Safety Evaluation, developed by Goodell-Grivas, Inc., under contract to FHWA.

The contents of this paper reflect our views, and we responsible for the facts and accuracy of the information presented herein. The contents do not necessarily reflect the official policy of the U.S. Department of Transportation.

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Surrogate Measures for Accident Experience at Rural Isolated Horizontal Curves

HAROLD T. THOMPSON AND DAVID D. PERKINS

The accident surrogate measures developed for hazardous-location identification and countermeasure evaluation at rural isolated horizontal curves are presented. An accident surrogate measure is defined as a quantifiable observation that can be used in place of or as a supplement to accident records. A list of potential accident surrogates was developed from four information sources: literature; a two-day workshop to obtain opinions and observations of highway safety professionals; analysis of an existing data base containing accident, geometric, operational, and environmental data; and selected field data collection at six rural isolated horizontal curves. Comprehensive sets of data were collected at 25 rural isolated curves. The data included measurements of operational and nonoperational characteristics and accidents. Statistical analyses of these data yielded five models for predicting specific types of accident rates. The strongest model developed in the study (R^2 = 0.81) indicates that the outside-lane accident rate can be predicted from measurements of the distance from the last traffic event on the outside lane and the speed differential between the approach speed and the curve midpoint speed for traffic in the outside lane. The other models (outside-lane accident rate, run-off-road accident rate, and two models for predicting rear-end accident rate) had R^2-values greater than 0.65. The results indicate that accident surrogates can be developed through a systematic identification and measurement of roadway, driver, and traffic characteristics.

A primary goal of any highway safety agency is to reduce traffic accidents attributable to highway system failures. Historically, these agencies have relied heavily on reported traffic accidents to identify hazardous locations, to justify and prioritize safety improvements, and to evaluate their effectiveness. However, total dependence on accident history is somewhat questionable due to the limitations of these data. For example, the fact that a significant percentage of total accidents at a location are not reported often introduces error and results in suboptimal decisions. Another limitation is encountered when decisions to continue, modify, or remove countermeasures need to be made sooner than the waiting time required to collect reliable accident data.

Because of these and still other limitations, many highway safety researchers support the premise that nonaccident measures in addition to accidents should be used in the identification of hazardous locations, review of planned improvements, and evaluation of completed safety improvements. Review of several studies shows a fairly strong relationship between accidents and various highway system characteristics such as geometrics, operations, environment, and driver behavior. However, there have been insufficient systematic efforts to investigate the feasibility of using such relationships as surrogates for accident experience in highway safety analyses.

A recent study entitled Accident Surrogates for Use in Analyzing Highway Safety Hazards (1) investigated the feasibility of using accident surrogate measures in

1. Identifying hazardous spot locations and sections of highway,
2. Evaluating the effectiveness of deployed safety countermeasures, and
3. Reviewing design plans of new facilities or improvements.

For the purpose of the study, an accident surrogate measure was defined as a quantifiable highway system feature that could be used in place of or as a supplement to accident data.

This paper presents the accident surrogates developed for highway safety analyses at rural isolated horizontal curves on two-lane roads. The surrogate development process involved (a) identifying potential highway system variables that could serve singly or in combination as surrogate measures and (b) developing explicit mathematical relationships between selected surrogate measures and accidents.

IDENTIFICATION OF CANDIDATE ACCIDENT SURROGATES

The identification of variables with potential as candidate surrogate measures 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: literature; a two-day workshop to obtain opinions and observations of highway safety professionals; analysis of the Michigan Dimensional Accident Surveillance (MIDAS) data base containing accident, geometric, operational, and environmental data; and selected field data collection at six rural horizontal curves.

These sources of information were synthesized to identify highway system variables worthy of further detailed analysis as surrogate measures in that a relationship between each variable and accidents had been demonstrated (or was strongly indicated). 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 relationship to accidents, clarity of definition, credibility, ease of data collection, and 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 the 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 criterion.

The selected candidate surrogate measures resulting from the final screening process are shown below. Although each surrogate did not rate high on all the criteria, each was considered at least passable on every criterion. The surrogate "speed-reduction efficiency" is defined as the ratio of the difference in actual speed reduction (average approach speed minus average speed at the curve midpoint) to the desired speed reduction (average approach speed minus the maximum permissible speed of the curve based on the friction factor).

Highway Safety Analysis		
Identification of Hazardous Locations	Evaluation of Countermeasures	Design Plan Review
Speed-reduction efficiency	Speed-reduction efficiency	Design-speed differential
Curvature, grade, and distance since last curve	Physical evidence of error	Curvature, grade, and distance since last curve
Physical evidence of driver error	Erratic maneuvers	
Erratic maneuvers		

FIELD INVESTIGATIONS

The second step in the surrogate development process was to develop explicit mathematical relationships between surrogate measures and accidents. This was accomplished by analyzing candidate surrogate and accident data at a number of test sites. Regression techniques were then used to identify the relationships between the candidate surrogates and accidents.

Selection of Candidate Surrogate Measures

Candidate surrogates were generally drawn from those tabulated above. However, some variables such as average annual daily traffic (AADT) and superelevation were added because of their logical association with accidents, whereas physical evidence of driver error was omitted due to difficulties relating to field measurement. The variables selected for field testing are listed below. The variables are identified as being either operational or nonoperational, since the intended use of these results required that the variables be separated. (In general, AADT is insensitive to highway safety treatments and thus was analyzed as a nonoperational variable.)

Nonoperational	Operational
AADT	Encroachment
Degree of curvature	Speed reduction
Grade	
Shoulder width	
Distance since last curve	
Superelevation	
Slope of roadside (ditch, shoulder)	
Type, location, and frequency of fixed objects	

Selection of Study Sites

A number of control variables 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 possible surrogate variables or as having shown some relationship to accidents. As a result, the following criteria were used to identify test sites:

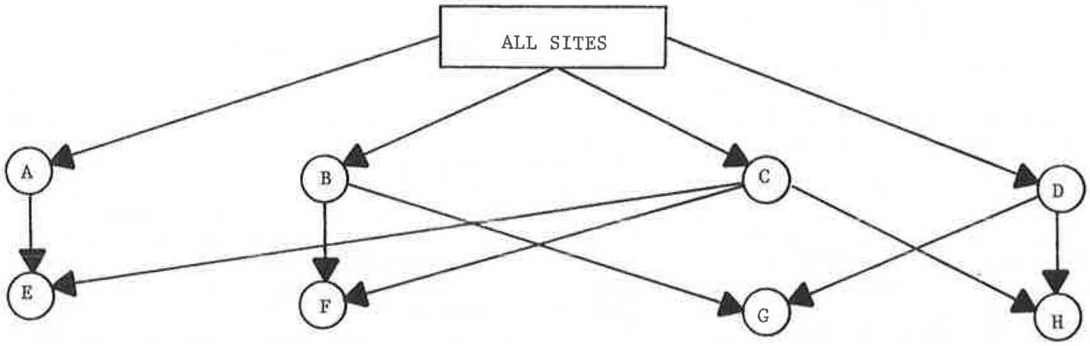
1. The curves should be located on two-lane, undivided roads and have a central angle of at least 20°.
2. Traffic volumes (AADT) should not exceed 8000 vehicles and posted speeds on curve approaches should be between 35 and 55 mph (advisory speeds on the curves may vary).
3. Lane widths should be between 10 and 12 ft and there should be gravel shoulders.
4. 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 (e.g., another curve, railroad crossing, stop sign, traffic signal, etc.).
5. The curves should not have extremely unusual roadside features.

Twenty-eight roadway sections containing isolated curves were identified through a search of the Oakland County, Michigan, inventory files. Oakland County was selected because of the availability of recent photologs, a complete file of highway improvement projects implemented since 1975, and reliable accident and volume data. Each of the sites was visited to determine whether they met all the criteria specified for test sections. Twenty-five of the sites were acceptable, and data were collected at each of these sites.

Stratification of Study Sites

The existence of complex interactions between geo-

Figure 1. Site stratification for rural isolated curves.



metric, traffic, and driver behavior variables and accident experience generally tends to mask explicit mathematical relationships between these variables and accidents. To reduce this masking effect, the test sites 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.

The variables used to stratify the locations were sight distance, grade, land use, and the posted speed limit.

In addition to the single-variable categories, additional categories were constructed by using sight distance and land use, grade and posted speed limit, and land use and speed limit. A total of nine groups were identified for the analysis (including all sites as a group). These groups are identified by letter in Figure 1.

Group A consists of curves with sight distance limited 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 and the workshop.

Group B consists of curves on relatively flat roadway sections (less than 4 percent 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 driveway on the curve (low residential land use). 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 the 25 curves. Group F consists of all sites meeting the criteria for groups B and C and contains 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.

Accident Data

Three years of accident data (1976, 1977, and 1978) were collected for each test site. Computer printouts of accidents were obtained for the specified limits of the sites plus all accidents occurring within 200 ft 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.

Independent/Dependent Variables

The potential surrogates (independent variables) collected and/or calculated for each of the study sites are listed in Table 1 along with the accident characteristics (dependent variables) used in the analysis.

Analysis Techniques

Regression techniques [the maximum R^2-improvement technique (Max R^2) contained in the Statistical Analysis System (SAS) was selected as the most appropriate regression technique] were used in the analysis in which the selected candidate surrogate variables were used as independent variables and three-year accident rates for total accidents and predominant accident types were used as dependent variables. Stepwise regression was used as the analysis procedure to test for statistically significant relationships between one or a combination of candidate surrogate variables and accident experience at the test sites.

Regression analyses were performed for specific stratifications to search for statistically significant relationships between accidents and (a) combinations of nonoperational and operational variables, (b) nonoperational variables only, and (c) 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.

RESULTS OF ANALYSIS

A total of 162 separate regression analyses were conducted on the data set by 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, nonopera-

Table 1. Independent and dependent variables included in analysis.

	Independent Variable	
Dependent Variable	Nonoperational	Operational
Accident rate: total (2), rear end (3), opposite direction (4), run off road (5), and fixed object (6)	AADT (9); degree of curvature (10); percent grade (12); superelevation error,[a] entire pavement width (69); shoulder width, average width for both shoulders (62); side-slope angle, ratio x:1, average for both sides of road (63); fixed-object rating for objects within 10 ft of pavement edge adjacent to outside travel lane (64); fixed-object rating for objects within 10 ft of pavement edge adjacent to inner travel lane (65)	Total encroachment rate[b] (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 curve approach and curve midpoint, mph (41); average speed reduction efficiency[c] (66)
Inside-lane accident rate (17)	AADT (9); degree of curvature (10); percent grade (12); distance since last traffic event, inner travel lane, miles (14); superelevation error, inner travel lane (67); shoulder width adjacent to inner lane, ft (42); slide-slope angle adjacent to inner lane, x:1 (44); fixed-object rating for objects within 10 ft of edge of inner travel lane (65)	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 start of curvature, mph (39); speed differential of vehicles in inner lane between points at start of curvature and curve midpoint, mph (40); speed differential of vehicles in inner travel lane between points on curve approach and curve midpoint, mph (41), speed-reduction efficiency on inner lane (60)
Outside-lane accident rate (8)	AADT (9); degree of curvature (10); percent grade (12); distance since last traffic event, outside travel lane, miles (13); superelevation error, outside travel lane (68); shoulder width adjacent to outside lane, ft (42); side-slope angle adjacent to outside lane, x:1 (45); fixed-object rating for objects within 10 ft of edge of outside travel lane (66)	Total encroachment rate for outside-lane traffic (19); centerline encroachment 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, mph (36); speed differential of vehicles on outside lane between points at start of curvature and curve midpoint, mph (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: Variable numbers are shown in parentheses.
[a]Difference between minimum superelevation required for prevailing conditions and actual superelevation (in/ft).
[b]Number of edgeline plus centerline touches per 100 vehicles entering curve.
[c]Ratio of observed speed reduction to desirable speed reduction due to curvature and superelevation, averaged for both directions of travel.

tional, or combined), the grouping of curves by physical attribute (nine groups), and the analyses of six 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 percent 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 whether nonlinear 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 when all 25 locations were used. The only variable that was independently correlated with total accident rate and that remained in the Max R^2-model at the 0.05 level of significance was degree of curvature. However, the R^2-value for this one-variable model was only 0.16, and thus it 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 surprising that there is no single surrogate that explains all accidents at all locations.

The most clearly defined surrogate measure for rural isolated curves, the outside-lane accident rate, 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), which used both operational and nonoperational variables (Table 2). 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 relatively high R^2-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 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 whether this could be accomplished through a logical procedure by 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. (All the models in Table 2 are constructed from variables that are significantly correlated with the relevant accident data at the 0.05 level.)

Table 2. Surrogate measures and associated mathematical models for rural isolated curves.

Accident Measure (accidents/ million vehicles)	Surrogate Measure	Site Characteristic	Model
Outside-lane accident rate (V08)	Distance to last event, outside lane (V13); speed differential (V38)	Low residential land use, posted speeds ≥ 45 mph	V08 = 0.032 27 + 0.5949V13 + 0.1510V38 R^2 = 0.81
Rear-end accident rate (V03)	ADT (V09), side-slope angle (V63)	Grade < 4 percent	V03 = -0.1026 + 0.000 041 84V09 +0.000 128 4V63 R^2 = 0.74
	ADT (V09)	Grade < 4 percent, low residential land use	V03 = -0.069 00 + 0.000 045 95V09 R^2 = 0.72
Run-off-road accident rate (V05)	Degree of curve (V10), superelevation error (V69)	Restricted sight distance, low residential land use	V05 = -2.975 + 0.4985V10 - 1.508V69 R^2 = 0.68

For rural isolated curves, reasonably good models (R > 0.65) were obtained for (Table 2)

1. Outside-lane accident rate for group H by using the distance to the last event and the speed differential on the outside lane,
2. Rear-end accident rate for group B by using the ADT and the side-slope angle,
3. Rear-end accident rate for group F by using the ADT, and
4. Run-off-road accident rate for group E by using the nonoperational degree of curve and the operational superelevation error.

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

1. For total accident rate, the independent variables selected by Max R^2 most frequently are speed differential on the outside lane, degree of curve, and total encroachment rate.
2. For rear-end accident rate, the independent variables selected most frequently are ADT and total encroachment rate.
3. 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 ft of inside lane.
4. For run-off-road accident rate, the independent variables selected most frequently are degree of curve and speed differential on the outside lane.
5. For inside-lane accident rate, the independent variables selected most frequently are encroachment rate on the inside edgeline and fixed objects within 10 ft of inside lane. (Neither of these shows up nearly as frequently as the independent variables for the other types of accident rates.)
6. 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.
7. 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 percent 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 or accident type or surrogate was limited.

SUMMARY AND CONCLUSIONS

The results of this study indicate that surrogate measures for accident experience can be identified. Further, 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 nonoperational 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 were tabulated at the beginning of this paper.

Data were collected for candidate surrogate measures and various categories of accident types at 25 study sites. Statistical analyses of these data yielded five reasonably strong models for predicting particular types of accident rates.

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 the 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 of 45 mph or greater.

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 here and developing new surrogates can now proceed at a much faster pace with more efficient data collection and analyses.

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The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the U.S. Department of Transportation.

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Candidate Accident Surrogates for Highway Safety Analysis

DAVID D. PERKINS AND HAROLD T. THOMPSON

The variables identified as potential accident surrogate measures for use in identification of hazardous locations, evaluation of safety countermeasures, and design plan review at 10 specific highway situations are presented. Situations included urban undivided tangent section, rural undivided winding section, rural isolated curve, lane drop, narrow bridge, exit gore area, urban nonsignalized intersection, rural nonsignalized intersection, rural undivided tangent section, and rural signalized intersection. Accident surrogate measures are defined as quantifiable highway system features and characteristics that can be used in place of or as a supplement to accident records. The list of candidate surrogates was developed from four information sources: literature, a two-day workshop to obtain opinions and observations of highway safety professionals, analysis of an existing data base, and selected field data collection.

Highway safety programs administered by the Federal Highway Administration (FHWA) are aimed at reducing traffic accidents attributable to highway system failures. To be effective, safety improvement programs must follow a systematic procedure to identify the safety deficiency, develop and implement a solution, and monitor the effectiveness of the implemented solution.

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 is apparent 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, it is a shortcoming 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.

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 have been only limited systematic efforts to investigate the feasibility of using such relationships as surrogates for accident experience in highway safety analyses.

A recent study entitled Accident Surrogates for Use in Analyzing Highway Safety Hazards (1) investigated the feasibility of using accident surrogate measures in

1. Identifying hazardous spot locations and sections of highway,
2. Evaluating the effectiveness of deployed safety countermeasures, and
3. Reviewing design plans of new facilities or improvements.

Accident surrogate measures are defined as quantifiable highway system features and characteristics 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 to 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 training and equipment.

In this paper we present the variables identified as potential accident surrogates based on information obtained from four information sources: literature, a two-day workshop to obtain opinions and observations of highway safety professionals, analysis of the Michigan Dimensional Accident Surveillance (MIDAS) data base, and selected field data collected at five highway situations. Variables identified as candidate surrogates came primarily from the literature and the workshop. The MIDAS data were used to investigate the potential for surrogates by analyzing geometric, traffic, and environmental variables contained in that data base. For other potential surrogates, limited field studies were undertaken to provide an additional quantitative source of input. No candidate surrogate was eliminated from future consideration on the basis of either the MIDAS analyses or the limited field studies. The candidate accident surrogates were later field tested on a much larger scale to determine the strength of their relationship with accidents and utility as surrogates for accidents.