teristics, 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.

ACKNOWLEDGMENT

This paper reports some of the findings of a study performed by Goodell-Grivas, Inc., under the sponsorship of the Federal Highway Administration, U.S. Department of Transportation.

We acknowledge with thanks the contributions of Tapan K. Datta of Goodell-Grivas, Inc.; William C. Taylor of the University of Michigan; and James I. Taylor of the University of Notre Dame.

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.

REFERENCE

1. Goodell-Grivas, Inc. Accident Surrogates for Use in Analyzing Highway Safety Hazards, 3 vols. FHWA, Repts. FHWA-RD-82-103 to 105, in preparation.

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Candidate Accident Surrogates for Highway Safety Analysis

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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.

Variables identified through these sources were grouped according to their relevance to 10 specific highway situations. Situations considered were

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 nonsignalized intersection,
8. Rural nonsignalized intersection,
9. Rural undivided tangent section, and
10. Rural signalized intersection.

LITERATURE REVIEW

The literature review consisted of past and current studies on the relationship between traffic accidents and elements of the highway system (geometry, roadside environment, traffic control, traffic operations, and driver behavior) for each of the selected highway situations. Reference sources included National Technical Information Service (NTIS), existing literature reviews, and the libraries of Wayne State University, University of Notre Dame, and University of Michigan.

The literature review identified 52 highway system elements as potential accident surrogates for one or more of the 10 highway situations. The variables and variable combinations were placed into two general categories--nonoperational and operational. Nonoperational variables relate to roadway geometry and cross-sectional elements, traffic control operations, driver performance, and driver behavior. Both types of variables are listed below:

Nonoperational variables:

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, and
34. Skid resistance.

Operational variables :

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, and
18. Red- and yellow-light violations.

The potential surrogates were categorized as "strong" or "other" according to the degree of convergence of research evidence and the reliability of the research studies considered during the literature review. 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 labeled "strong".

A potential surrogate is defined as "other" when it is 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 maneuvers) 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 variables in accident studies, based on their logical relationship to safety, justifies their selection as "other" potential surrogates, even though the relationships to accidents have not been validated.

Figures 1 and 2 show the selected nonoperational 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.

WORKSHOP

The workshop was attended by 13 highway safety professionals with backgrounds in traffic engineering, highway safety research, and highway safety administration. Participants were asked to examine and critique a prepared list of geometric, operational, traffic control, and environmental factors. The list included the nonoperational and operational variables identified in the literature review together with more than 50 other variables identified by other researchers on the basis of logical (as op-

Figure 1. Potential surrogate classifications for nonoperational variables.

Situations \ Non-Operational Variables	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 surrogate; "O" denotes other potential surrogate.

Figure 2. Potential surrogate classifications for operational variables.

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

Note: "S" denotes strong potential surrogate; "O" denotes other potential surrogate.

posed to statistical) relationships to accidents.

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 the various highway situations (e.g., isolated curves, exit gore areas, and railroad crossing). The indices that make up the causal chain include information, human factors, vehicle control, congestion, and recovery. Definitions for these indices are provided below (note that the indices are defined such that higher values indicate higher degrees of hazard):

1. Information index: This is a measure of the information system deficiencies that 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.
2. Human factors index: This 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.
3. Vehicle control index: This is a measure of the geometric and environmental characteristics that 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.
4. Congestion index: This is a measure of the operational characteristics that 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.
5. Recovery index: This is a measure of the roadway and roadside characteristics that 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.

The causal chain of events is based on the following scenario (Figure 3). A driver is presented with information from a variety of sources, including signing, the environment, and other vehicles. Through this information and past driving experiences, 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 with what the driver perceives or expects, corrective adjustments in vehicle path or speed must be made. The vehicle control and congestion indices contain factors that determine the outcome of these adjustments. That is, if the vehicle remains under control and traffic conditions are such that an adjustment can be made without interference with other vehicles, an accident is avoided. If either of these conditions does not exist, the driver is faced with a recovery situation that results in either a near miss (recovery and no accident) or a single- or multiple-vehicle accident.

Participants were then asked to review a comprehensive list of variables for each hazard index for each highway situation. Factors were added, removed, and/or redefined to fit the specific combination of index and highway situation. From these lists, workshop participants were asked to identify a limited set of variables that had the strongest intuitive and/or empirical relationship to accidents.

ANALYSIS OF MIDAS DATA BASE

The MIDAS system was analyzed to determine whether 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 9000 miles of state roadway system in Michigan. Geometric data included laneage and horizontal and vertical alignment. Environmental data included roadside development 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 or no median, and turn lanes. Accident data included frequency of fatal plus injury accidents by type. Accident rates could be calculated directly from the volume and accident frequency data.

The analysis consisted of categorizing the data into the individual highway situations. MIDAS data were available for 7 of the 10 highway situations.

Analysis of variance (ANOVA) 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 ANOVA indicated a significant difference.

Because of the availability of only fatal and injury accidents, highway situations in urban areas were not considered in the ANOVA. The rural highway situations that were analyzed included isolated curves, undivided winding sections, undivided tangents, signalized intersections, and nonsignalized intersections. Many variables contained in the MIDAS data base could not be statistically analyzed due to the small number of locations for some variable categories. Summarized ANOVA findings follow:

1. Effect of average daily traffic (ADT) on rate of injury and fatal accidents was found for signalized intersections.
2. The effects of posted speed limits on rate of injury and fatal accidents were examined for all highway situations. The only statistically significant finding was that nonsignalized intersections with higher posted speed limits (50-55 mph) have a higher rate of injury and fatal accidents than intersections with lower speed limits (40-45 mph). This finding holds for ADT ranges from 2000 to more than 10 000 vehicles/day.
3. Intersections carrying 10 000 vehicles or more per day with volume-to-capacity (V/C) ratios of 0.5 to 1.0 have significantly lower mean rate of injury and fatal accidents than do intersections with V/C ratios between 0.0 and 0.5.
4. The effects of lane width on rate of injury and fatal accidents were examined only for isolated-curve sections and winding-roadway sections. The only significant finding was that winding sections with narrow pavement widths have a higher mean rate of injury and fatal accidents than sections with wider pavement widths.
5. Shoulder-width effects were examined for isolated curves and winding sections. No significant results were found for isolated curve sections, and no significant findings that would apply to the overall range of conditions for winding sections were detected.

6. No significant effects attributed to the presence or absence of a vertical curve were found for any of the highway groups.

The ANOVA generally indicates that some of the factors analyzed have a significant effect on rate of injury and fatal accidents. These factors were considered 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, candidates that did not show significant relationships were not eliminated.

ANALYSIS OF SELECTED FIELD DATA

As a supplement to the literature review, workshop, and MIDAS data base analysis, supplemental data collection and analysis activities of a limited nature were undertaken to provide an additional 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, including rural isolated curves, rural winding sections, urban undivided tangents, rural signalized intersections, and lane-drop locations.

Sites were selected in Oakland County, Michigan. In the selection of sites, basic cross-sectional and operational features, such as number of lanes and ADT, were limited to control for accident variance due to these characteristics.

Four statistical analysis techniques were used to test the relationships between the collected candidate surrogate measures and predominant accident types: (a) nonparametric (Spearman rho) correlation analysis, (b) parametric (Pearson) correlation anal-

Figure 3. Causal chain of events for potential accidents.

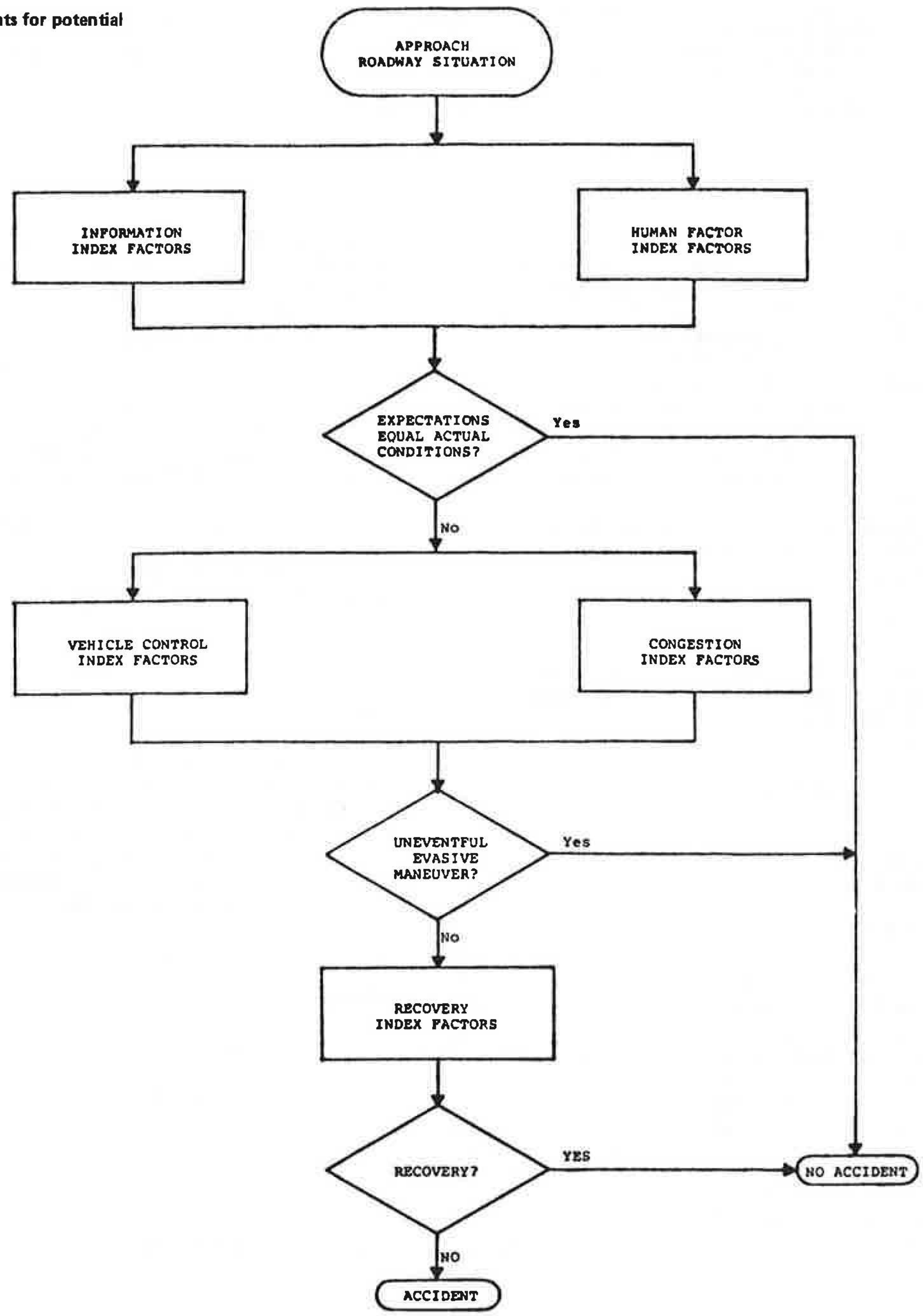

Table 1. Summary of selected surrogates by highway situation and type of highway safety analysis.

	Application in Highway Safety		
Highway Situation	Identification of Hazardous Locations	Evaluation of Countermeasures	Design Plan Review
Urban undivided tangent section	Access points/mile, turning volumes, speed changes/mile, fixed objects/mile	Speed changes/mile	Access points/mile, projected turning volumes
Rural undivided winding section	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 curve	Speed reduction efficiency; curvature, grade, and distance since last curve; physical evidence of driver error; erratic maneuvers	Speed reduction efficiency, physical evidence of driver error, erratic maneuvers	Design speed differential; curvature, grade, and distance since last curve
Lane-drop location	Erratic maneuvers, merge gap availability, taper length, posted speed and sight distance	Erratic maneuvers, merge gap availability	Taper length, posted speed and sight distance
Narrow bridge	Ratio of bridge deck to pavement width, traffic mix, sight distance (time), physical evidence of driver error	Sight distance (time), physical evidence of driver error	Ratio of bridge deck to pavement width, traffic mix
Exit gore area	Deceleration lane length, sight distance, erratic maneuvers	Erratic maneuvers	Deceleration lane length, sight distance
Urban nonsignalized intersection	Traffic volume, approach speed and sight distance, traffic conflicts	Approach speed and sight distance, traffic conflicts	Projected traffic volume
Rural nonsignalized intersection	Traffic volume, approach speed and sight distance, traffic conflicts	Approach speed and sight distance, traffic conflict	Projected traffic volume
Rural undivided tangent section	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 intersection	Traffic conflicts, traffic volume, sight distance, delay	Traffic conflicts, delay	Projected traffic volume, sight distance

ysis, (c) stepwise multiple regression analysis, and (d) independent-groups analysis. These tests were performed to obtain several types of quantitative information on the strengths of the relationships.

The analysis results provided varying degrees of support to the previously identified candidates. However, because the number of sites used in the analysis was relatively small, 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 of use as accident surrogates and therefore warrant further analysis.

CANDIDATE ACCIDENT SURROGATES

As a final step in the identification of candidate surrogates, each of the previously identified potential surrogates was evaluated according to five criteria, including

1. Relationship to accidents,
2. Clarity of definition,
3. Credibility,
4. Ease of data collection, and
5. Affectability.

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.

Candidate surrogates resulting from the final screening process are shown in Table 1 by highway situation and type of safety analysis. Although each surrogate did not rate high on all of the criteria, each was considered at least passable on every criterion. These surrogates are considered worthy candidates for further study, development, and validation in that they exhibit a potential for producing a usable accident surrogate.

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