Introduction

Highway accident statistics indicate that the annual number and rate of fatal accidents has declined to the lowest levels since the early 1960's in U.S. This, along with the fact that annual vehicle-miles of travel have generally increased throughout the same period, gives an indication that positive gains are being achieved from recent highway safety efforts. In general, programs aimed at improving the safety condition of the highway, the vehicle and the driver are responsible for the increase in highway safety.

Highway Safety programs administered by the U.S. Federal Highway Administration (FHWA) are aimed at reducing traffic accident fatalities, injuries and property damages attributable to highway system failures as opposed to those attributed to vehicle or driver failures.

The establishment of an improvement project for highway safety purposes must follow a systematic procedure to identify the safety deficiency, develop and implement a solution and monitor the effectiveness of the implemented solutions. The overall "Process for Safety Improvements" consists of three basic elements.

1. Planning Procedures
2. Development and Implementation Procedure
3. Evaluation and Reporting Procedures
Planning procedures include the identification of hazardous locations. The identification of hazardous locations should be based on analysis of data related to system-wide accidents, hazard potential, geometrics, roadway environment and traffic control devices. Those locations which exhibit abnormal accident experience become candidate locations for future highway safety improvements. Once locations have been identified and prioritized for improvement, each must be examined to determine the most probable accident causes. These factors provide direct input to project development and implementation procedures. Most of the identification and prioritization schemes currently in use are based on historical accident records. While these techniques are widely used, the limitations of accident data (accidents are a rare event and it is almost universally accepted that a significant percentage of total accidents at a location generally are not reported in most communities) often introduces error and may result in suboptimal decisions.

The second element of the highway safety process involves selecting specific countermeasures to remedy locational deficiencies. If more than one improvement or countermeasure is feasible as a remedial measure, a pre-implementation evaluation may be required. This involves a comparison of the expected hazard reduction from alternative countermeasures. Those countermeasures which yield the maximum expected benefit (accident reduction and operational improvement) and which are most cost-effective are selected for implementation.

Evaluation and reporting procedures are performed to provide the entire highway safety process with quantifiable evidence of the effectiveness of implemented projects. First, the evaluation information facilitates decisions in planning procedures and data analysis by providing the analyst with the types of data which are most indicative of specific types
of deficiencies, thereby making future identification of hazardous locations more efficient. Secondly, the evaluation provides direct input to project development activities. This is done by allowing the analyst to specify those projects and countermeasures which maximize the reduction of hazards while avoiding projects with marginal effectiveness.

The dependence of the entire highway safety improvement process solely on accidents, as is currently being practiced, is somewhat questionable when we consider the limitations of accident data. Researchers have long realized such limitations, and have worked on the premise that the identification of hazardous locations, review of planned improvements and evaluation of completed safety improvements should consider measures other than just accidents. The need for such an approach is particularly important for:

- Identification of hazardous locations on low-volume highways where the frequency of accident occurrences per year is very low.
- Assessment of safety improvement plans (design plans) in terms of potential benefits.
- Evaluation of completed highway safety improvements. Some safety engineers strongly believe that it is unreasonable to wait a long time (e.g., three years) to find out whether or not a safety improvement worked.

Thus, the deficiencies in the use of only accident data in the highway safety improvement process, are obvious and require further study and research. While considerable research has been expended in establishing relationships between accidents and various highway and operational characteristics on a piece-meal basis, it is essential that further research be directed toward identifying measures (highway and operational characteristics) other than accidents, which can be used in the overall highway safety
improvement process. The basic goal of the project, entitled "Accident Surrogates for Use in Analyzing Highway Safety Hazards", is to address a series of questions relative to the above problem. The specific questions may include but not be limited to:

- What are the highway, operational and accident characteristics which describe the hazardousness of specific highway situations?
- Do the surrogate measures selected on the basis of past research studies, exhibit sensitivity with accident history?
- Do safety improvements at a location change the accident characteristics as well as the surrogate measures?
- Can a set of methodologies using surrogate measures be developed for:
  - Identification and prioritization of hazardous locations?
  - Evaluation of completed highway improvement projects?
  - Assessment of effectiveness of design plans and specifications?

This paper presents an outline of the study approach, results of up-to-date progress and planned future direction.

Background

A large number of past studies have attempted to determine the relationship between geometric elements and highway safety in recent years. In fact, one publication alone summarizes 150 such studies conducted since 1953 (Traffic Control and Roadway Elements, Chapter 7, 1970). The basic premise in these studies is that accident occurrence generally decreases with the utilization of optimum design standards. Thus, it is assumed that geometric elements play an important role in assessing highway safety, and therefore, can be utilized in the assessment of accident potential.
One problem encountered in several of these studies is the inability to establish a specific relationship between accident occurrence and a particular geometric variable or combination of these variables. For example, Raff\(^1\) (1973) states in his conclusions that:

"The most striking feature of this study is the amount of irregularity in most of the results. Few of the data which have been presented in tables and graphs can be fitted by really smooth curves. There is considerable scatter about the overall trends, and it is quite likely that some subtle relationships have been masked by these irregularities.\(^1\)"

Another problem can be observed from the inconsistencies of research results. For example, Raff\(^1\) concluded that pavement width and shoulder width were somewhat related to accident rates at horizontal curves. He also concluded that shoulder width did not correlate consistently with accident rates. Whereas, Billion & Stohner\(^2\) concluded in a study, that roads when classified by grades, curvature and level tangent sections, indicated lower accident rates for highways with wider shoulders.

Studies of the relationship between traffic operations measures and accident occurrence appearing in the literature are fewer in number than those studies dealing with geometric elements. Nevertheless, there does exist a substantial number of these studies. Operational measures appearing in the literature range from stream characteristics such as average daily traffic (probably the most popular), speed characteristics, volume/capacity ratio, and measures of driver behavior such as traffic conflicts and erratic maneuvers.

Close examination of several of the studies of the operational measures indicate that inconsistencies also exist as in the case of the geometric studies. For example, analysis of several of the more recent traffic conflicts studies point out some very marked differences of opinion re-

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garding the validity of this indicator as a basis for predicting accident potential.

Study Approach

The research study has been broken down to the following specific tasks:

Literature Review

The purpose of this task is to perform a review of current and past studies, published papers and reports which investigated the relationships between elements of the traffic system (the roadway, the driver and the vehicle) and accident factors, which have proven relationships to accident occurrences. Due to the intended scope of this research project, primary emphasis will be placed upon investigation of pertinent prior efforts which:

- Establish a relationship between some measure or combination of measures, of accident experience and geometric elements and/or major traffic operations measures.
- Identify methodologies for assessing the effectiveness of various safety improvements.
- Identify measures or "checks" which can be used in the design phase to identify possible safety deficiencies.

Identify relationship between highway features/operating characteristics and accidents

The purposes of this research task is to:

- Describe theoretical relationships between highway design and operating characteristics and the probability of an accident occurring
or of increasing the severity of an accident.

. Identify surrogates for accident experience consistent with the defined relationships.

. Evaluate surrogates on a number of pragmatic criteria and select those most promising for use in highway safety studies.

**Testing selected surrogate measures**

Tests will be conducted to determine whether the surrogate measures identified in the previous task are statistically related to accidents prior to the development of the study methodologies.

One of the purposes of this task is to evaluate the relationship between accident measures and values of the surrogate measures identified earlier.

Another purpose of this part of the project is to determine whether a change in the surrogate measure is accompanied by a change in the accident experience at highway locations where a safety improvement(s) have been made.

**Develop methodology for using surrogate measures in safety analysis**

This task will develop three methodologies for using surrogate measures which are indicators of accident experience for the following type of analyses:

. Identification and prioritization of hazardous locations

. Evaluation of completed safety countermeasures

. Safety analyses of highway construction plans

**Test and refine surrogates and methodologies**

The purpose of this task is to test the three methodologies developed previously using actual data under real-world situations and modify and refine the methodologies wherever warranted.
Study Results

The project is only about 30% complete and as such no conclusive statements can be made as yet regarding the results of this study. The discussion in this section will be limited to the research tasks which have been fully and/or partially completed to date.

The review of the state-of-the-art and the experience of the project team has been utilized to develop a comprehensive list of the factors which have been found related to accident rates in the past. From this list of factors, which included both geometric as well as operational, an analysis was performed to determine a candidate list of factors to be considered in this study. It is important to point out that, this study did not attempt to develop a set of surrogates which are universally applicable to all situations. As such, a very specific set of situations were selected to be included in this study. 28 specific situations were selected as candidates for this particular study. They have been presented in Table 1. For each of these situations, an analysis was performed to find out which factors, both geometric as well as operational, have been related to or construed to be related to accident rates in the past. From this list of factors, it was obvious that it is not possible to pare it down to a manageable number of factors which can be used in performing further analysis. As such, five different safety indices under which all of these factors can be categorized were defined. These are; information index, human factors index, vehicle control index, congestion index and recovery index. The indices were defined as follows:

Information Index
This index will be a measure of the information system deficiencies which detract from the drivers ability to select a safe speed and path as roadway conditions change. The absence of lane markings and inadequate advance
# TABLE 1 - Candidate Situations

<table>
<thead>
<tr>
<th>Situation</th>
<th>Intersection Related</th>
<th>Roadway Section</th>
<th>Others</th>
</tr>
</thead>
</table>
| Urban     | - Urban Signalized Intersection  
- Urban Unsignalized Intersection  
- Pedestrian-Highway Grade Crossing | - Urban Undivided Tangent Section  
- Urban Undivided Winding Section  
- Urban Divided Winding Section  
- Continuous Two-Way Left Turn Lane | |
| Rural     | - Rural Signalized Intersection  
- Rural Unsignalized Intersection | - Rural Undivided Tangent Section  
- Rural Divided Tangent Section  
- Rural Undivided Winding Section  
- Rural Isolated Horizontal Curve | |
| General   | | | - Long Down-grades  
- Long Up-Grades  
- Exit Gore Area  
- Merge Area  
- Weaving Area  
- Tunnel  
- Narrow Bridges  
- Bridges  
- Rail-Highway Grade Crossing  
- Toll Booth |
warning signs are examples of factors that would contribute to a high information index.

**Human Factors Index**

This index will be a measure of the factors that increase the probability that a driver will enter a situation requiring evasive actions which exceed the man-machine response capabilities. A sharp horizontal curve following the crest of a vertical curve is an example of a factor that would contribute to a high human factor index.

**Vehicle Control Index**

This index will be 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 would contribute to a high vehicle control index.

**Congestion Index**

This index will be 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 number of driveways and parked vehicles along a roadway are examples which would contribute to a high congestion index.

**Recovery Index**

This index will be 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 which would contribute to a high recovery index.
The relationship of these indices can be described with the help of Figure 1. The information system provides data to allow the driver to select both the proper speed and path to negotiate a specific set of highway situations. A proper information system results in the driver identifying conditions on the roadway similar to the actual physical conditions. Similarly, a deficiency in the human factor index may result in drivers confronting a situation, to which they may not be capable of responding. When both of these indices are appropriate, the accident potential is minimized.

Individual vehicle control and traffic congestion may result in either a non-accident or an accident situation. The factors in these two indices with certain values determine whether a specific automobile on a roadway will end up in an accident situation or not. Once a situation occurs that vehicle control is lost or congestion characteristics become such that the vehicle approaches an accident, the driver may or may not be able to avoid the accident. The values of the factors under the recovery index represent the motorists' ability to steer the car back into control and/or reduce the severity of a crash.

Within each of the indices, the general category of factors were outlined for specific situations. It was observed that it is necessary to have these general category factors prioritized and also the individual indices prioritized for each specific situation because no consensus could be found directly from the literature. It was decided that a group of experts from across the nation would be selected to conduct a workshop to identify those factors and those groupings of highest importance for each specific situation. A workshop was conducted in the form of modified Delphi session to achieve this objective. The results of this workshop session assisted in identification of specific indices which are more significant and more
important for a specific situation and also within each indices the specific factors which are of more importance than the others.

The workshop session included participants ranking: 1) the situations which have most potential for analysis using surrogate measures, 2) the indices for each situation, and 3) factor groupings within each index for specific situations. A sample factor ranking form for urban signalized intersection (Figure 2) indicates how the factor groupings with influencing factors within parenthesis have been categorized under each safety index.

After the situations were identified by the workshop participants, an analysis was performed, identifying the type of most frequent accident for each particular situation and then searching through the literature as well as the experience of the research team to identify the probable causes of those accidents. These probable causes lead to the identification of the factors which had been identified through the workshop session as well as the state-of-the-arts review. Finally, these factors either singly or in combination with other factors, were identified as surrogate measures which can be used in highway safety analysis. It is important to point out that, all types of situations and surrogate measures are not amenable for all three types of analysis process (identification of hazardous location, review of the design plan, evaluation of safety improvements). A preliminary list of some operational measures which will finally be developed in the form of surrogate measures after adequate testing has been presented in Table 2. The next step of the study involves finalizing the list of surrogate measures and then performing analysis to relate measures to accident rates. The data base, which is planned for use includes 9,000 miles of highway network in the State of Michigan. Several sites will be selected for each of these situations to relate accident experience to the measures which have been identified through this study. Two types of statistical
**RANKING FORM**

Instructions: Under each index, rank order the list of categories according to the relative importance of the category in characterizing the degree of hazard for the situation listed below. The types of similar geometric, operational, traffic control and environmental factors which typically makeup each category are also provided in parenthesis for your reference. A ranking of one (1) indicates that the category and its factors are most important. Rank the remaining categories in descending order of importance.

**Situation: URBAN UNSIGNALIZED INTERSECTION**

<table>
<thead>
<tr>
<th>INFORMATION INDEX</th>
<th>HUMAN FACTOR INDEX</th>
<th>VEHICLE CONTROL INDEX</th>
<th>CONGESTION INDEX</th>
<th>RECOVERY INDEX</th>
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<tbody>
<tr>
<td>Pavement Marking (Channelization, Lane Lines, Marking Visibility)</td>
<td>Distractions (Visual Clutter)</td>
<td>Laneage (Left-Turn Lane, Right-Turn Lane)</td>
<td>Traffic (Traffic Volume, V/C Ratio, Peak Hour Factor, Available Gaps, Traffic Mix)</td>
<td>Vehicle Speed</td>
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<td>Signing (Street Name Signs)</td>
<td>Channelization (Unexpected Lane Assignment)</td>
<td>Sight Distance (Stopping Sight Distance, Cross Traffic Sight Distance)</td>
<td>Control (Intersection Control, Pedestrian Control, Parking Regulation)</td>
<td>Skid Resistance</td>
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<tr>
<td>Control (Pedestrian Control, Parking Regulations)</td>
<td>% Non-Local Traffic</td>
<td>Weather (Amount of Rain/Fog, Amount of Snow/Ice)</td>
<td>Control (Intersection Control, Pedestrian Control, Parking Regulation)</td>
<td>Geometrics (Number of Lanes, Curb and Gutter)</td>
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<td></td>
<td>Sight Distance</td>
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<td>On-Street Parking</td>
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<td>Bus Stop Location</td>
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Figure 2
<table>
<thead>
<tr>
<th>Situations</th>
<th>Surrogate Measures</th>
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</thead>
<tbody>
<tr>
<td>Exit Gore</td>
<td>Erratic maneuver, Mean speed of exiting vehicles at gore, Information system deficiency rating, Tire marks at gore, Crash barrier hits or dents</td>
</tr>
<tr>
<td>Narrow Bridge</td>
<td>Driver expectancy, Guardrail or bridgerail dents or marks, Physical evidence of encroachment, Information system deficiency</td>
</tr>
<tr>
<td>Rural Undivided Winding</td>
<td>Shoulder encroachment (physical evidence), Number of speed change cycles</td>
</tr>
<tr>
<td>Section</td>
<td></td>
</tr>
<tr>
<td>Urban Undivided Tangent</td>
<td>Curb cut related conflict rates per mile</td>
</tr>
<tr>
<td>Section</td>
<td></td>
</tr>
<tr>
<td>Urban Unsignalized Section</td>
<td>Cross traffic conflict, Critical speed, Gap distribution</td>
</tr>
<tr>
<td>Lane Drops</td>
<td>Information system deficiency, Driver expectancy, Average speed differential, Erratic maneuvers (run-on-shoulder, sudden lane change, sudden braking), Merge conflict, Physical evidence of driver error</td>
</tr>
<tr>
<td>Rural Isolated Horizontal</td>
<td>Information system deficiency, Driver expectancy, Average speed differential, Erratic maneuver, Physical evidence of driver error</td>
</tr>
<tr>
<td>Curve</td>
<td></td>
</tr>
<tr>
<td>Rural Signalized Intersection</td>
<td>Traffic conflict, Mean approach speed, Information system deficiency, Measure of traffic volume</td>
</tr>
</tbody>
</table>