which best await future studies to develop a broader range of surrogates.

RESULTS

ISOLATED CURVES

Table 5 shows the results when equations from the Goodell-Grivas and Leisch studies were used to "predict" the accident rates at the western New York curves. With the Goodell-Grivas equations, the road departure accident rates were predicted fairly well from degree of curvature and superelevation error. (Superelevation error by itself was found unrelated to the western New York accident rates, so the success of equation (1) seems due mainly to the degree of curvature.) The predicted outside-lane accident rates did not correlate significantly with the actual rates.

The equation from the Leisch study generates a Discriminant Factor from degree of curvature, curve length, and shoulder width; the Discriminant Factor predicts either a "high" or "low" accident site. As in the Leisch study, the actual accident rates per 0.6 mi (1 km) were determined within traffic-volume groups, and the upper and lower extremes were distinguished from the remaining curves. As table 5 shows, equation (3) did not identify high- and low-accident curves very well.

In the process of developing new accident prediction equations for the western New York curves, most of the potential surrogates were eventually rejected for one or more reasons, summarized in table 6. Only degree of

Table 5. Validation tests (New York data) of accident-estimating equations from other studies.

A. Equations from the Goodell-Grivas study (Datta et al., 1983)

Road departure accidents per 10^6 vehicles

$$= (-)\ 2.975 + 0.499\ (\text{degree of curvature}) - 18.096\ (\text{superelevation error}) \qquad (1)$$

$R^2 = 0.33 \qquad (p<.001)$

Outside-lane accidents per 10^6 vehicles

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

$R^2 = 0.01$ (not significant)

B. Equation from the Leisch study (Glennon et al, 1983)

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

If $D \geq 0.36$, a high-accident site is predicted.

If $D < 0.36$, a low-accident site is predicted.

	Actual Accident Rate Groups[1]				
	Low	Medium	High	Total	
$D \geq .36$	14 28.6%	27 55.1%	8 16.3%	49 100.0%	Chi-square = 1.23 (not significant)
$D < .36$	9 39.1%	12 52.2%	2 8.7%	23 100.0%	
Total	23	39	10	72	

[1] Accident rate groups were determined within traffic volume strata, following procedure from Leisch study.

Table 6. Final status of curve accident surrogate candidates.

Variable	Accepted as Accident Surr.	Bases for Rejection: Reliability Poor	Variance Low	Bivariate Relat. To Accidents: Weak/Nil	Opp.[1]	Multivar. Rel. to Acc. Nil	Validation Support Nil
Operational Variables							
AADT est. from total veh/h	X						
OL veh/h; total veh/h; AADT per State	Supplanted by AADT est. from total veh/h.			X			
Ave. speed reduction: OL		(X)	X			X	
Centerline encroachment rate: OL		(X)				X	
Centerline encroachment rate: IL		X		X			
Centerline encroachment rate: total		(X)		X			
Edgeline encroachment rate: OL		(X)		X			
Edgeline encroachment rate: IL		X				X	
Edgeline encroachment rate: total		(X)		X			
Nonoperational Variables							
Degree of curvature	X						
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

[1]Opp. = Relationship to accidents opposite expectations; dubious hazardousness indicator.

curvature and AADT remained in the final predictive equations. (Note that degree of curvature was the only variable appearing in the predictive equations of the Goodell-Grivas study, the Leisch study, and this one.) As table 7 shows, predicted accident rates correlated fairly well with the actual rates in New York and Ohio, but the correlations for Alabama were not significant. The Alabama results are attributable to the fact that the Alabama curves had few accidents; 87 percent had no accidents or only one.

Table 7. Best curve equations developed from western New York data.

Total accidents per 10^6 vehicles

$$= [0.15 + 0.000026 \text{ (degree of curvature x AADT)}]^2 \qquad (4)$$

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

$$= [0.000029 \text{ (degree of curvature x AADT)}]^2 \qquad (5)$$

R^2 = 0.29 for western New York ($p < .001$)
= 0.31 for Ohio ($p < .001$)
= nil for Alabama

Table 8 shows how well equation (4) identified hazardous curves when applied to the validation States of Alabama and Ohio. Eight of the nine sites predicted to be in the high (hazardous) accident-rate group had at least a medium accident rate, while most of those predicted to have low accident rates did so in fact. On the other hand, most curves in the high actual accident-rate column were not predicted to be high. An important aspect to note in table 8 is the low average 3-year accident counts, especially in the low and medium categories. A difference of only one or

Table 8. Validity demonstration: Application of equation(4) to combined Alabama and Ohio curves.

Predicted Accident Rate	Actual Accident Rate (3-Year Base): Low ($<.06$ acc/10^6 veh) No. Curves	(Ave. No. Acc.)	Medium ($.06-.63$ acc/10^6 veh) No. Curves	(Ave. No. Acc.)	High ($>.63$ acc/10^6 veh) No. Curves	(Ave. No. Acc.)	All No. Curves	(Ave. No. Acc.)
Low ($<.2$ acc/10^6 veh)	32	(0)	15	(1.4)	6	(3.6)	53	(0.8)
Medium ($.2-.4$ acc/10^6 veh)	3	(0)	9	(1.2)	5	(4.3)	17	(1.9)
High ($>.04$ acc/10^6 veh	1	(0)	6	(2.5)	2	(8.5)	9	(3.6)

Chi-square = 14.8 ($p<0.01$)

two accidents at a site could change its classification, which suggests the role of chance in the results.

UNSIGNALIZED INTERSECTIONS

In the analysis of the intersection data, most candidate variables were rejected as accident surrogates (table 9). The final predictive equations (table 10) included operational variables only, and they differed somewhat between tee and cross intersections. Since equations fitted optimally to one data set are usually less than optimal for another data set, the relationships in a validation test would probably be weaker than shown in table 10.

DISCUSSION

To put the findings into perspective, it should be noted that in the planning stage of this study, an analysis indicated that 3-year accident counts at spot locations predict the counts for the following 3 years with a correlation around 0.5., i.e., $r^2 = 0.25$. More research is needed on this, but the results suggest that the equations developed in this study may predict future accident experience about as well as past accident experience has.

Further perspective was provided by an examination of the strongest relationships mathematically possible between surrogates and accident rates, given the modest reliability of accident data over time. This exercise suggested that the theoretically maximum R^2 possible between a surrogate equation and accident rates would be around 0.45. The maximum is imposed by the reliability of accident data and of the surrogate measures. Chance restricts the reliability of accident data, but less reliable surrogate measures may be improved by methods such as more precise instrumentation, clearer definitions, more thorough personnel training, psychometric scaling methods, and using sample design principles for collecting operational data.

Table 9. Final status of intersection accident surrogate candidates.

Variable	Accept; Validation Needed	Bases for Rejection: Reliability Poor	Variance Low	Bivariate Relat. To Accidents: Weak/Nil	Opp.[1]	Multivar. Relation To Acc. Nil
Operational Variables						
Veh/h: major road	X					
Veh/h; minor road	X					
Ave. veh. delay: minor road	X (tee)					
Percent left turns: minor road	X (cross)					
Percent left turns: major road						X
AADT est. from veh/h: major road	Supplanted by veh/h: major road					
Nonoperational Variables						
Geometry	Surrogates determined for tee and cross intersections separately.					
Type of traffic control		*	X	X		
No. luminaires within 200 ft (61 m)		*			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		

* = indeterminate because of low variance in reliability subsample.

(X) = borderline acceptability

[1] Opp. = Relationship to accidents opposite expectations; dubious hazardousness indicator.

Table 10. Best intersection equations developed from western New York data.

<u>Tee intersections</u>

Total accidents per 10^6 entering vehicles

$$= \left[0.68 - 0.054 \text{ (ave. vehicle delay, minor road)} + 2.50 \text{ (minor road vol.} \div \text{major road vol.)} \right]^2 \quad (6)$$

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

<u>Cross intersections</u>

Total accidents per 10^6 entering vehicles

$$= \left[0.78 + 0.0022 \sqrt{\text{major road veh/h. x minor road veh/h.}} - 0.0077 \text{ (\% left turns, minor road)} \right]^2 \quad (7)$$

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

CONCLUSIONS AND RECOMMENDATIONS

The following are the main conclusions of the study:

1. 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.

2. For rural unsignalized intesections, evidence suggests the following surrogates as promising but not validated:

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

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

   Further work is needed to identify nonoperational surrogates, develop more reliable surrogate measures, develop predictive equations, and test their validity.

3. While more evidence on accident rate reliability is needed, the limited evidence of this study suggests that the isolated curve and unsignalized intersection surrogates predict accident experience as well as past accident experience does, and further improvements are feasible.

Recommendations are as follows:

1. For rural curves, unsignalized intersections, and any other locations of interest, the reliability of the accident rates should be determined; surrogate development should be considered only for the kinds of locations where test-retest reliability is 0.4 or more.

2. Since experienced highway engineers often use on-site observations to judge whether a site is hazardous or not, it is recommended that the methods and criteria they use be studied for potential accident surrogates.

3. Further surrogates development for rural curves and unsignalized intersections should emphasize highly reliable measures. The following promising surrogates were found in the literature review and are still considered promising using more sophisticated techniques than were possible in this effort. The suggested approach to pursue is listed with each variable.

- Roadside hazard (curves): develop reliable scale, using psychometric methods.
- Vehicle lateral placement variance (curves): use current measurement technology; check reliability and improve if necessary.
- Skid rating (curves): use current technology, check reliability and improve if necessary.
- Vertical alignment (curves and intersections): develop procedure of sampling roadway points for reliable averages; record exact values.
- Horizontal alignment (intersections): investigate sources of unreliability and improve as necessary.
- Sight distance (intersections): use current technology, check reliability and improve as necessary.
- Minor road average vehicle delay (intersections): increase sampling time to improve reliability.

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