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ACCIDENT SURROGATES FOR USE IN ANALYZING HIGHWAY SAFETY HAZARDS

VOL. 2 TECHNICAL REPORT

Research, Development,
and Technology

Turner-Fairbank Highway
Research Center
6300 Georgetown Pike
McLean, Virginia 22101

U.S. Department
of Transportation

**Federal Highway
Administration**

**Report No.
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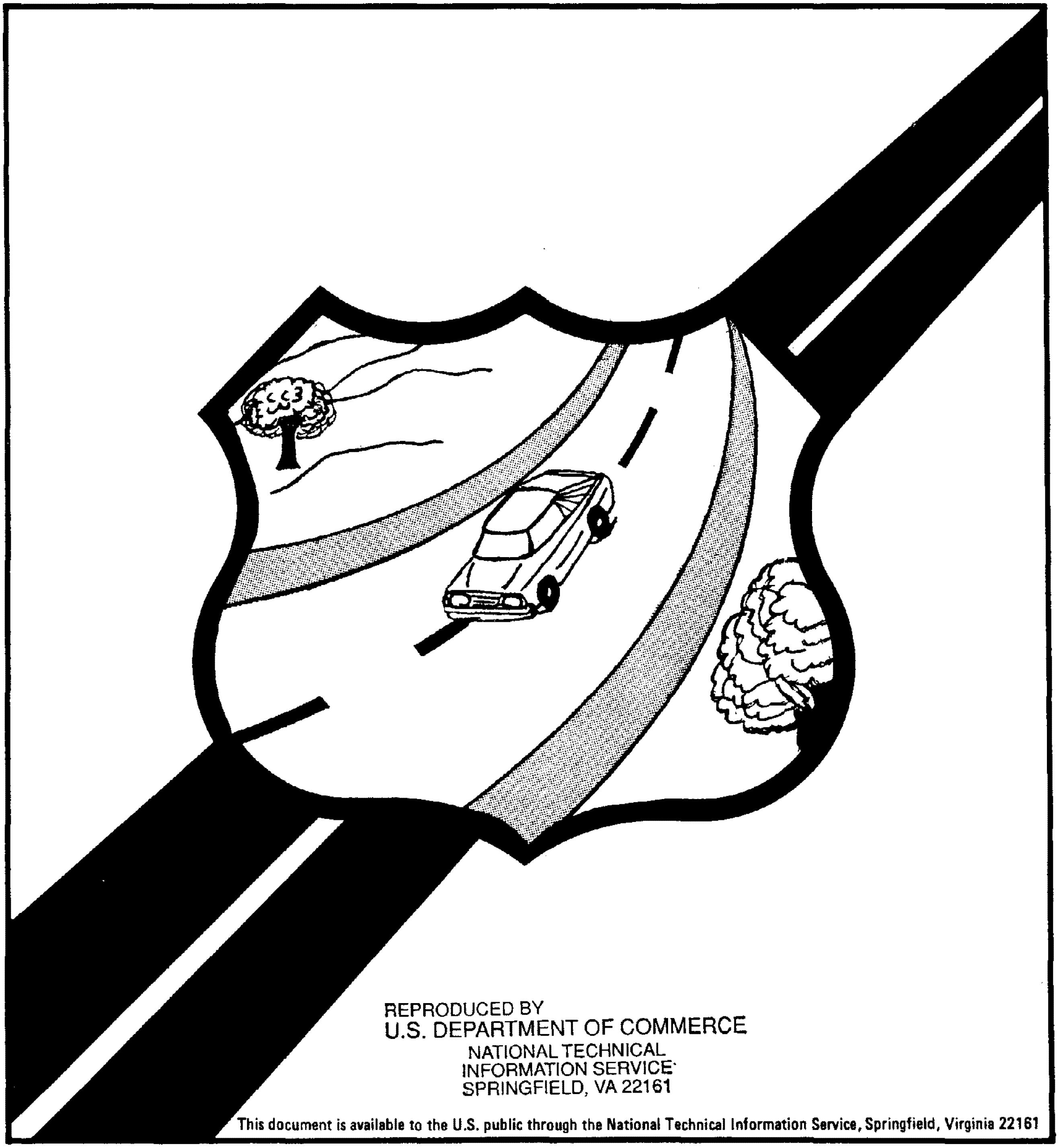
**Final Report
August 1983**



FOREWORD

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

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

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

Stanley R Byington

Stanley R. Byington
Director, Office of Safety and
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J.I. Taylor, H.T. Thompson

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16. Abstract

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

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

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

FHWA/RD-82/103 Volume I - Executive Summary
FHWA/RD-82/104 Volume II - Technical Report
FHWA/RD-82/105 Volume III - Appendices A-G

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METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

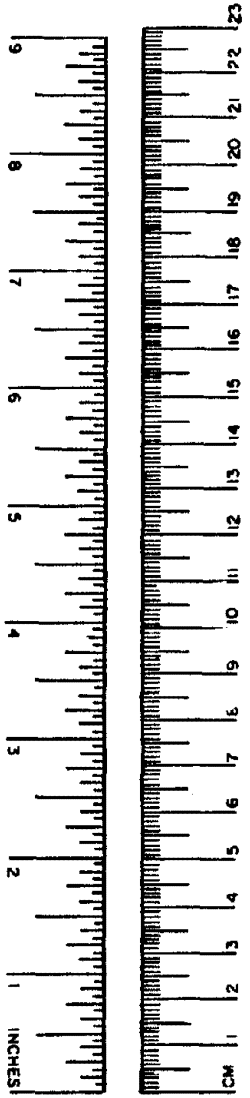
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

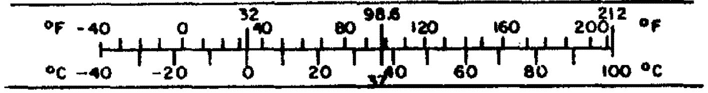
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ml	milliliters	8.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



INTRODUCTION

Statement of the Problem

Highway safety administration, like all phases of highway design, construction and maintenance, faces severe limitations in staff, budget and funding availability. It is therefore important to approach highway safety matters in a systematic and cost-effective manner.

Historically, highway safety agencies have relied heavily on reported traffic accidents to identify problem locations, justify and prioritize safety projects and evaluate their effectiveness. Many highway safety professionals, however, recognize significant shortcomings in the highway safety process when accidents are used as the sole criterion for highway safety planning and evaluation. One shortcoming arises when decisions to continue, modify or remove countermeasures need to be made sooner than the waiting time required to collect accident statistics. In other instances, unreliable or incomplete accident statistics may lead to erroneous decisions regarding countermeasure selection or effectiveness assessment. Another shortcoming arises when safety problems are characterized by accident potential as opposed to the occurrence of accident patterns or trends. These situations often occur on low volume roads, in rural areas and at rail-highway grade crossings.

Scope of the Study

Because of these limitations, many highway safety professionals support the premise that identification of problem locations and effectiveness evaluations should consider alternative measures in addition to accidents. Past studies indicate that highway system characteristics such as geometrics, operations, environment and driver behavior are related to accident experience. Several research efforts have identified precise relationships between individual characteristics and accidents. However, there has been insufficient systematic efforts to investigate the feasibility of using such relationships as surrogates for accident experience in highway safety analyses.

This study investigates the feasibility of using accident surrogate measures in highway safety analyses. For the purpose of the study, an accident surrogate measure is defined as a quantifiable observation that can be used in place of or as a supplement to accident records. From a theoretical viewpoint, an accident surrogate measure must possess a definite relationship with accidents and be sensitive to safety-related changes in the highway system. From a practical viewpoint, surrogate measures must be relatively easy to collect with minimal manpower, training and equipment.

Objectives of the Study

The objectives of the study are:

- To identify observable highway system features and characteristics that indicate the relative hazardousness of highways.
- To develop accurate, quantitative measures of selected factors to be tested as potential surrogate measures.
- To quantify the relationship between these selected measures and accident experience.
- To develop methodologies that utilize accident surrogates for identifying hazardous sites and sections of roadway, for evaluating the effectiveness of completed accident countermeasures and for reviewing design plans of new facilities or improvements.

Study Methodology

The objectives of the study were accomplished by (1) identifying highway system variables to serve singly or in combination as surrogate measures, (2) developing explicit mathematical relationships between selected surrogate measures and accidents, and (3) developing and testing methodologies which incorporate the resulting relationships in highway safety analysis procedures.

The identification of variables having potential as candidate surrogate variables was accomplished by obtaining information on actual and perceived relationships between accidents and elements of roadway, driver and vehicle systems. Four information sources provided input on these relationships; (1) literature, (2) a two-day workshop to obtain opinions and observations of highway safety professionals, (3) analysis of an existing data base containing accident, geometric, operational and environmental data, and (4) selected field data collected at ten typical roadway situations. These information sources were synthesized to identify highway system variables that warranted further detailed analyses as surrogate measures. The variables resulting from this synthesis were stratified according to their relevance to specific highway locations and associated predominant accident types. The variables were further stratified as non-operational and operational. Non-operational variables consist of static highway system elements of the roadway, roadside and environment. Operational variables consist of dynamic highway system elements including traffic flow and driver behavior characteristics.

Regression analysis was used to develop linear and nonlinear models between observed field data and accidents records. Models were tested for three highway situations; rural isolated two-lane curves, two-lane tangents in urbanized areas, and rural signalized intersections on two-lane roads. Independent variables included operational and non-operational variables that were identified in the initial analysis step and for which data were field collected by trained traffic technicians. Models containing only operation variables, only non-operational variables, and combinations of both were developed. Regression models found to be valid under both logical and statistical scrutiny are recommended for use as surrogate measures at the highway situations studied.

Next, methodologies were developed to incorporate the surrogate measures into safety processes to identify and prioritize high-hazard locations, evaluate the effectiveness of deployed accident countermeasures and review design plans of highway improvements. Surrogate measures containing both operational and non-operational variables are used in procedures to identify hazardous locations. Surrogate measures containing only operational variables are used in procedures to evaluate countermeasure effectiveness. Design plan review procedures incorporate surrogate measures that contain only non-operational variables.

SELECTION OF CANDIDATE SURROGATES

Candidate surrogates were identified based on the combined inputs from four information sources. The sources include: (1) review and summary of past research efforts to relate accidents to elements of the highway system, (2) a consensus of opinions from a panel of engineers, researchers and administrators having operational experience in the field of highway safety, (3) the results of analyses performed on an existing computerized data base of accidents, geometric, operational and environmental information, and (4) the results of analyses performed on a limited sample of accident and highway data collected specifically for this study. Figure 1 shows the relationships among these sources in identifying potential surrogates for further in-depth analyses.

Literature Review

The literature review consisted of reviewing past and current studies on the relationships between traffic accidents and elements of the highway system. Highway system elements included variables relating to roadway geometry, roadside environment, traffic control, traffic operations and driver behavior.

The initial review was broad in scope, to obtain accident-highway element relationships for a wide range of highway situations, but was later reduced in scope to concentrate on ten specific highway situations (Table 1). These situations were selected as having a high potential for meaningful safety analyses using accident surrogate measures by a panel of highway safety professionals during a two-day workshop in which a modified Delphi technique was employed (the Delphi technique used in the workshop described in the next section).

The literature review consisted of obtaining and abstracting available studies for each of the selected highway situations. Reference sources included NTIS, existing literature reviews, and the libraries of Wayne State University, University of Notre Dame and University of Michigan.

To ensure reliability of the highway elements finally selected as potential surrogates, criteria were established to identify studies with a high degree of practical and statistical confidence. The criteria upon which each study was evaluated were:

1. The existence of a sufficiently large sample of accidents and locations to substantiate the study results.
2. Firmly established research procedures designed to minimize rival explanations for observed accident relationships.

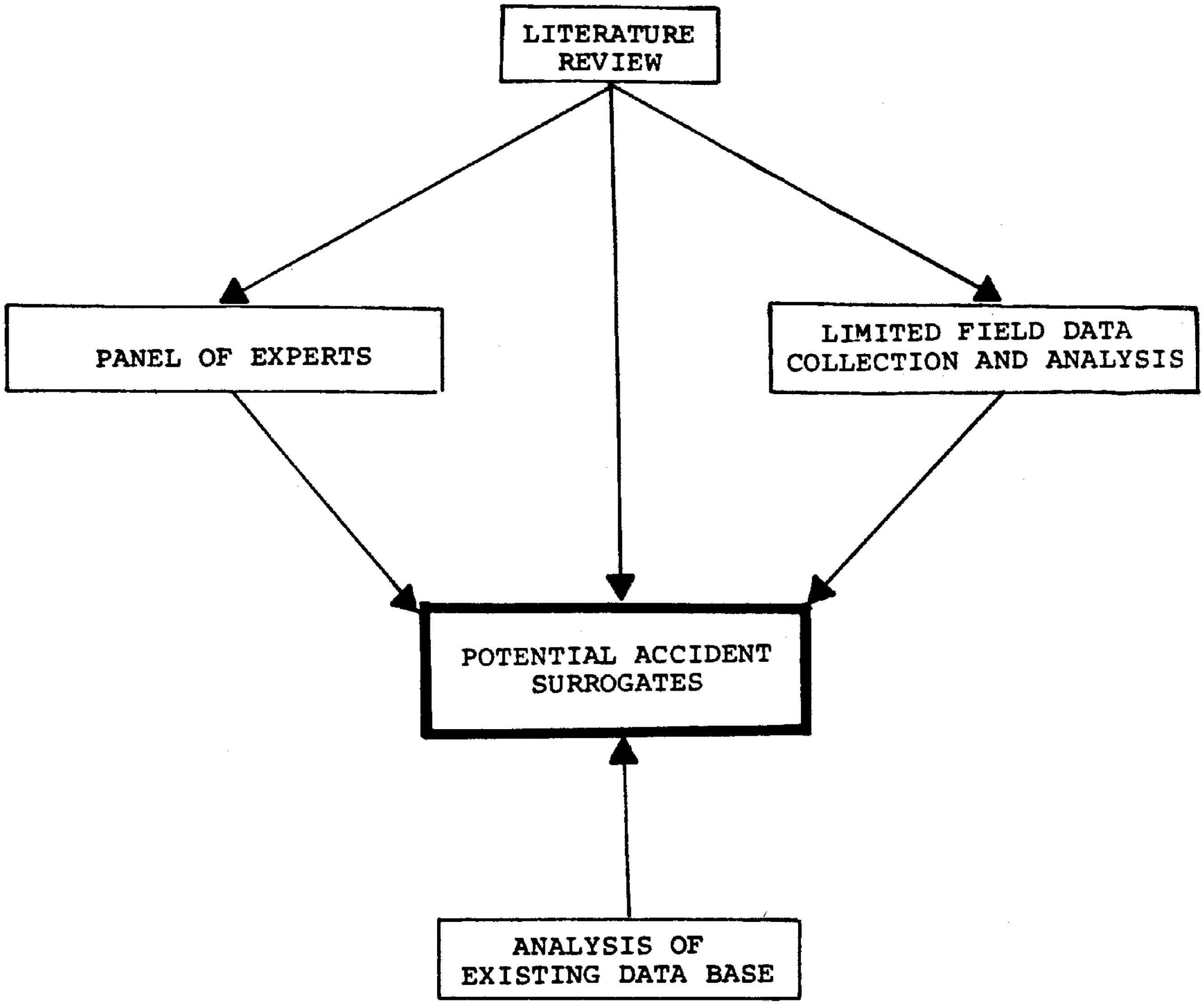


Figure 1. Relationship of literature review activities in identifying potential accident surrogates.

Table 1. Highway situations considered in the in-depth literature review.

1. Urban Undivided Tangent Section
2. Rural Undivided Winding Section
3. Rural Isolated Curves
4. Lane Drop Locations
5. Narrow Bridge
6. Exit Gore Area
7. Urban Non-Signalized Intersection
8. Rural Non-Signalized Intersections
9. Rural Undivided Tangent Section
10. Rural Signalized Intersection

3. Use of appropriate tests to assess the statistical validity of the study results.

4. Conclusions based on logical and consistent analysis results.

Studies that were deficient in one or more of these criteria were eliminated from consideration. Consequently, many highway elements identified as potential surrogates by other researchers on the basis of logical (as opposed to statistical) relationships were not identified in this literature review as strong potential accident surrogates. (Many such variables, however, were identified and listed as potential surrogates as a result of the workshop).

The literature review identified fifty-two highway system elements as potential accident surrogates for one or more of the ten highway situations shown in Table 1. The variables and variable combinations were placed into two general categories; non-operational and operational. Non-operational variables relate to roadway geometry and cross-sectional elements, traffic control devices and environmental features. Operational variables relate to traffic operations, driver performance and driver behavior. Tables 2 and 3 list these variables.

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

An "other" potential surrogate is defined as a measure for which there is less empirical evidence and no specific relationship is defined in the literature. Standards and guidelines, such as AASHTO design standards, were selected as "other" potential surrogates. Other examples include length of taper at lane drop locations and sight distance. These variables and their relationships to accidents are logical from an engineering practices viewpoint, but often there is limited evidence of statistical validity, or the studies are based on small samples.

Operational surrogates (such as erratic maneuver rates) were used in several studies for evaluating the operational effects of countermeasures. These studies attempt to quantify the level of driver error that is logically related to the level of hazardousness. The use of such operational

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

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

Table 3. Operational variables identified in the literature review.

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

variables in accident studies, based on their logical relationship to safety, justify their selection as "other" potential surrogates, even though the relationships to accidents have not been validated.

Figures 2 and 3 list the selected non-operational and operational variables (respectively) and the associated potential surrogate designation. An "S" indicates a "strong" potential surrogate and an "O" indicates an "other" potential surrogate.

A literature review summary and annotated bibliography are provided in Appendix A. The summary contains a synopsis of information regarding the critical highway elements and associated research findings for the ten highway situations. The annotated bibliography contains a brief summary of each study referenced in the literature review.

Workshop

The initial literature review resulted in a listing of highway system variables with proven and/or logical relationships to accident experience. At the outset, the listing consisted of over 100 individual geometric, operational, traffic control and environmental factors.

To facilitate a detailed examination, the factors were categorized under one or more "hazard indices" used to describe the causal chain of events leading to an actual or potential accident at various highway situations (i.e., isolated curves, exit gore areas, railroad crossings, etc.). The indices that comprise the causal chain include information, human factors, vehicle control, congestion, and recovery. Definitions for these indices are provided in Table 4. (Note that the indices are defined such that higher values indicate higher degrees of hazard).

The causal chain of events is based on the following scenario (Figure 4). A driver is presented with information from a variety of sources, including signing, the environment, and other vehicles. Through this information, the driver develops mental perceptions and expectations of the driving environment. If these perceptions and expectations agree with the actual conditions, the driver can select an appropriate speed and path and safely maneuver the vehicle. If the actual conditions do not meet what the driver perceives or expects, corrective change in vehicle path or speed must be made. The vehicle control and congestion indices contain factors that determine the outcome of the evasive maneuver. That is, if the vehicle remains under control and traffic conditions are such that the corrective maneuver can be made without interfering with other vehicles, an accident is avoided. If either of these conditions do not exist, the driver is faced with a recovery situation that results in either a near-miss (recovery and no accident) or in a single or multiple vehicle accident.

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

Note: "S" denotes strong potential surrogates "O" denotes other potential surrogates

Figure 2. Potential surrogate classifications for non-operational variables.

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

Note: "S" denotes strong potential surrogates "0" denotes other potential surrogates

Figure 3. Potential surrogate classifications for operational variables.

Table 4. Highway safety index definitions.

Information Index

This index is a measure of the information system deficiencies which detract from the driver's ability to select a safe speed and path as roadway conditions change. The absence of lane markings and inadequate advance warning signs are examples of factors that contribute to a high information index.

Human Factors Index

This index is a measure of the existence of conditions that fail to meet typical driver expectancies, therefore increasing the probability that a driver will respond incorrectly to a situation requiring evasive actions. A sharp horizontal curve following the crest of a vertical curve is an example of a factor that would contribute to a high human factors index.

Vehicle Control Index

This index is a measure of the geometric and environmental characteristics which constrain the driver's ability to maintain control of the vehicle in a traffic stream. Inadequate sight distance and icy pavements are examples of factors that contribute to a high vehicle control index.

Congestion Index

This index is a measure of the operational characteristics which constrain the driver's ability to avoid an accident through a controlled vehicle maneuver. Congested flow and excessive numbers of driveways and parked vehicles along a roadway are examples of factors that contribute to a high congestion index.

Recovery Index

This index is a measure of the roadway and roadside characteristics which inhibit the driver's ability to avoid an accident or to reduce the severity of an accident resulting from partial or total loss of vehicle control. Narrow shoulders and roadside objects are examples of factors that contribute to a high recovery index.

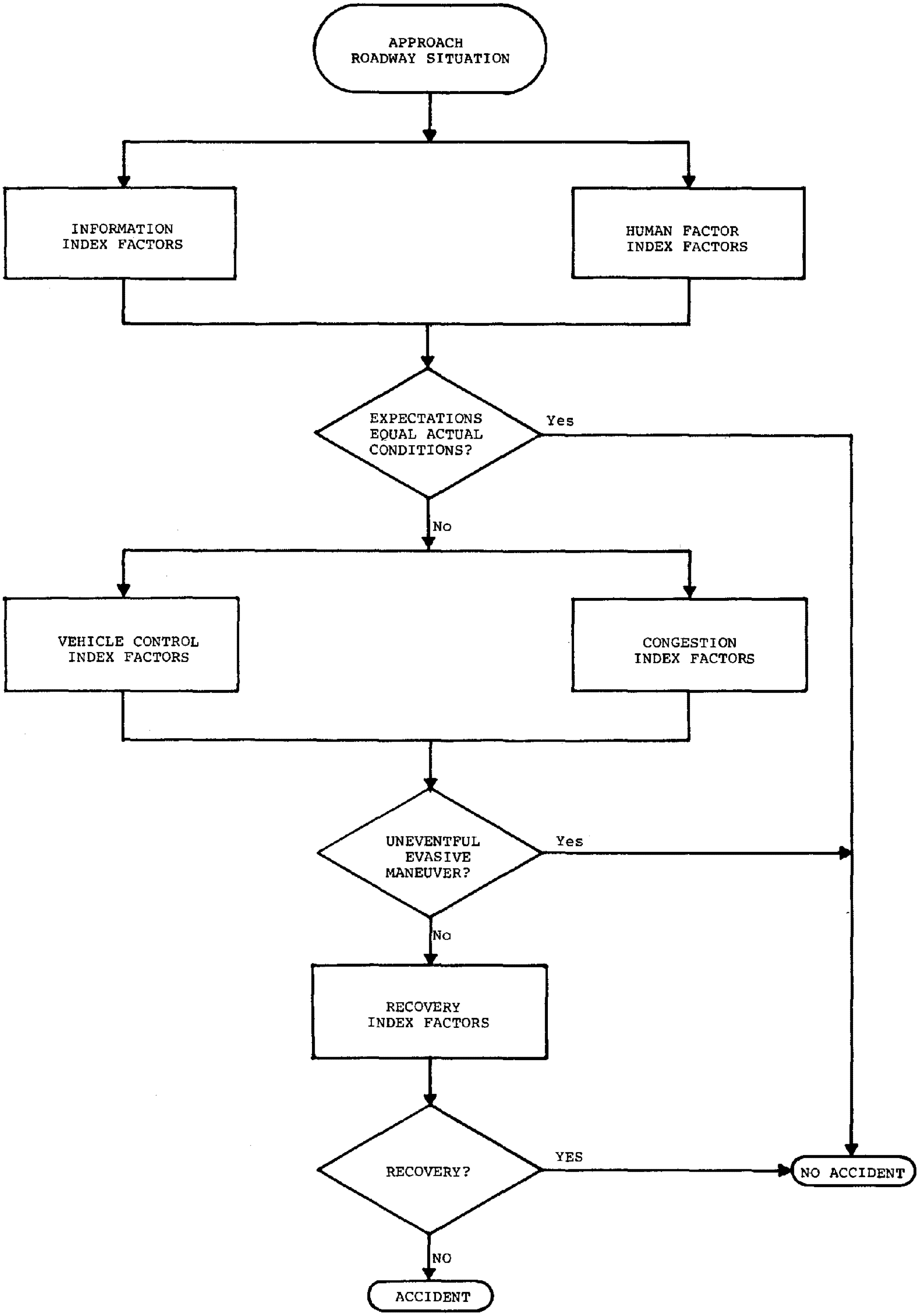


Figure 4. Causal chain of events for potential accidents.

The indices and the factors within each index vary in degree of importance for various highway situations. To determine the relative importance of the indices and factors, a workshop was conducted to obtain input from a cross-section of highway safety professionals (engineers, researchers, and administrators). The workshop participants and their affiliations are listed in Appendix B.

The workshop had four objectives.

1. To examine and critique prepared lists of the geometric, operational, traffic control and environmental factors related to the hazard indices (information, human factor, vehicle control, congestion, recovery) for specific highway situations.

2. To assess the relative importance of each hazard index, as related to accident potential at each of the highway situations.

3. To assess the highway situations according to the potential for highway safety analysis using surrogate measures.

4. To assess the relative importance of the factors identified for each index.

The workshop results were used to reduce the number of highway situations to be studied and the number of variables to be considered as candidate surrogate measures.

Each workshop objective was sequentially addressed by all participants. Each workshop session consisted of presenting the group with a problem statement, pertinent definitions and a suggested approach to achieving the objective under consideration. The first objective, which was prerequisite to the remaining objectives, was to develop a comprehensive list of highway system factors for each hazard index. The participants formed groups of 3-4 each to encourage discussion. Each group was provided with a prepared list of factors for one hazard index. The lists were prepared by the research team using input from the literature, current practices and past experiences. Factors were added, removed and/or redefined and each group presented the resulting lists to the entire group for concurrence or further discussion. The final lists provided input to subsequent workshop activities. The remaining objectives were accomplished using a modified Delphi process. The relative importance of hazard indices for each of 28 highway situations was obtained by requesting each participant to rank order the five indices. Mean ranking values were calculated and reported to the entire group. Those individuals whose rankings varied significantly from the average score were requested to justify their scores. Open discussions were then conducted on the validity of the justification. A second ranking iteration reduced the ranking variance considerably, thus, suggesting a consensus ranking of the group. Additional iterations were not warranted due to the amount of variance reduction and time constraints. A similar approach was used to select 10 of the 28 highway situations that were perceived by the participants to be best suited for safety analyses using surrogate measures. The selected situations and the indices that were ranked highest are shown in Figure 5.

The final objective was achieved by obtaining participant rankings (from two iterations) to identify specific factors having the strongest intuitive and/or empirical relationships with accidents. The selection of a limited set of factors for later use in developing surrogate measures was important because many factors were identified as potentially appropriate (although differing in relative importance) for specific index-situation combinations. Appendix C contains the results of the panel rankings for the ten selected highway situations.

Analysis of Existing Data Base

The Michigan Dimensional Accident Surveillance (MIDAS) model was analyzed to determine if other highway system variables should be considered as candidate surrogates.

At the time of the analysis, the MIDAS data base contained geometric, environmental, traffic, cross section, and accident data for 9,000 miles of state roadway system in Michigan. Geometric data included laneage, horizontal alignment (tangent or curve categorized by advisory speed limit) and vertical alignment (passing or no passing zone). Environmental data included roadside development, intersection/midblock and intersection traffic control. Traffic data included estimated hourly and daily volumes and speed limit. Cross section data included lane width, shoulder width, curb type, median/no-median and turn lanes. Accident data included fatal plus injury accident frequency by type. For each highway segment (0.2 mile) or intersection, the computer file contains specific physical and operational characteristics, such as the number of lanes and the traffic volume. Accident rates were calculated directly from the volume and accident frequency data.

The MIDAS model was developed by the Michigan Department of Transportation to analyze accident, volume, and roadway features data on the entire State roadway system. One of the functions of the model is to group all roadway sections with identical physical and environmental characteristics into single cells of a multi-cell array; e.g., 10-foot, two-lane roadways with 40 mph curves in urban areas. Because this data set enables the analyst to determine accident frequencies and rates for sets of variables, the model was selected for identifying candidate surrogate measures. Data for a five-year period were used in the analysis.

Selected Situations	Indices Rated as Highly Important to Accident Potential				
	Information	Human Factor	Vehicle Control	Congestion	Recovery
Urban Undivided Tangent Sections	X			X	
Rural Undivided Winding Sections	X		X		X
Rural Isolated Curves	X				
Lane Drop Locations	X	X			
Narrow Bridges	X	X			
Exit Gore Areas	X		X		X
Urban Non-signalized Intersections	X			X	
Rural Non-signalized Intersections	X		X		
Rural Undivided Tangent Sections	X				X
Rural Signalized Intersections	X	X			

Figure 5. Selected highway situations and associated hazard indices.

At the time the analysis was performed, the MIDAS data base contained only fatal and injury accident data. Using only fatal and injury accidents, no accidents were reported at many sites within some cells. A large number of zero accident sites results in skewed distributions and large variances, and require large sample sizes for detecting relationships between variables.

The analysis procedure consisted of first categorizing the data into the individual highway situations identified by the panel. MIDAS data were available for the following highway situations.

1. Urban non-signalized intersections
2. Rural isolated curves
3. Rural undivided winding sections
4. Rural signalized intersections
5. Rural non-signalized intersections
6. Urban undivided tangent sections
7. Rural undivided tangent sections

MIDAS data were not available for the remainder of the ten highway situations selected by the workshop panel (lane drops, exit gores, and narrow bridges).

Several statistical analysis techniques were used to analyze the MIDAS data. Bivariate correlation analysis and step-wise linear regression were used to examine relationships between fatal and injury accidents and selected highway system variables. Analysis of variance tests were also conducted to examine differences in mean fatal and injury accident rates resulting from various roadway and operational stratifications. The t-statistic was employed to determine the direction of the difference in cases where the analysis of variance test indicated a significant difference (e.g., does shoulder width on roadways with 10-foot lanes have a higher or lower effect on the accident rate than shoulder width on roadways with 12-foot lanes?)

Linear stepwise regression programs contained in the Statistical Package for Social Sciences (SPSS) were used to determine what variables or combination of variables best explained the variation in injury and fatal accidents. The dependent variables included the total number of injury and fatal accidents, and the number by each accident type, e.g., rear-end, angle, sideswipe, etc. The highway system variables (pavement width, shoulder width, etc.) were the independent variables. The resulting R^2 values were all less than 0.2, which indicates that there are, at best, weak relationships between injury and fatal accidents and the highway system variables for the situations examined.

Possible explanations for these low correlations are the existence of many locations with zero accidents, which consequently resulted in a clustering of data points at zero. This clustering reduces the stength of the R^2 values for the total data set. For many highway situations, over 50 percent of the sample sites had zero injury and fatal accidents. In addition, some of the variables used in the regression analysis were discrete. For example, lane width, posted speed and shoulder width were contained in MIDAS as discrete variables. This characteristic, along with the relatively high number of zero data points, resulted in dense clustering at specific values, thereby minimizing the probability of obtaining a statistically significant regression coefficient.

The analysis of variance was used to divide observed variation in the data into parts, with each part assigned to a known source or variable. The purpose of the analysis was to determine whether a particular part of the variation was greater than would be expected by chance. The results of the analysis of variance were used to determine if specific variables have a significant effect on injury and fatal accident rates. Even where a significant difference is identified, the analysis does not indicate the direction of the difference (an increase or decrease in injury rate associated with, for example, an increase or decrease in lane width), nor does the analysis indicate which specific characteristic is significantly different. For example, the analysis may indicate a significant difference in injury and fatal accident rates for three speed categories, i.e., 25 to 35, 40 to 45, and 50 to 55 mph. Although it is useful to know that posted speed limit is related to differences in injury rates, this information is of limited practical value. To enhance the results of the analysis of variance tests, further comparisons between two specific categories of the mean injury rates were made with the t-statistic in each case where the analysis indicated a significant difference. As a general rule, both the analysis of variance and the t-test were conducted at the 0.05 level of significance. In addition, the results were interpreted for practical significance as well as statistical significance.

Because of the availability of only fatal and injury accidents, highway situations in urban areas were not considered in the analysis of variance. The effects of the operational and geometric factors on injury and fatal accident rates are shown in Table 5 for the four highway situations analyzed. Many variables contained in the MIDAS data base could not be statistically analyzed due to the small number of locations (sample size) for some variable categories. A summary of the pertinent findings is given below:

1. The effect of ADT on injury and fatal accident rates was found to be significant for all highway groups except rural signalized intersections. The general conclusion that can be drawn is that locations with low volume levels (0-2,000 ADT for non-signalized intersections and 0-5,000 ADT for

Table 5. Summary of analysis of variance tests.

Rural Highway Group \ Variable	Effects of the Variable on Injury and Fatal Accident Rates					
	Posted Speed Limit	V/C Ratio	ADT	Lane Width	Shoulder Width	Vertical Curve
Non-Signalized Intersections	S	S	S	—	—	NS
Signalized Intersections	NS	—	NS	—	—	NS
Isolated Curves	NS	—	S	NS	NS	—
Winding Sections	NS	—	S	S	S	NS

Note: S = Statistically significant effect at the 0.05 level of significance

NS = No significant effects at the 0.05 level of significance

- = Sample size too small to test or data were not available in the database for highway situation.

isolated curves and winding sections) have significantly higher injury and fatal accident rates than sections with high ADT levels (volumes exceeding 2,000 at non-signalized intersections and 5,000 at isolated curves and winding sections). Mean injury and fatal accident rates tend to be higher at signalized intersections carrying 1,000-5,000 ADT, compared to intersections carrying volumes exceeding 5,000 vehicles per day, but the difference is not statistically significant.

2. The effects of posted speed limits on injury and fatal accident rates were examined for all four highway situations. The only statistically significant finding was that nonsignalized intersections with higher posted speed limits (50-55 mph) have a higher injury and fatal accident rate than intersections with lower speed limits (40-45 mph). This finding holds for ADT ranges from 2,000 to greater than 10,000 vehicles per day. At isolated curves, injury and fatal accident rates tend to be higher on routes with speed limits of 40-45 mph, but the data are not sufficient to determine if this trend holds for a variety of geometric conditions.

3. Volume to capacity ratio data were not available for three highway groups, and only limited data were obtained for non-signalized intersections. It was found that intersections carrying 10,000 vehicles or more per day with V/C ratios of 0.5 to 1.0 have significantly lower mean injury and fatal accident rates than do intersections with V/C ratios between 0.0 to 0.5. This finding indicates that higher levels of congestion reduces the potential for injury accidents, possibly through reduced operating speeds and increased driver awareness. However, because of the unavailability of property damage accidents, it was not possible to determine the effect of V/C on total or non-injury accident experience which has generally been found to increase with increasing levels of V/C ratio.

4. The effects of lane width on injury and fatal accident rates was only examined for isolated curve sections and winding roadway conditions. The only significant finding was that winding sections with narrow pavement widths have higher mean injury and fatal accident rates than sections with wider pavement widths. In particular, winding sections with 12-foot lanes have significantly lower mean injury and fatal accident rates than sections with 11-foot lanes.

5. Shoulder width effects were examined for isolated curves and winding sections. No significant results were found for isolated curve segments and no significant findings that would apply to the overall range of conditions for winding sections were detected. Two highly specific findings resulted from the tests. On sections with 10 and 11-foot lane widths and narrow shoulders, injury and fatal accident rates are higher than rates on sections with wide shoulders (10 to 12 feet). Also, on sections with 12-foot lanes, segments with 4 to 8-foot shoulders have significantly higher injury and fatal accident rates than sections with 8 to 10-foot shoulders. It may be inferred from these two findings that sections with narrow shoulders have higher rates than sections with wide shoulders, but additional data should be collected and analyzed for a wider range of characteristics before this hypothesis is accepted.

6. No significant effects attributable to the presence or absence of a vertical curve were found for any of the highway groups. This result does not necessarily mean that sight distance restrictions do not affect injury and fatal accident rates, as only two categories of vertical curve (sites with and sites without vertical curve) could be obtained. This limitation may be primarily responsible for the findings in this area of analysis.

The analysis of variance tests generally indicate that some of the factors analyzed have a significant effect on injury and fatal accident rates. These factors were considered as candidate surrogates. Because of the limitations of the MIDAS data base and the fact that only injury and fatal accidents were included in the analyses, care should be exercised before discounting the factors which do not show significant relationships.

Field Data Collection and Analysis

The literature review and workshop results provided initial input to the identification and development of candidate surrogate measures. Some of these candidate surrogates were investigated using the MIDAS data base. For others, supplemental data collection and analysis activities, of a limited nature, were undertaken to provide an additional quantitative source of input in the determination of candidate surrogates.

Candidate surrogate measures, identified from the aforementioned sources and analyses, were collected at five highway situations.

- Rural Isolated Curves

- Rural Winding Sections
- Urban Undivided Tangents
- Rural Signalized Intersections
- Lane Drop Locations

Test sites for each situation were selected in Oakland County, Michigan. (Oakland County was selected partly because of the availability of a countywide accident data base which contains reported accidents covering several years). In selecting sites, basic cross-sectional and operational features, such as number of lanes and average daily traffic, were held constant or nearly constant across all sites to control for accident variance due to these characteristics.

Rural isolated curves were two-lane, uncurbed horizontal curves, with sparse residential or agricultural land uses in the immediate vicinity and no other curves within 0.5 miles of the test site. Sites with traffic volumes in excess of 7,000 vpd were excluded.

Rural winding sections were two-lane uncurbed roadway sections containing at least three curves per mile. All roadways were located in areas of sparse residential or agricultural land uses. Sites with traffic volumes in excess of 12,000 vpd were excluded.

Urban undivided tangents were 2, 4, and 5-lane facilities, for which data were collected separately. Urban land uses included medium to high density residential or strip commercial land uses. Traffic volume ranges for 2, 4, and 5-lane facilities ranged from 10,000 - 20,000 vpd, 12,000 - 30,000 vpd and 25,000 - 35,000 vpd, respectively.

Rural signalized intersections were located on two-lane roads, and fixed-time, two-phase signals with exclusive left-turn lanes on all approaches. Peak hour approach volumes ranged from 2,000 - 3,500 for all approaches combined.

Lane drops consisted of directional transitions from two-lane to one-lane. All lane drops were located in urban areas, with directional traffic volumes ranging from 8,000 - 10,000 vpd.

The variables collected for each highway situation are shown in Table 6. A team of experienced traffic technicians collected the field data. Standard data collection procedures and equipment, including radar meters, stopwatches and tally boards were used. Sample sizes for variables requiring the observation or measurement of traffic operational characteristics were:

- Speed-Related Surrogates: 50-100 vehicles during off-peak traffic periods.

Table 6. Accident surrogates* collected by situation type.

RURAL ISOLATED CURVES	RURAL WINDING SECTIONS	URBAN UNDIVIDED TANGENTS	RURAL SIGNALIZED INTERSECTIONS	LANE DROP LOCATIONS
1. Average Daily Traffic	1. Average Daily Traffic	1. Average Daily Traffic	1. Average Daily Traffic	1. Avg. Daily Traffic
2. Posted Speed Limit	2. V/C Ratio	2. V/C Ratio	2. V/C Ratio	2. Percent Trucks
3. Advisory Speed Limit	3. Percent Trucks	3. Percent Trucks	3. Percent Trucks	3. Posted Speed Limit
4. Lane Width	4. Lane Width	4. Percent Midblock Turns	4. Percent Turning Volumes	4. Sight Distance
5. Shoulder Width	5. Number of Lanes	5. Posted Speed Limit	5. Posted Speed Limit	5. Number of Lanes
6. Degree of Curve	6. Total Fixed Objects/Mile	6. Lane Width	6. Sight Distance	6. Length of Taper
7. Total Fixed Objects/Mile	7. Rigid Fixed Objects/Mile	7. Total Fixed Objects/Mile	7. Number of Lanes	7. Erratic Maneuvers Per Hour
8. Rigid Fixed Objects/Mile	8. Non-Rigid Fixed Objects Per Mile	8. Rigid Fixed Objects/Mile	8. Presence of Grade on Approach	8. Erratic Maneuvers Per 100 Vehicles
9. Non-Rigid Fixed Objects Per Mile	9. Avg. Length of Tangents Between Curves	9. Non-Rigid Fixed Objects Per Mile	9. Pavement Type	9. Percent Merge Maneuvers in Taper
10. Superelevation	10. Presence of Grade	10. Lane Width	10. 85th Percentile Approach Speed	
11. Side Slope Angle	11. Pavement Type	11. Pavement Type	11. Average Approach Speed	
12. Distance Since Last Curve	12. Number of Curves/Mile	12. Presence of Edgelining	12. Standard Deviation of Approach Speed	
13. Presence of Edgelining	13. Posted Speed Limit	13. Total Access Points/Mile	13. Coefficient of Variation of Approach Speed	
14. Erratic Maneuvers/Hour	14. Advisory Speed Limit	14. Intersections/Mile	14. Percent in Pace of Approach Speed	
15. Erratic Maneuvers/100 Veh.		15. Commercial Driveways/Mile	15. Average Approach Volume to Approach Speed Ratio	
16. Speed Reduction Efficiency (Avg. Speed)		16. Residential Driveways Per Mile	16. Deceleration Rate	
17. Speed Reduction Efficiency (85th Percentile Speed)		17. Number of 3 mph Speed Changes/Mile		
18. Percent Reduction in Average Speed				
19. Percent Reduction in 85th Percentile Speed				

Note: Selected surrogate definitions are provided in Appendix E.

- Erratic Maneuvers: 4 hours per site during peak traffic periods.

- Speed Changes: 4 passes per direction with test vehicles per section during peak traffic periods.

- Merge Maneuvers: 4 hours per site during peak traffic periods.

Accident data were obtained for three years (1976-78) from the Traffic Improvement Association of Oakland County accident data base for each test site. Frequency or frequency per mile accident measures were used in the analyses because of the limitations on ADT for each type of situation. Accidents were stratified by type and included fatal, injury and property damage accidents. When intersections were located within non-intersection type situations (e.g. urban undivided tangents), accidents within 200 feet of intersections were excluded to minimize the effects of intersection operations on accident experience within the section.

Four statistical analysis techniques were used to test the relationships between the collected candidate surrogate measures and total and predominant accident types; (1) non-parametric (Spearman Rho) correlation analysis, (2) parametric (Pearson) correlation analysis, (3) stepwise multiple regression analysis, and (4) paired groups analysis. These tests were performed to obtain several types of quantitative information on the strengths of the relationships.

The Spearman rank order correlation technique does not require assumptions on the distributions of the variables, and is appropriate when sample sizes are relatively small and assumptions of normality and variance-equality cannot be confidently made.

Parametric correlation analyses were also performed, using the Pearson Product-Moment technique. This analysis provided additional quantitative input to the process of selecting candidate surrogate measures.

In the paired groups analysis, corresponding variables for the high accident group, and the low accident group were tested to determine if they were significantly different. If the two accident groups are significantly different and the corresponding highway system variables groups are significantly different, the conclusion is that the variable may be strongly related to the accidents. The statistical test of significance used in the paired groups analysis was the Mann-Whitney test for two independent samples.

The step-wise multiple regression technique contained in the SPSS model was used to provide additional input. While the number of sites used in the analysis was small, the identification of candidate surrogates was used only to suggest that further data collection and testing should be performed to determine whether the observed relationships were confirmed with large sample sizes. No candidate surrogate was eliminated from future consideration on the basis of these tests. Rather, the test results were used as another source of input (along with the literature review, workshop and MIDAS analyses) in identifying those candidate variables that have a high probability for use as accident surrogates, and therefore warrant further analysis.

The highway system variables that were identified as candidate surrogate measures were categorized as "strong" and "other" potential surrogates, based on the significance of their relationship with accidents. A summary of the variables and variable combinations identified in this analysis, along with the associated accident categories (dependent variables), is provided in Appendix D.

Summary of Findings

A necessary condition for the development of an usable accident surrogate measure is that there be an explicit relationship between that surrogate and accident experience. The efforts reported in this Chapter were all directed at developing lists of potential surrogates for which such a relationship has been demonstrated (or is strongly indicated).

All relationships found in the four information sources have been reported, regardless of whether or not a meaningful and useful surrogate can be developed for identifying hazardous locations, evaluating countermeasures, and/or reviewing design plans. In a sense, all the surrogate measures identified thus far have passed the first screen in the process of choosing "selected" candidate surrogates (i.e., candidates for further study, development and validation) in that a relationship to accidents is indicated.

In this section, the foregoing inputs are synthesized and recategorized according to the potential for producing an usable surrogate.

In an attempt to increase the validity and future utility of the final list of surrogate measures, members of the project team evaluated each candidate surrogate according to five criteria. The criteria include; (1) relationship to accidents, (2) clarity of definition, (3) credibility, (4) ease of data collection, and (5) affectability. The first four criteria are straightforward. However, further definition of affectability is necessary. Affectability is the likelihood that an improvement in the surrogate at a site will result in an improvement in the accident experience at that site. As an example, consider that the posted advisory speed at a horizontal curve is found to be a good indicator of the accident experience -- i.e., higher accident rates become more likely as the posted advisory speed decreases. In the sense that this relationship is reasonably well established, posted advisory speed is a potential surrogate. However, it is clear that simply changing the advisory speed panel (to a higher value) will not result in an improvement in accident experience at a particular curve, because most likely this action will increase accident frequency. Hence, even though "posted advisory speed" might well be rated high on relationship to accidents, clarity of definition, credibility, and ease of data collection, it will be rejected as a surrogate for countermeasure evaluation on the basis of the affectability criteria.

Table 7 shows the possible ranges of conformity that resulted when the candidates were subjected to each criteria. The selected surrogate measures are shown in Table 8. Not every candidate surrogate rates high on all of the criteria, but each surrogate is deemed at least passable on every criterion.

Note that some of listed candidate surrogates are modified forms of others -- redefined slightly to fit the particular intended use of the surrogate -- identification, evaluation, or plan review. For example, "traffic volume" (a field measurement in the identification process) becomes "projected traffic volume" in the plan review process.

Table 7. Selected criteria and levels of possible conformances.

1. Relationship to Accidents
    - A. Demonstrated,
    - B. Highly probable if data were available,
    - C. Considered likely, and
    - D. Possible
2. Clarity of Definition
    - A. Clearly defined, anyone can collect the surrogate with the same result.
    - B. Concept clear, but some terms are subject to interpretation (e.g., sight distance at intersection).
    - C. Factors known but specific formulation is not established (e.g., "some combination" of curvature and grade at horizontal curves, or "some measure" of density and rigidity of fixed objects).
    - D. Conceptual only at this time (e.g., driver expectancy).
3. Credibility
    - A. Acceptable to all engineers and researchers once accident relationship is established.
    - B. Will be accepted by some, but viewed with suspicion by others.
    - C. Will require so much subjective judgment there will likely be little confidence in results.
4. Ease of Data Collection
    - A. Simple and inexpensive (e.g., records, photologs).
    - B. Short visit to site is required.
    - C. Few hours of data collection with standard equipment.
    - D. Extensive data collection and/or use of non-standard equipment (e.g., determination of lateral placement).
5. Affectability (i.e., the likelihood that an improvement in the value of the surrogate at a particular site (or section) will.result in an improvement in the accident experience at that site.)
    - A. Demonstrated that improvement will result.
    - B. Improvement is likely.
    - C. Uncertain whether there will be an effect.
    - D. Unlikely improvement will result.
    - E. Accident experience likely to increase.

Table 8. Summary of selected candidate surrogates* by highway situation and type of highway safety analysis.

Highway Situation	Application in Highway Safety		
	Identification of Hazardous Locations	Evaluation of Countermeasures	Design Plan Review
Urban Undivided Tangent Sections	. Access Points/Mile . Turning Volumes . Speed Changes/Mile . Fixed Objects/Mile	. Speed Changes/Mile	. Access Points/Mile . Projected Turning Volumes
Rural Undivided Winding Sections	. Curves/Mile . Lane Width and Shoulder Width . Physical Evidence of Driver Error . Speed Changes/Mile	. Physical Evidence of Driver Error . Speed Changes/Mile	. Curves/Mile . Lane Width and Shoulder Width
Rural Isolated Curves	. Speed Reduction Efficiency . Curvature, Grade and Distance Since Last Curve . Physical Evidence of Driver Error . Erratic Manuevers	. Speed Reduction Efficiency . Physical Evidence of Driver Error . Erratic Maneuvers	. Design Speed Differential . Curvature, Grade and Distance Since Last Curve
Lane Drop Locations	. Erratic Manuevers . Merge Gap Availability . Taper Length . Posted Speed and Sight Distance	. Erratic Maneuvers . Merge Gap Availability	. Taper Length . Posted Speed and Sight Distance
Narrow Bridges	. Bridge deck to pavement width ratio . Traffic Mix . Sight Distance (Time) . Physical Evidence of Driver Error	. Sight Distance (Time) . Physical Evidence of Driver Error	. Bridge Deck to Pavement Width Ratio . Traffic Mix
Exit Gore Areas	. Deceleration Lane Length . Sight Distance . Erratic Maneuvers	. Erratic Maneuvers	. Deceleration Lane Length . Sight Distance
Urban Non-Signalized Intersections	. Traffic Volume . Approach Speed and Sight Distance . Traffic Conflicts	. Approach Speed and Sight Distance . Traffic Conflicts	. Projected Traffic Volume
Rural Non-Signalized Intersections	. Traffic Volume . Approach Speed and Sight Distance . Traffic Conflicts	. Approach Speed and Sight Distance . Traffic Conflict	. Projected Traffic Volume
Rural Undivided Tangent Sections	. Access Points/Mile . Speed Changes/Mile . Lane Width . Physical Evidence of Driver Error	. Speed Changes/Mile . Physical Evidence of Driver Error	. Access Points/Mile . Lane Width
Rural Signalized Intersections	. Traffic Conflicts . Traffic Volume . Sight Distance . Delay	. Traffic Conflicts . Delay	. Projected Traffic Volume . Sight Distance

*Note: Selected surrogate definitions are provided in Appendix E.

FIELD STUDIES

The third objective of the study was to develop explicit mathematical relationships between selected candidate surrogate measures and accident experience. This was accomplished by selecting and analyzing three of the roadway situations and associated candidate surrogate measures for analysis. Regression techniques were used to develop the relationships between these candidate surrogates and accidents.

Selection of Situations and Candidate Surrogate Measures For Study

The literature review, workshop and preliminary data analysis were used to generate a final list of candidate surrogate measures for each of ten highway situations. Consistent with the analysis plan, specific situations were chosen for evaluating the feasibility of developing and using accident surrogates in roadway analyses. Each situation was examined to determine those variables and/or combination of variables that exhibited the strongest and most consistent relationships between predominant accident type and the candidate surrogates. Three roadway situations representing rural and urban as well as spot and extended sections were selected. The selection was based on the combined assessment of the convergence of research evidence, and both qualitative and quantitative support from the information sources. The selected situations were:

- Isolated curves on rural two-lane roads
- Signalized intersections on rural two-lane roads
- Undivided two-lane tangent sections within urbanized areas

Desirable locational and geometric characteristics for each situation were established to facilitate study site selection. An attempt to reduce accident variance due to factors other than those selected for testing was made by limiting the range of these control variables rated as being either surrogate variable or which may have shown relationship with accidents. However, the variables which either singly or in combination were identified as possible candidate surrogates were not subject to these limitations.

The following situation definitions were used for the study:

Isolated Curves

The curves should be located on two-lane, undivided roads and have a central angle of at least 20°. Traffic volumes (AADT) should not exceed 8,000 vehicles and posted speeds on curve approaches should be between 35 and 55 mph (advisory speeds on the curves may vary). Lane widths should be between 10 and 12 feet with gravel shoulders. At least 1/4-mile distance should separate the study site from a preceding highway event that necessitates driver action to adjust vehicle path and/or speed (i.e., another curve, railroad crossing, stop sign, traffic signal, etc.). The curves should not have extremely unusual roadside features.

Rural Signalized Intersections

The intersections should be located on two-lane roads with 10 to 12 feet lane widths with skid resistance in the range of acceptable surface condition (any pavement section which was observed to be slick in appearance was not included), and no unusual delineation, sign and/or signal treatments. Major approaches should have either left-turn or right-turn lanes. There should be no major traffic generators on the corners and the signals should be fixed-time two phase controlled.

Urban Undivided Tangents

All tangents should have two 10 to 12 foot lanes. Speed limits should be 25-50 mph. All tangents should be at least 1/2 mile in length.

Approximately 20 to 30 sites were identified which met the criteria for each situation type. All test sites were located within Oakland County, Michigan because of the availability of recent photologs, a complete file of highway improvement projects implemented since 1975, and reliable accident and volume data.

For each situation, candidate surrogate measures for the hazard indices rated most important were selected as test variables. The candidates were generally drawn from Table 8. However, some candidate surrogates were not used; i.e., the collection of traffic conflicts data was not within the scope of the study, physical evidence of driver error presented difficulties relating to field measurement, and fixed objects (other than signs) were not factors due to the existence of wide shoulders on the urban tangents. The selected variables were then reviewed to ensure logical association with accidents and affectability (by countermeasure implementation). Table 9 shows the non-operational and operational variables selected for each situation.

Field Data Collection Procedures

Study sites were randomly selected from among the sites identified on the basis of the established site characteristics. Following site selection, three years of accident data (1976, 1977, 1978) were collected for each highway location. Computer printouts of accidents were obtained for the specified limits of the sites plus all accidents occurring within 200 feet of the site boundaries. Each accident was examined with respect to vehicle involvement, contributory circumstances, and vehicle paths. Accidents were then stratified by type of accident and severity. Locations with unusual accident patterns such as a high incidence of car-animal accidents were eliminated from further consideration.

Table 9. Candidate surrogates tested in the study.

HIGHWAY SITUATION	Type of Highway System Variable	
	NON-OPERATIONAL	OPERATIONAL
Rural Isolated Horizontal Curve	. Degree of Curvature . Grade . Shoulder Width . Distance Since Last Curve . Superelevation . Slope of Roadside (Ditch, Shoulder) . Type, Location & Frequency of Fixed Objects	. Encroachments . Speed Reduction
Rural Signalized Intersection	. Vertical and Horizontal Alignment . Sight Distance to Signal and at Intersection . Posted Speed . Signal Characteristics (# Phases, Amber Time, Etc.) . Distance Since Last Intersection	. Percent Trucks . Turning Volume . Traffic Volume . Approach Speed . Erratic Maneuvers
Urban Undivided Tangent	. Access Points . V/C Ratio*	. V/C Ratio* . Speed Changes . Percent Midblock Turns

*Note: The candidate surrogate measure, volume to capacity ratio (v/c ratio) consists of both non-operational (capacity) and operational (peak hour volume) measures and was therefore included in both analysis categories.

Test Site Stratification

Complex interactions between geometric, traffic and driver behavior variables and accident experience may mask explicit mathematical relationships between individual (or small subsets) of these variables and accident experience. To reduce this masking effect, the sites within a specific type of roadway situation were stratified into subsets of sites with similar major characteristics. For example, if one or a combination of independent variables is a good surrogate for curves with restricted sight distance and another set of variables is a good surrogate for curves with no sight restrictions, these relationships can only be determined if the two categories of curves are separated during the analysis. It is possible that neither relationship would be significant for the combined sample of test sites.

Overview of Analysis Techniques

Regression analysis was conducted using field data (selected candidate surrogate variables) as independent variables and 3-year accident rates for total accidents and predominant accident types as dependent variables. Stepwise regression was used to test for statistically significant relationships between one or a combination of candidate surrogate variables and various measures of accident experience at the selected highway situations.

Regression Analysis

The Maximum R^2 Improvement technique (MAXR^2) contained in the Statistical Analysis System (SAS) was selected as the most appropriate regression technique. It is superior to regular stepwise regression in that it selects the "best" one-independent variable model, the "best" two-independent variable model, etc., based on maximizing the proportion of explained variance in the dependent variable.

Regression analyses were performed for specific stratifications within each highway situation to search for statistically significant relationships between accidents and: (1) combinations of non-operational and operational variables, (2) non-operational variables only, and (3) operational variables only. Surrogates developed from these three independent analyses were to be used for identification of hazardous locations, design plan review and countermeasure evaluation, respectively.

Statistical Analysis

The purpose of the regression analyses was to determine whether statistically significant mathematical relationships exist between one or a combination of independent variables and accident experience. To accomplish this, the summary statistics from runs of the regression program were examined to determine the significance of the regression equation and the individual regression coefficients.

The results of the F-test generated by the regression program were used to determine the significance of the regression equation. In these analyses, the 0.05 level of significance was used. The significance of the association between dependent and independent variables, as well as the incremental increase in R^2 for each independent variable entered into the regression model, were examined. The t-test was used to evaluate the simple correlation coefficients between each independent variable in the regression model and the dependent variable. Rejection of the null hypothesis at the 0.05, 0.10 and 0.20 levels of significance was established as the criteria for significant association.

In addition to the test of association, the significance of the contribution of each independent variable to the R^2 value was examined. The statistic used to test the significance of the contribution of each independent variable was the F ratio.

The MAX R^2 regression program calculates the F value and level of significance for each independent variable, and these data were used to evaluate the significance of the independent variables in the model. An analysis criterion established was that the F ratio for each independent variable had to be significant at the level of significance corresponding to that of the previous test (0.05, 0.10 and 0.20). This test ensures that it is unlikely that any single independent variable appears in a regression model where, in fact, no relationship between that variable and the dependent variable exists. Because the objective of the regression approach is to maximize the R^2 value (the percentage of variance explained), the test ensures that a significant increase in R^2 is being attained with the addition of a meaningful independent variable.

Each regression model was examined with respect to the significance of the regression equation and the individual regression coefficients. Regression models that (1) contained independent variables, all of which were related to the dependent variable at the designated level of significance and contributed toward the total R^2 at a corresponding level of significance and (2) exhibited an F-ratio that was significant at the 0.05 level were identified as significant relationships. However, subsequent analysis and interpretation was limited to the results reported at the 0.05 level of significance.

Examination of Residuals

A residual is a deviation (or error) of an observed value of the dependent variable from the estimated value generated by a regression model. Residuals are used in the computation of many summary statistics, such as R^2 and the standard error of the estimate. Residuals can also be used to determine the appropriateness of some of the assumptions made when linear regression is performed.

The SPSS software package was used to generate scatter plots of standardized residuals versus standardized values of the dependent variable for each of the regression models. Each plot was visually examined for "patterns" that indicate the assumptions of linear regression are being violated. In all cases, the plots were observed to be consistent with the assumptions required for linear regression. Therefore, non-linear transformations were deemed unnecessary.

Rural Isolated Curves

Twenty-eight roadway sections containing isolated curves were identified through a search of the Oakland County inventory files. Each of these sites was visited to determine whether they met all the criteria specified for the test sections. Twenty-five of the sites were acceptable, and data were collected at each of these sites.

The data set shown in Appendix F includes physical characteristics (degree of curvature, grade, shoulder width, etc.), operational characteristics (vehicle speed at various locations, edgeline and centerline encroachments, etc.). In addition, accident records were obtained for 1976, 1977 and 1978 at these sites. A listing of the variables is shown in Table 10 under the heading of "independent variables".

Site Stratification

Consistent with the analysis plan developed for this study, the 25 sites were stratified into several categories of sites with similar values for one or more important variables. The purpose of this stratification was to identify smaller subgroups of sites that exhibit a greater degree of similiarity than the entire group, thus reducing the variance of at least one of the variables considered to be related to accidents.

The variables used to stratify the locations were:

- Sight distance
- Grade
- Land use
- Posted speed limit

In addition to the single variable categories, additional categories were constructed using sight distance and land use; grade and posted speed limit; and land use and speed limit. A total of 9 groups were identified for the analysis (including all sites as a group). These groups are identified by letter designation in Figure 6.

Group "A" consists of curves with limited sight distance caused by trees, embankments or other obstacles close to the roadway or the inside of the curve. This group contains 19 of the 25 curves. The rationale for this stratification is that the restriction in sight distance could alter the degree to which driver expectancy is met, and this factor was identified as important in both the literature review and the workshop.

Group "B" consists of curves on relatively flat roadway sections (less than 4% grade). Nearly all of the sites fall in this class (22 of 25). The rationale for this stratification is to moderate the effect of combined horizontal and vertical curvature on the accident rate.

Group "C" consists of roadway sections with zero or one driveways on the curve. As in group "A", this is done to reduce the variation in the driver expectancy across the sample. Twenty of the 25 sites fall in this category.

Group "D" consists of all roadway sections with a posted speed of 45, 50 or 55 mph. Nineteen of the 25 curves fall in this category. This factor was used because the posted speed limit may affect driver characteristics at those sites, thus increasing the variance in the data.

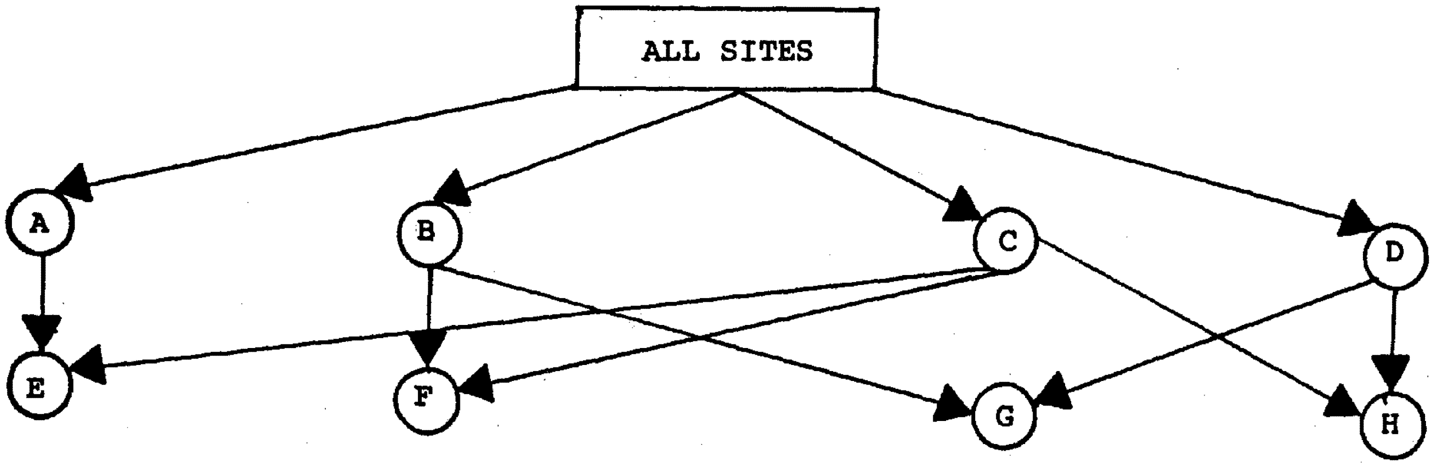
Group "E" consists of all the sites meeting the criteria for group "A" (limited sight distance) and group "C" (few driveways). This group contains 14 of 25 curves. Group "F" consists of all sites meeting the criteria for groups "B" and "C", and contain 17 curves; group "G" consists of all sites meeting the criteria for groups "B" and "D" and contains 16 curves; and group "H" consists of all sites meeting the criteria for groups "C" and "D", and contains 15 curves.

Independent/Dependent Variables

The potential surrogates (independent variables) collected and/or calculated for each of the study sites are listed in Table 10, along with the accident characteristics (dependent variable) used in the analysis. The independent variables are identified as being either operational or non-operational, since the intended use of these results requires that the variables be separated.

Results of the Analysis

A total of 162 separate regression analyses were conducted on the data set using the MAX R^2 stepwise linear regression model. This number of runs was required because of the stratification by type of independent variable (operational, non-operational, or combined), the grouping of



All sites (sample size, n=25)

Group A: Sites with restricted sight distance (n=19)
Group B: Sites with grades less than 4% (n=22)
Group C: Sites with low residential land use (n=20)
Group D: Sites on roads posted 45 mph or greater (n=19)
Group E: Combination of A and C (n=14)
Group F: Combination of B and C (n=17)
Group G: Combination of B and D (n=16)
Group H: Combination of C and D (n=15)

Figure 6. Site stratification for rural isolated curves.

Table 10. Independent variables available for selection by stepwise regression process (variable numbers shown in parentheses).

Dependent Variable(s)	Independent Variables
Total (2), rear-end (3), opposite direction (4), run-off-road (5), fixed object (6) accident rates	Non-Operational: Average annual daily traffic (9)* Degree of curvature (10) Grade, percent (12) Superelevation error, difference between minimum superelevation required for prevailing conditions and actual superelevation, inches per foot over entire pavement width (69) Shoulder width, average width for both shoulders (62) Sideslope angle, ratio x:1 average for both sides of road (63) Fixed object rating for objects within 10 feet of pavement edge adjacent to outside travel lane (64) Fixed object rating for objects within 10 feet of pavement edge adjacent to inner travel lane (65)
	Operational: Total encroachment rate, number of edgeline plus centerline touches per 100 vehicles entering curve (17) Speed differential of vehicles in outside travel lane between points on curve approach and curve midpoint, mph (38) Speed differential of vehicles in inner travel lane between points on the curve approach and curve midpoint, mph (41) Average speed reduction efficiency, ratio of observed speed reduction to desirable speed reduction due to curvature and superelevation, averaged for both directions of travel (66)

Note: In general, AADT is insensitive to highway safety treatments and thus was analyzed as a non-operational variable.

Table 10. Independent variables available for selection by stepwise regression process (variable numbers shown in parentheses) (continued).

Dependent Variable(s)	Independent Variables
Inside Lane Accident Rate (17)	Non-Operational: Average annual daily traffic (9)* Degree of curvature (10) Grade, percent (12) Distance since last traffic event for inner travel lane, miles (14) Superelevation error, difference between minimum superelevation required for prevailing conditions and actual superelevation, inches per foot in inner travel lane (67) Shoulder width adjacent to inner lane, feet (42) Sideslope angle adjacent to inner lane, x:1 (44) Fixed object rating for objects within 10 feet of edge of inner travel lane (65)
	Operational: Total encroachment rate for inner lane traffic (18) Centerline encroachment rate for inner lane traffic (34) Edgeline encroachment rate for inner lane traffic (35) Speed differential of vehicles in inner lane between points on curve approach and the start of curvature (39) Speed differential of vehicles in inner lane between points at the start of curvature and the curve midpoint (40) Speed differential of vehicles in inner travel lane between points on the curve approach and curve midpoint, mph (41) Speed reduction efficiency on inner lane (60)

Note: In general, AADT is insensitive to highway safety treatments and thus was analyzed as a non-operational variable.

Table 10. Independent variables available for selection by stepwise regression process (variable numbers shown in parentheses) (continued).

Dependent Variable(s)	Independent Variables
Outside Lane Accident Rate (8)	Non-Operational: Average annual daily traffic (9)* Degree of curvature (10) Grade, percent (12) Distance since last traffic event for outside travel lane, miles (13) Superelevation error, difference between minimum superelevation required for prevailing conditions and actual superelevation, inches per foot in outside travel lane (68) Shoulder width adjacent to outside lane, feet (42) Sideslope angle adjacent to outside lane, x:1 (45) Fixed object rating for objects within 10 feet of edge of outside travel lane (66)
	Operational: Total encroachment rate for outside lane traffic (19) Centerline encroachemnt rate for outside lane traffic (32) Edgeline encroachment rate for outside lane traffic (33) Speed differential of vehicles in outside lane between points on curve approach and start of curve (36) Speed differential of vehicles on outside lane between points at start of curvature and curve midpoint (37) Speed differential of vehicles in outside travel lane between points on curve approach and curve midpoint, mph (38) Speed reduction efficiency on outside lane (59)

Note: In general, AADT is insensitive to highway safety treatments and thus was analyzed as a non-operational variable.

curves by physical attribute (9 groups), and the analyses of 6 stratifications of the dependent variable.

The simple correlation coefficients for each combination of one independent and one dependent variable were computed. Confidence limits of 95, 90 and 80% were used to test these correlations. Any independent variable for which the correlation coefficient was not significantly different than zero at the specified confidence level was rejected as a possible factor in the multiple regression model for predicting that dependent variable. Thus, only variables that are independently correlated to accidents were included in the stepwise multiple regression runs.

Residual error plots were also examined for each regression model that satisfied the statistical criteria for model selection. This check was performed to determine if non-linear transformations were necessary based on the variance of the residuals (constant variance is assumed in linear regression) and the existence of outliers. Transformations of the data were not indicated for any of the models presented in this section.

The analysis failed to identify a good surrogate measure for the total accident rate using all 25 locations. The only variable that was both independently correlated with total accident rate and remained in the MAX $R2$ model at the 0.05 level of significance was degree of curvature. However, the $R2$ value for this one variable model was only 0.16, and thus is not considered to be a strong surrogate for total accidents.

The results are consistent with those from the literature review, the workshop and the analysis of MIDAS, in that this factor was identified as "important" in all three. It is not suprising that there is no single surrogate which explains all accidents at all locations.

The most clearly defined surrogate measure for rural isolated curves resulted from the analysis of outside lane accidents on highway sections with zero or one driveway per section and a speed limit greater than or equal to 45 mph (group "H"), using both operational and non-operational variables (Table 11). The coefficient of multiple correlation R^2, for this model was 0.81, and the variables used were "distance to last traffic event on the outside lane (V13)" and "speed differential between the approach speed and curve midpoint speed for traffic in the outside lane (V38)". The form of the predictive model is:

Outside lane accident rate = 0.032 + 0.595 (V13) + 0.151 (V38)

The relatively high $R2$ value is not unexpected since both the independent variable and the dependent variable contain only a subset of the total sample. For this particular data base, then, it was possible to define a surrogate measure that is easily measured, capable of being

Table 11. Surrogate measures and associated mathematical models for rural isolated curves.

Accident Measure	Surrogate Measure(s)	Site Characteristics	Model
Outside Lane Accident Rate (accidents/MV), V08	Distance to Last Event Outside Lane, V13 Speed Differential, V38 (Outside Lane Speed Reduction)	Low Residential Land Use and Posted Speeds of 45 mph or Greater	$V08 = 0.03227 + 0.5949\ V13 + 0.1510\ V38$ $R^2=0.81$
Rear-End Accident Rate (accidents/MV), V03	ADT, V09 Side Slope Angle, V63	Grades Less Than 4%	$V03 = -0.1026 + 0.00004184\ V09 + 0.0001284\ V63$ $R^2 = 0.74$
Rear-End Accident Rate (accidents/MV), V03	ADT, V09	Grades Less Than 4% and Low Residential Land Use	$V03 = -0.06900 + 0.00004595\ V09$ $R^2 = 0.72$
Run-Off-Road Accident Rate (accidents/MV), V05	Degree of Curve, V10 Superelevation Error, V69	Restricted Sight Distance and Low Residential Land Use	$V05 = -2.975 + 0.4985\ V10 - 1.508\ V69$ $R^2 = 0.68$

measured immediately following implementation of a safety countermeasure, and strongly correlated to one particular type of accident.

One of the primary objectives of this study was to determine if this could be accomplished through a logical procedure using both the experience of practicing engineers and statistical testing. This objective has been met for this particular subset of the data.

Similar results were obtained for other accident classifications, situations and groupings. Some of the more promising results are described in the following paragraphs, and the results of the analyses are shown in Appendix G. (All the models in Table 11 and Appendix G are constructed from variables that are significantly correlated with the relevant accident data at the 0.05 level -- i.e., though some variables with significance levels of 0.10 and 0.20 are listed in the tabulations (and so identified), they were not used in the development of the models shown).

For rural isolated curves, reasonably good models ($R2>0.65$) were obtained for (Table 11):

- Outside lane accident rate for group "H", using the non-operational variables distance to last event and degree of curve.
- Rear-end accident rate for group "B", using the variables "ADT" and "side slope angle".
- Rear-end accident rate for group "F", using the variable "ADT".
- Run-off-road accidents rate for group "E", using the non-operational and operational variables "degree of curve" and "superelevation error".

Further examination of the correlation and regression results shown in Appendix G provides additional insight regarding variations in accident experience at horizontal curves.

- For "total accident rate", the independent variables selected by Max R2 most frequently are "speed differential on the outside lane", "degree of curve" and "total encroachment rate".
- For "rear-end accident rate", the independent variables selected most frequently are "ADT" and "total encroachment rate".
- For "opposite direction accident rate," the independent variables selected most frequently are "speed differential on the inside

lane", "degree of curve" and "fixed objects within 10' of inside lane".

- For "run-off-road accident rate", the independent variables selected most frequently are "degree of curve" and "speed differential on the outside lane".
- For "inside lane accident rate", the independent variables selected most frequently are "encroachment rate on the inside edgeline" and "fixed objects within 10' of inside lane". (Neither of these shows up nearly as frequently as the independent variables for the other types of accident rates).
- For "outside lane accident rate", the independent variables selected most frequently are "speed differential on the outside lane", "distance to last event in outside lane" and "degree of curve".
- The success in developing models also varied by subgroupings of the sites. Eliminating sites with posted speeds below 45 mph enhanced success considerably, eliminating sites with grades greater than 4% was next most helpful.

These observations are consistent with intuition, and lend credence to the data and statistical procedures. However, this was an exploratory study of accident surrogates, and hence the data base for any given situation/accident type/surrogate was limited.

Case Applications

Five isolated curves were selected in Macomb County, Michigan for the purpose of testing the application of the selected accident surrogate models. Macomb County is adjacent to Oakland County and is quite similar with respect to terrain, traffic control devices, and urban-rural mix. Due to the limited sample size and limited number of accidents, statistical reliability between the actual and predicted accident rates was not expected. The intent of the test was to illustrate how field data could be used to predict hazard potential using surrogate measures. The comparison of predicted and actual accident experience should provide insight into the feasibility and appropriateness of future development and research on accident surrogate measures.

All sites were selected using the same criteria as used for previous site selection. Accident and volume data were collected for three years (1977-1979). Volumes ranged from 1,100 to 3,200 vehicles per day. Appropriate operational and non-operational variables were collected at each site using the same personnel and collection procedures as previously used. Two of the five sites were eliminated, one due to extreme pavement deterioration on the approaches to the curve, and the other due to an incomplete accident record.

The three remaining sites were used to test the application of selected accident surrogate measures. Each site met the requirements of one of the nine site groupings used for model development.

Accident rates at each of the three test sites were predicted using the indicated independent variables. (These are the strongest models, as shown in Table 11)

- Outside lane accident rate using speed differential and distance since the last traffic event.
- Outside lane accident rate using distance since the last traffic event and degree of curvature.
- Rear-end accident rate using ADT and side slope angle.
- Rear-end accident rate using ADT.
- Run-off-the-road accident rate using degree of curvature and superelevation error.

Figure 7 shows a comparison between predicted and actual outside lane accident rates using speed differential and distance since the last event. While the model overpredicts the outside lane accident rate for each site, the relative position of the sites is predicted correctly.

Figure 8 shows the predicted versus actual results for the same dependent variable using only non-operational variables (degree of curvature and distance since the last traffic event). This model also overpredicts accident experience, but to a lesser degree than the preceding model.

Figure 9 shows the predicted and actual rear-end accident rates using the surrogate containing ADT and side slope angle. Although a negative accident rate cannot occur (as predicted), it can be seen that the predicted rates typify the actual rates for this illustration.

In Figure 10, the model for rear-end accidents indicates little or no rear-end accident experience based on the traffic volume or the curve. This prediction is highly related to the low rear-end accident experience at the three test sites.

Figure 11 shows that the model for run-off-the-road accident experience underpredicts the actual accident experience for one curve. However, the predicted and actual rates were almost identical for two sites. The model ranked the sites according to the actual accident rate.

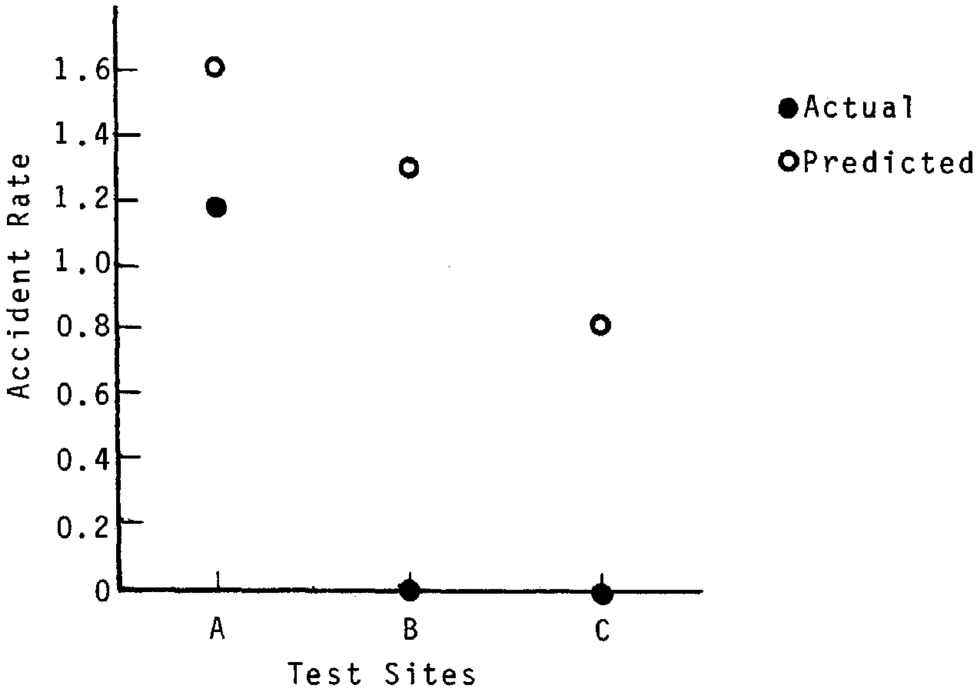


Figure 7. Comparison of predicted and actual outside lane accident rate at rural curves using speed differential and distance since the last traffic event.

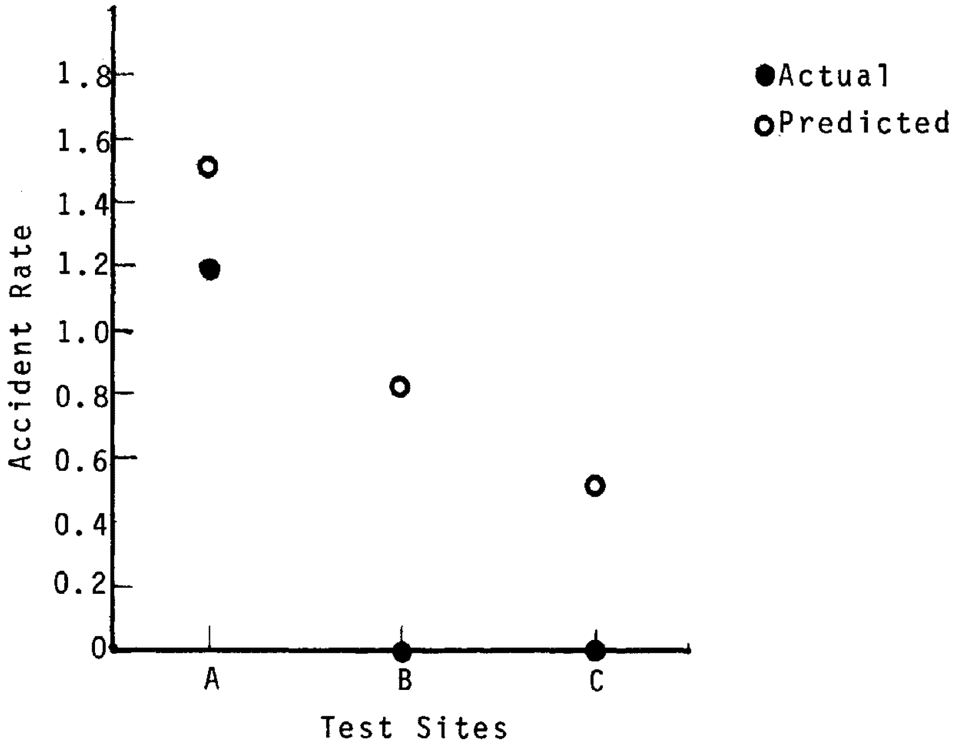


Figure 8. Comparison of predicted and actual outside lane accident rate at rural curves using distance since the last traffic event and degree of curvature.

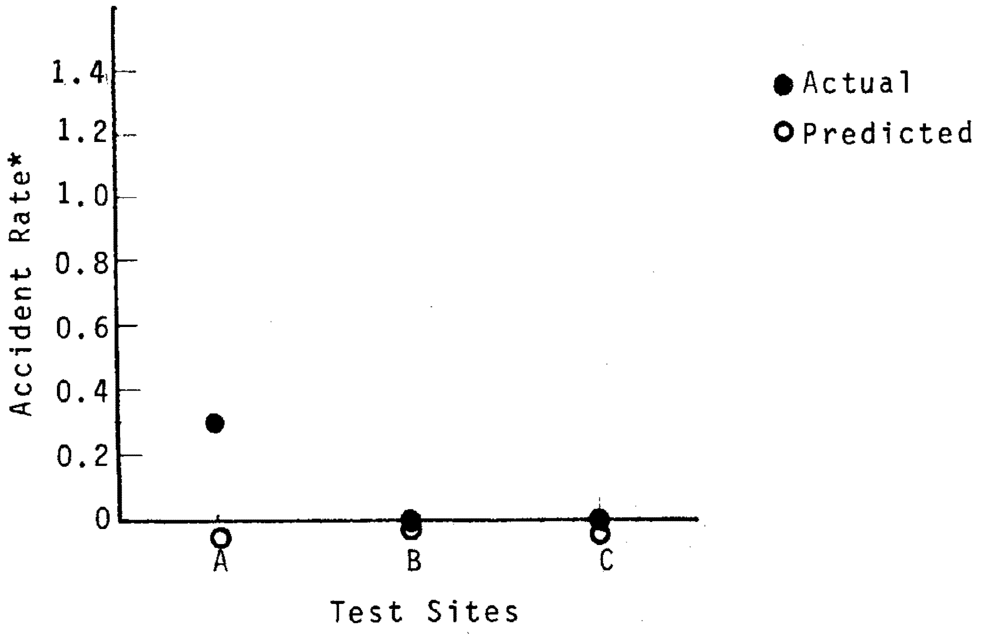


Figure 9. Comparison of predicted and actual rear-end accident rate at rural curves using ADT and side slope angle.

Note: Negative accident rates were predicted because the range of the independent variables used in model development was exceeded for the case application sites.

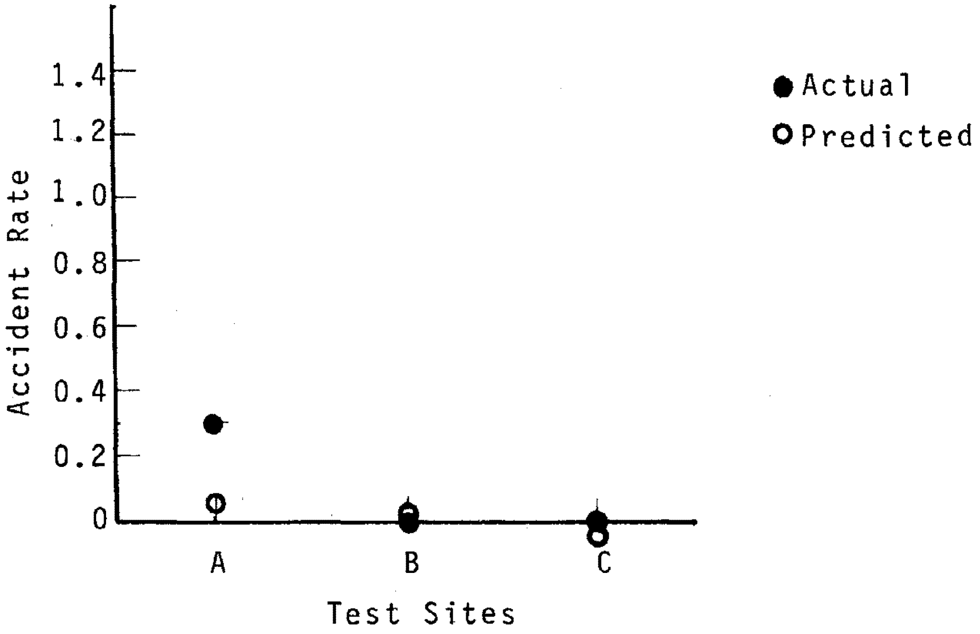


Figure 10. Comparison of predicted and actual rear-end accident rate at rural curves using ADT.

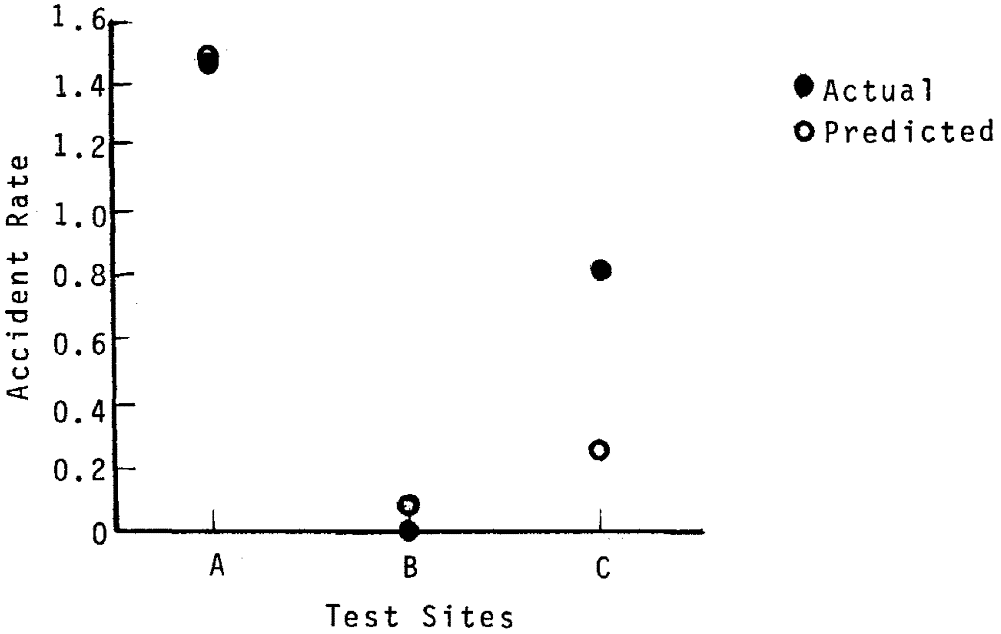


Figure 11. Comparison of predicted and actual run-off-road accident rate at rural curves using degree of curvature and superelevation error.

Rural Signalized Intersections

Site Selection and Data Collection

Thirty signalized intersections were identified as candidate test sites in the rural townships of Oakland County, Michigan. Each site was visited to ensure the site selection criteria were satisfied. Nineteen intersections were identified as appropriate based on the selection criteria. No additional sites were rejected on the basis of unusual accident patterns. Pertinent data for the 19 sites are given in Appendix F. The data set includes physical characteristics relating to non-operational candidate surrogates (distance since last traffic event on each approach, signal splits, sight distance, etc.), and operational characteristics (approach speeds, turning volumes, vehicle mix, erratic maneuvers, etc.). Accident records were also obtained for 1977, 1978 and 1979 for each site. The total list of variables is shown in Table 12.

Site Stratification

Data for all 19 sites were used in the initial computer runs. Four subsets of the sites were also used in similar analyses. The site variables used to develop the subsets are:

- Presence of a separate left-turn lane (Group A)
- Presence of a separate right-turn lane (Group B)
- Adequacy of sight distance to the signal on the intersection approaches (Group C)
- Posted speed limit on the approaches (Group D)

Group "A" consists of only intersections with separate left-turn lanes on at least one approach. This group contains 14 sites. The rationale for this stratification is that the presence of separate left-turn lanes has a significant effect on intersection capacity, operations and safety.

Group "B" consists of only intersections with separate right-turn lanes (or tapers) on each intersection approach. This group contains 13 sites.

Group "C" consists of intersections with unrestricted sight distance to the signal heads. Intersections with sight distances of less than 0.2 miles were excluded from the group. This group contains 13 sites.

Group "D" consists of intersections located on roads with posted speed limits of 45 mph or greater on at least two approaches. This group contains 14 sites. Sites with lower approach speeds were eliminated because the posted speed limit may affect driver characteristics at the site, thus increasing the variance in accidents.

Table 12. Independent variables available for selection by stepwise regression process (variable numbers shown in parentheses).

Dependent Variables	Independent Variables
Total (10), rear-end (11), opposing left-turn (12), right-angle (13), driveway (14), injury (16), property damage (17), accident rates	Non-Operational: Average annual daily approach volume (57) Average distance since last traffic event (58)
	Operational: Average approach speed (59) Average truck percentage (60) Average left-turn percentage (61) Average right-turn percentage (62) Signal violation rate (56) Erratic maneuver rate (51)
Rear-end accident rate on north (18), east (19), south (20), west (21) approach and total accident rate on north (22), east (23), south (24), west (25) approach	Non-Operational: Average daily approach volume for the north (06), east (07), south (08), west (09) approach Distance since last traffic event on the north (33), east (34), south (35), west (36) approach
	Operational: Percent green time for north-south (27) and east-west (28) directions Percent amber for the north-south (29), east-west (30) directions Percent red for the north-south (31), east-west (32) directions Approach speed on the north (37), east (38), south (39), west (40) approach Percentage of trucks in the north-south (41), east-west (42) directions Percentage left-turns from north (43), east (45), south (47), west (49) approach Percentage right-turns from the north (44), east (46), south (48), west (50) approach Erratic maneuver rates on the north (52), east (53), south (54), west (55) approach

Independent/Dependent Variables

The potential surrogates (independent variables) collected and/or calculated for each of the study sites are listed in Table 12, along with the accident characteristics (dependent variables) used in the analysis.

A total of 225 separate regression analyses were conducted on the data set using the MAX R^2 stepwise linear regression model. This number of runs was required because of the stratification by type of independent variables (operational, non-operational, or combined), the grouping of intersections by physical attribute (5 groups), and the analyses of 15 stratifications of the dependent variable:

- Total accident rate
- Rear-end accident rate
- Opposite left-turn accident rate
- Right angle accident rate
- Driveway accident rate
- Injury accident rate
- Property damage only accident rate
- Rear-end accident rates by approach
- Total accident rate by approach

Results of the Analysis

Statistical criteria identical to that used for the preceding situation was used to analyze the regression results. Examination of the residual errors for the selected regression models again showed no need for data transformations.

As in the preceding situation, the analysis failed to identify a good surrogate measure for total accident rate in any of the five site groups. In fact, only two models met the least restrictive statistical selection criteria (0.20 level of significance). This finding however was not unexpected due to the complex nature of accident patterns at signalized intersections.

The most clearly defined surrogate measure for rural signalized intersections resulted from the model to predict opposing left-turn accident rate using signal violation rate (V56, number of vehicles observed to violate amber and red phase), and the percent trucks, (V60) (see Table 12). This surrogate is applicable for both the identification of hazardous locations and evaluation because of the operational nature of the variables. This model was produced for group "C" which consists of intersections with unrestricted sight distance to the signal head. An R^2 value of 0.63 was reported for the model. The form of the predictive model is:

Opposing left-turn accident rate = 0.5895 + 0.4101 (V56) - 0.0801 (V60)

While model development efforts were not as statistically reliable as those for horizontal curves, specific models were found that met one statistical criteria of (1) non-zero correlation coefficients between dependent and independent variables significant at the 0.05 level, and (2) R^2 of 0.60 or greater for the models.

The model with the highest value of R^2 (0.67) relates the accident rate on North approaches to "percent amber on N-S approaches" and "percent left-turns, north" for all intersections with unrestricted sight distances to the signal heads (see Table 13). As this model includes data from only a single directional approach (north) at each of only 13 sites, and is not confirmed in similar data sets for the other directional approaches (or in the aggregate for all intersection approaches) it is not considered very meaningful.

The other two models meeting the statistical criteria both relate to the opposing left turn accident rate. The model for the 13 intersections with unrestricted sight distances to the signal heads has "signal violation rate" and "percent trucks" as the independent variables (see Table 13); the model for the 14 intersections with posted speed limits of 45 mph or greater has "approach speed" and "signal violation rate" as the two independent variables.

More general observations from examination of the Tables in Appendix G are:

- It was not possible to develop a meaningful model for "total accident rate" for any of the five site groupings.
- The two models for "rear end accident rate" have only "average annual daily approach volume" as the independent variable -- i.e., rear-end accident rate can only be related to volume at the intersection.
- For "opposing left-turn accident rate", the independent variable selected most frequently is "signal violation rate".
- For "right angle accident rate", the independent variable selected most frequently is "cycle length".
- The models do not indicate any other consistent relationships between independent variables and the other classification of accident rates.

Table 13. Surrogate measures and associated mathematical models for rural signalized intersections.

Accident Measure	Signal Measure(s)	Site Characteristics	Model
Opposing Left Turn Accident Rate, V12 (accidents/MV)	Signal Violation Rate, V56 Percent Trucks, V60	Unrestricted Sight Distance to Signal Heads	$V12 = 0.5895 + 0.4101\ V56$ $-0.08015\ V60 \quad R^2 = 0.63$
Opposing Left Turn Accident Rate, V12 (accidents/MV)	Approach Speed, V59 Signal Violation Rate, V56	Posted Speed Limit of 45 mph or Greater on Approaches	$V12 = 3.077 + 0.3404\ V56$ $-0.07217\ V59 \quad R^2 = 0.60$

- Overall, the strongest models were developed with "opposing left-turn accident rate" as the dependent variable. Analysis involving other categories of accident rates did not yield consistent and meaningful results.

- Model development was somewhat more successful when the data set was limited to the 14 intersections with posted speed limits of 45 mph or greater on at least two approaches (Group "D").

The analysis suggests that the use of accident surrogates at rural signalized intersections has limited potential. This may be due to the increased complexity of the driving and decision-making tasks associated with signalized locations (as contrasted with at horizontal curves).

Case Applications

Because the analysis failed to produce a strong statistical model for this roadway situation, case applications provided no useful information.

Urban Undivided Tangents

Thirty-six sections of two-lane tangent roadway located in the urbanized areas of Oakland County, Michigan were selected as test sites. All sections were similar in cross-sectional features. However, average daily traffic volumes ranged from 5,000 to 23,000. All test sections are located between major signalized intersections and vary in length (0.56 - 0.95 miles). Accidents on each test section were screened to remove accidents relating to the signalized intersections at either end of the test sites. The resulting accident data therefore represent accidents relating to the roadway sections and corresponding elements.

Six of the 36 sections were randomly selected for use in case illustrations. Pertinent data for the remaining 30 tangent sections are given in Appendix F and defined in Table 14. The data set includes physical characteristics (number of signs, number of intersections, number of driveways, etc.), operational characteristics (speed changes, percentage of midblock turns, etc.) and accident data for 1976, 1977 and 1978.

Site Stratification

There was no need or opportunity to stratify this highway situation because of the similarity in the variables (i.e., posted speed limit, lane width, presence of curbs, shoulder width, mix of adjacent land uses, etc.).

Independent/Dependent Variables

Table 14 shows the operational and non-operational independent variables available for selection by the MAX R^2 stepwise linear regression process for each dependent variable investigated. Note that some of the independent variables come directly from the data base (e.g., ADT) while others are calculated from the data base (e.g., signs per mile, driveways per mile).

As in the case of rural signalized intersections and rural isolated curves, three different regression analyses were performed for each of six dependent variables; one run using all the independent variables listed for the relevant dependent variables: one run where the independent variables were limited to operational variables; and one run limited to non-operational variables. A total of 18 separate regression runs were made for the analysis.

Results of the Analysis

Table 15 shows the results of the regression analysis for urban undivided tangents. Based on the statistical criteria used in previous analyses, no model provides a strong surrogate for accident experience for this highway situation.

Table 14. Independent variables available for selection by stepwise regression process (variable numbers shown in parentheses).

Dependent Variables	Independent Variables
Total (12), rear-end (13), opposite direction (14), accident rates	Non-Operational: Volume to capacity ratio (33) No. of driveways per mile (34) No. commercial driveways per mile (35) No. residential driveways per mile (36) No. unsignalized intersections per mile (37) No. signalized intersections per mile (38) No. of signs per mile (39) No. of regulatory signs per mile (40) No. of warning signs per mile (41) No. of information signs per mile (42)
	Operational: ± 3 mph speed changes per mile (43) Percent turns along section (30) Percent trucks (31) Volume to capacity ratio (33)
Driveway (15), angle (16) accident rates	Non-Operational: Volume to capacity ratio (33) No. of driveways per mile (34) No. commercial driveways per mile (35) No. residential driveways per mile (36)
	Operational: ± 3 mph speed changes per mile (43) Volume to capacity ratio (33)

Table 14. Independent variables available for selection by stepwise regression process (variable numbers shown in parentheses) (continued).

Dependent Variables	Independent Variables
Fixed-object accident rate (17)	Non-Operational: Volume to capacity ratio (33) No. of driveways per mile (34) No. commercial driveways per mile (35) No. residential driveways per mile (36) No. unsignalized intersections per mile (37) No. signalized intersections per mile (38) No. of signs per mile (39) No. of regulatory signs per mile (40) No. of warning signs per mile (41) No. of information signs per mile (42)
	Operational: Percent turns along section (30) Volume to capacity ratio (33)

Table 15. Linear regression results for urban undivided tangents.

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

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

The most clearly defined surrogate measure is for "fixed object accident rate" on the test sections. The variable used to predict this accident experience is "volume-to-capacity ratio". The R^2 value, however, is quite low (0.25) for this regression model (see Table 15). This same variable (volume/capacity) is the independent variable in the only model developed for predicting "rear-end accident rate" also -- simply confirming the common assumption that traffic volume (perhaps modified by roadway capacity) is the best predictor of accident rates on tangent roadway sections.

The results from these analyses indicate little potential for accident surrogate measures on urban tangents. Possible reasons for this may be the character of this highway situation, being a "section" as opposed to a "spot". On sections, the complexity of the accident picture increases dramatically over that of spot locations due to the wide variations in the driving tasks, highway information systems and driving environments, and the interactions thereof. For spot locations a driver is faced with fewer decisions and actions which, in turn, increases the feasibility of identifying specific variables on which to develop accident surrogates.

Case Application

Although strong accident surrogates could not be identified for this situation, data from the six randomly selected sites were used to demonstrate application of the best surrogate (for fixed object accidents) for the purpose of comparing predicted and actual accident rates.

Figure 12 shows comparisons for predicted and actual fixed object accidents using the volume-to-capacity ratio as the predictor variable. It can be seen that even though the selected model is quite weak (R^2 = 0.25), it generally predicts the rank order of the actual accident rates at the six test sites.

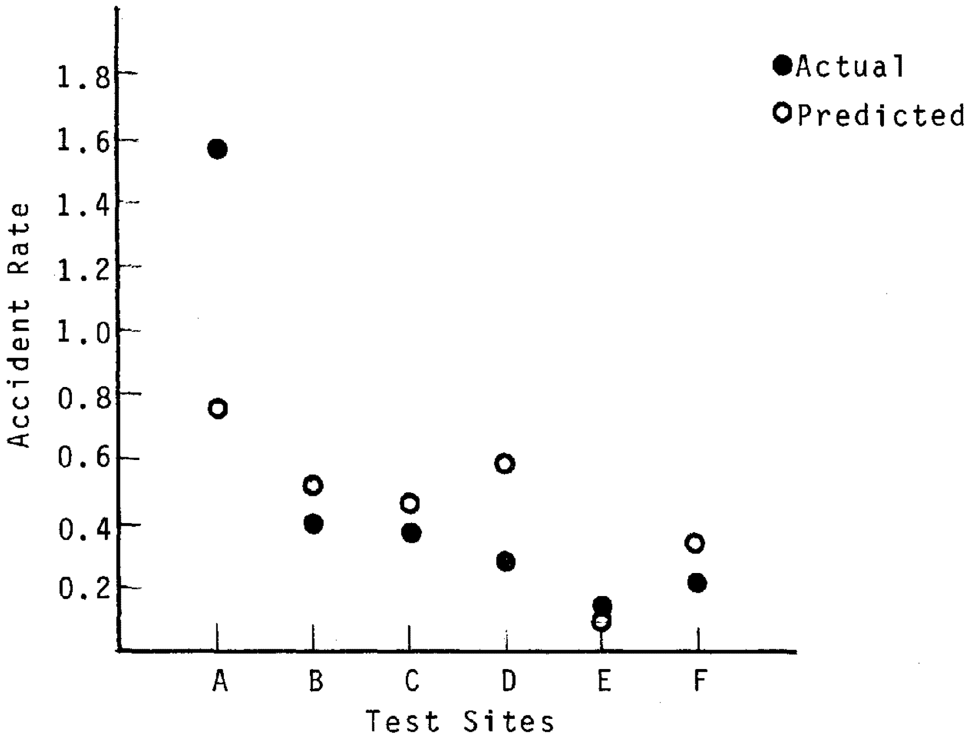


Figure 12. Comparison of fixed object accident rate at urban tangents using V/C ratio.

APPLICATION OF STUDY RESULTS

The final objective of the study was to develop methodologies that utilize selected accident surrogates for identifying hazardous locations, evaluating the effectiveness of completed countermeasures and reviewing design plans for new facilities or improvements. To accomplish this objective, procedures are presented to guide the user in applying accident surrogates in the context of the three highway safety activities.

The accident surrogates identified in the preceding section should not be considered as universal surrogates for accidents. Design standards, enforcement levels, driver characteristics, terrain, traffic control device applications, and many other highway system variables affect the types of variables that may serve as accident surrogates within a particular highway jurisdiction. The surrogates developed and reported in this study are based on three specific highway situations within a single Michigan county using county-level data. No attempt has been made to test the validity of these measures outside the test county. It may be that the surrogate measures are appropriate for these and similar locations only within that one county. Accident surrogates, therefore, may have to be developed based on the data and highway system characteristics of the individual highway agency or jurisdiction.

The development of surrogate measures, however, may benefit from the procedures demonstrated in this study.

For example, the listings of candidate surrogate measures for various highway situations may provide a starting point in the search for surrogate measures. Also, the procedure for selecting and developing surrogate models may prove useful to potential users.

Surrogate measures used for evaluation should have a demonstrated cause and effect relationship with the implemented countermeasures. That is, the magnitude of the surrogate measure should be affected by the introduction of a countermeasure. The time and coordination required to examine the affectability of various surrogate measures through initial surrogate data collection, countermeasure deployment and follow-up data collection was beyond the scope of the study. Therefore, the characteristic of affectibility is assumed (based on logic) but not validated as a part of this study.

Given the availability of implementable surrogate measures, the general methodologies contained in the following sections can be converted into detailed procedures which utilize specific surrogate/accident relationships for various highway situations to achieve the desired results of the applied methodology (i.e., identification of hazardous locations, evaluation of safety countermeasures and design plan review to identify potentially hazardous design elements or highway features).

Methodology For Identifying and Ranking Hazardous Locations

The objective of this methodology is to identify hazardous locations which warrant safety improvement and rank the resulting locations according to relative safety deficiencies. The locations are to be drawn from a listing of locations which are presumed to be hazardous by virtue of accident experience, or are suspected of being hazardous because certain geometric or operational characteristics are in evidence, or has been included in the list of candidates because of complaints received from the public.

The methodology consists of the five sequential steps that are described below:

1. Identify Potentially Hazardous Sites and Group by Situation
2. Develop Data Collection Plan
3. Collect and Reduce Field Data
4. Determine Accident Potential
5. Rank Locations

Identify and Stratify Sites

This step consists of developing a list of all locations that merit further study because of observed or suspected hazard potential. A site may be identified for a variety of reasons, including high accident experience, substandard highway design or control, public complaints, or the presence of highway system features which are associated with high hazard potential (blunt-end guardrails, narrow bridges, etc.).

Identified sites should be documented with respect to the reasons for identification such as accident experience, complaints, detection by field review, etc. In addition, a full site description should be prepared to facilitate site stratification. The site description should include location type, environmental setting (i.e., rural or urban) and type of highway situation (i.e., isolated curve, tangent section, winding section, signalized intersection, bridge, highway/railroad crossing, etc.).

Next, the locations should be stratified into groups with similar locational characteristics (highway situations). That is, group all urban signalized intersections together, group all rural signalized intersections together, group all rural winding sections together, and so on. This is necessary because surrogate/accident relationships will usually differ by highway situation and the urban/rural nature of the environment.

In performing this grouping it may be necessary to further subdivide each group based on classification variables like volume ranges, number of lanes, area population, etc. The exact guidelines for the classification scheme should be determined by the user of the methodology based on the variation in critical variables within each group of sites.

Develop Data Collection Plan

This step consists of establishing a plan for collecting field data for each site. Consideration should also be given to collecting data for those surrogates to be used in countermeasure evaluation which are not used in identification. Most, if not all, operational measures used in identification will also be used in evaluation. However, it is possible that some surrogates may be useful only in evaluation.

Certain data elements, particularly those included in the non-operational identification surrogates, will already be available in some form as a result of the site selection studies. In that case one need only check to see that the variables are in the same quantitative range and format (and were measured to the same accuracy) as that assumed in the development of the surrogate/ accident relationship.

For example, it is conceivable "distance since last curve" may be one of the variables included in a non-operational surrogate for accidents at horizontal curves. In the screening process, it may be sufficient to know whether this distance exceeds one mile or not (i.e., if the distance is greater than one mile, the curve should be included on a list of potentially hazardous sites). If a more definitive surrogate/accident relationship has been established, however, and the actual distance is part of the equation, then one must include measurement of that specific distance as part of the data. The accuracy of the measurement should be consistent with the measurements made in developing the surrogate/accident relationship (perhaps simple map measurements will be sufficient; perhaps odometer readings will be required).

It is likely that a number of operational measures will be included in the identification surrogates, and almost certainly more data will be required than is available in Step 1. Major considerations in arriving at an appropriate sampling plan for each surrogate variable are: (1) the raw data measurement accuracy specifications (e.g., nearest 0.1 mile; nearest 2 mph); (2) sample size requirements to obtain the required accuracies; (3) any special constraints (e.g., time of day; day of week); and (4) the statistical reliability of the surrogate/accident relationship -- i.e., with what accuracy can the relationship specify accident potential given that the accuracies of the individual surrogate variables meet certain specifications.

The confidence level in the assessment of accident potential will be dependent on the data collection plan, with tighter specifications requiring greater data collection effort. (It is to be noted, however, that the resulting confidence level can be no greater than that inherent in the surrogate/accident relationship no matter how precisely we determine the values of the individual variables in the surrogate).

It is not really feasible to formulate universal rules for designing "a data collection plan for identification surrogates" -- the plan is too dependent on the specific situation/surrogate/accident combination and the desired confidence level for the assessment of accident potential.

Collect and Reduce Field Data

This step consists of implementing the data collection plan developed in Step 2. Data collection personnel may need training to collect some of the specialized data elements, such as traffic conflicts, erratic maneuvers, etc. For those data used in countermeasure evaluation, it is extremely important that the actual data collection procedure (i.e., deviations from data collection plan) be documented so that they may be duplicated following project implementation. After all data are collected, they must be transformed into the format for input into the analysis process.

Determining Accident Potential

This step consists of inputing the data variables from Step 3 to the surrogate/accident relationships to determine the relative accident potential (hazardousness) of each location within each highway situation. This step will utilize the relationships to generate a measure of accident potential for each location. It should be noted that only those accidents considered to be correctable were employed in developing accident surrogates and, further, that many of the surrogates were found to be related to only certain types of accidents (surrogates will be useful in identifying these types of accidents). For example, if specific surrogates were developed for sideswipe and single vehicle run-off-road accidents at rural isolated horizontal curves, then only those accident types will be "predictable" through the use of those surrogate measures in the identification process.

Rank Locations

This step consists of analyzing the measures of accident potential generated from the surrogate/accident relationships and developing a rank-ordered listing of locations by potential hazard for each situation. Since surrogates may exist as either threshold values or continuous relationships, consideration must be given as to how to combine both types of output in assessing relative hazardousness. One approach may be to develop a site/surrogate matrix which gives a value for each surrogate type for each site, and then rank-order by "worst" combinations. Further, accident data could also be included at each site as additional input to the assessment process.

Following the identification and rank-ordering of hazardous sites the next logical step is to review physical and operating conditions to identify circumstances contributing to undesirable accident surrogate values. Alternative geometric and operational characteristics should then be brought about through design and traffic control changes, with the expectation that these changes will eliminate or lessen the negative effects of those circumstances.

Methodology For Evaluating Accident Countermeasures

The objective of this methodology is to evaluate the effectiveness of highway safety projects implemented to reduce accidents and/or hazard potential at a specific highway location (spot or section). The judgment of the effectiveness of a countermeasure project is then based on an observed change in the value of the surrogate measure(s) between the improved and unimproved condition. This methodology is intended to provide a "short-term" indication of the effectiveness of the project. Planning for the evaluation study, in advance of the implementation of the project, is mandatory.

The methodology consists of the five sequential steps:

1. Develop the Evaluation Plan
2. Collect and Reduce Field Data
3. Determine Project Effectiveness
4. Document Evaluation Results
5. Develop and Update Effectiveness Data Base

Develop the Evaluation Plan

The development of an evaluation plan prior to the implementation of the project is mandatory since values of the accident surrogate measure must be obtained both before and after project implementation.

Evaluation plan development consists of categorizing each project site into a highway situation (i.e., urban signalized intersection, rural winding section, rural isolated curve, etc.) and evaluating objectives and measures of effectiveness (MOE's) related to the expected immediate and/or intermediate impacts of the project. The selection of objectives and MOE's are limited to the characteristics of the developed quantitative surrogate/accident relationships for each highway group. If relationships are not related to the expected safety impacts of the project, the project is not amenable to evaluation by this methodology.

Once the objectives and MOE's have been selected, the experimental design for the evaluation must be selected. The selection of the experimental design and appropriate theme variations (e.g., time series, randomized assignment of treatment and control groups, etc.), must be based on an understanding of assumptions, strengths, and weaknesses of each design and a knowledge of the practical limitations and constraints which exist for the evaluating agency (e.g., manpower and time availability). A complete discussion of experimental design plans is included in "Highway Safety Evaluation (DOT-FH-11-9684)".

Based on the selection of objectives, MOE's and an experimental design, the data needs for the evaluation should be specified. Data need specification should include the type of field data to be collected, the location (control and/or project sites) and sample size requirements. Data specifications used in the development of the surrogate/accident relationships must be followed. Detailed evaluation plans should be followed in subsequent steps.

Collect and Reduce Field Data

This step consists of collecting before and after field data related to the evaluation data needs listed in Step 1. If the methodologies for identifying and ranking hazardous locations were used to identify locations, before data may already be available. However, if more than one year has elapsed between development of before surrogates and project implementation, surrogate variables should be collected again. If only a subset of the identified hazardous locations are to be improved, the unimproved locations may serve as control sites for the evaluation. Otherwise control sites must be selected and data collection activities must be performed as prescribed by the experimental design and data needs determined in Step 1.

"After" data collection activites must be identical to "before" activities. Any deviations from the established data collection activities should be recorded and used in both the before and after period.

The field data must be reduced to provide a direct measure of the surrogate needed to determine values for the "before" and "after" conditions for all data collection sites.

Determine Project Effectiveness

This step consists of comparing the before and after values of the accident surrogate measures according to the selected experimental plan and testing (statistically) the significance of any observed changes. The nature of the surrogate measure (discrete or continuous) dictates the selection of a statistical testing procedure.

Based on the observed change on the MOE's (surrogate measures) and the statistical significance of the changes, conclusions are made regarding the effectiveness of the project.

Document Evaluation Results

This step consists of preparing a written report of the observed effectiveness of the project. The report should consist of a narrative of the project, the objective, MOE's and experimental design selected for the evaluation along with the rationale for their selection, the observed changes in the accident measures, the statistical test used, and significance of observed changes. The final conclusions on the effectiveness of the project must be provided.

Develop and Update Effectiveness Data Base

This step consists of tabulating the observed changes in the accident surrogates resulting from the project in a form which is usable by program planning personnel. The format allows for updating the effectiveness of the projects as new data become available, thereby improving the reliability of the data base and improving the ability of planners to make decisions regarding project selection. In addition, the data base allows for the comparison of changes in surrogate and accident measures in the event that an effectiveness evaluation based on changes in accident measures is performed at a later date.

Methodology For Design Plan Review

The objectives of this methodology is to identify and evaluate highway design features as shown on design drawings and specifications. The design features to be evaluated may include roadway geometrics, cross-sectional elements and roadway configuration, depending on the identified relationships to accidents at the type of highway situation being studied.

The methodology consists of the five sequential steps:

1. Identify Safety-Related Design Features
2. Determine Safety Deficiencies
3. Determine Potential Design Changes
4. Review Design Plans for Consistency
5. Revise Design Plans

Identify Hazard-Related Design Features

This step involves the categorization of the highway design plan into one or more of the highway situations for which accident surrogate measures are available. The design plan may involve one highway situation or a number of situations in the case where an extended section makes up the design plan. For instance, the plan may consist of a highway section containing a rural undivided tangent, a rural signalized intersection, another tangent and a rural unsignalized intersection. Since accident surrogates may differ according to the highway situation, each situation must be considered separately.

For each highway situation contained in the design plan, a list of hazard-related design features must be developed. The listing must include the geometric accident surrogates identified for the situation.

Determine Safety Deficiencies

This step involves a comparison of the values of the hazard-related design features with threshold values developed from the surrogate/accident relationships for a particular situation. The threshold values may exist for single design features or for combinations of several features depending on the nature of the surrogate/accident relationship (only surrogate variables related to features obtainable from design plans are considered). It may also be necessary to obtain projections of traffic volumes depending on the surrogate variables to be considered.

Determine Potential Design Changes

This step consists of determining the appropriate design change(s) such that the design plan does not exceed the threshold values established for the highway situation.

Review Design Plans for Consistency

Potential revisions identified in Step 3 must be reviewed with respect to their safety impact on adjacent situations (sections). This step compares the potential design changes to the design features of all situations (components) of the proposed highway to insure consistency in design. For example, while proposed design changes such as a different skid treatment, wider lane, and/or a change in cross-slope may reduce the accident potential at a particular situation, these revisions may create driver expectancy problems at adjacent sections thus increasing the accident potential at those sections.

Revise Design Plans

This step consists of revising the identified hazardous design features such that the design plan does not exceed the threshold values established for the highway situation.

SUMMARY AND CONCLUSIONS

This study provides evidence that surrogate measures for accident experience can be identified. Furthermore, a procedure for doing so has been developed and demonstrated to a limited degree. This procedure involved extensive review of the literature pertaining to studies of the effect of various operational and non-operational highway, driver and traffic variables on accident experience; the judgment of a group of highway safety experts on which variables were most promising in terms of developing mathematical relationships with accidents; the analyses of existing data bases to assess probable relationships; a limited amount of field data collection to supplement the other sources; and a synthesis of all these inputs to select the variables most likely to lead to meaningful surrogates.

Results of the application of that procedure within this study are shown in Table 8. For ten highway situations, the variables most likely to be included in meaningful surrogate measures to (1) identify hazardous locations, (2) evaluate implemented countermeasures, and (3) review design plans are identified.

Comprehensive sets of data were collected for 25 rural isolated horizontal curves, 19 rural signalized intersections, and 30 urban undivided tangent sections -- three of the ten situations shown in Table 8. The data included operational and non-operational characteristics and measurements as independent variable, and various categories of accident types as dependent variables.

Statistical analyses of these data yielded five reasonably strong models for predicting particular types of accident rates at horizontal curves, and Table 13 has 3 weaker models for predicting accidents at rural signalized intersections. No acceptable models could be developed for urban tangent sections.

The strongest model developed in the study indicates that the "outside lane accident rate" at horizontal curves can be predicted from measurements of the "distance since last traffic event on the outside lane" and "speed differential between the approach speed and curve midpoint speed for traffic in the outside lane". The model is strongest when applied to highways with a posted speed limit at 45 mph or greater.

In all of the situations, the success in developing regression models declined markedly as the category of accident type was broadened, or the constraints on the physical or operational characteristics of the sites to be included in the data set were loosened. Further, the feasibility of identifying useful surrogate measures and accident experience prediction models is related to the character of the highway situation and the complexity of the driving task -- as evidenced by the relative successes in developing models for isolated horizontal curves, rural intersections, and urban tangent sections in this study. On rural isolated curves, for example, the driver need only perceive the direction and degree of curvature, assess the related highway and traffic environmental factors (superelevation, shoulders, other traffic, etc.) and then select an appropriate speed and path. Roadway geometry, sight distance, traffic volumes and other factors will dictate what the speed and pathway should be, but the "ideal path" can be fairly well defined and results of inappropriate decisions (encroachments, accidents) are obvious and measurable. However, as the complexity of the highway situation increases, the number of temporal and spatial decisions and possible actions increases. This creates difficulties in identifying and measuring inappropriate responses, and relating measurable roadway, driver and traffic characteristics to accidents.

The prediction models formulated in this study are based on data from a limited geographic area, and may only be appropriate for selected safety studies within that area. Some caution should be exercised in extrapolating the models to other areas with differing laws, law enforcement, driver behavior, terrain, weather and traffic control devices. It is quite possible that the models are applicable in wider areas (and that is certainly desirable, given the effort required to construct such models), but testing will be required to determine their suitability in other geographic areas.

With qualifications imposed by the size of the data set, the primary objective of the study, which is to demonstrate that accident surrogates can be developed through a systematic identification and measurement of roadway, driver and traffic characteristics has been accomplished. Generalizing the surrogates formulated herein and developing new surrogates can now proceed at a much faster pace with more efficient data collection and analyses.

RECOMMENDATIONS

Additional testing and analysis is necessary in the following areas to develop other accident surrogates and to demonstrate their usefulness in highway safety analyses:

- Further testing and analysis should be performed for those accident surrogates identified in this study. Development of surrogates on a statewide (or nationwide) basis would enhance the utility of accident surrogates.

- Other types of highway situations should be examined for the purpose of identifying surrogates. Emphasis should initially be given to "spot" situation as opposed to sections. Complexity of the driving task should be considered as an important factor in assessing the feasibility of identifying "good" accident surrogates.

- Long term study should be directed at identifying the effect of safety measures on both accident experience and surrogate values. This is a prerequisite to the use of surrogate measures for countermeasure effectiveness evaluation.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

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

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

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

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

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

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

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

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

4. Improved Materials Utilization and Durability

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

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

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

6. Improved Technology for Highway Construction

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

7. Improved Technology for Highway Maintenance

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

0. Other New Studies

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

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