Identification of Hazardous Locations on Rural Highways in Kentucky

Charles V. Zegeer
Kentucky Department of Highways

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MEMORANDUM TO: J. R. Harbison  
State Highway Engineer  
Chairman, Research Committee

SUBJECT: Research Report No. 392; "Identification of Hazardous Locations on Rural Highways in Kentucky," KYP-72-45; HPR-1(9), Part III

Our report No. 357 ("Evaluation of the High-Accident Location Spot-Improvement Program in Kentucky"), issued in February 1973, brought into circumspection the need for an evaluation of the criterion chosen in 1968 as an interim or temporary identification of high-accident sites. When the original criterion was chosen, it seemed understood that an evaluation would follow eventually. The report submitted herewith fulfills that objective. The criteria now recommended is based largely on analyses of histories and experiences gained in the Traffic Division’s "Spot-Improvement Program." Some insights and judgments were involved. The element of judgment will continue to be necessary and admissible from the standpoint of site investigations and action decisions.

In order to implement the "flagging" criteria proposed, a new computer program will be needed to compile and sort accident data. The at-desk analysis of "flagged" sites will require the use of traffic volumes and foreknowledge of reference indices.

This report, together with No. 357 and No. 378 ("Traffic Accident Reporting in Kentucky") completes a planned, package program of research related to safety.

Respectfully submitted,

Jas. H. Havens  
Director of Research

JHH:gd  
Enclosure  
cc’s: Research Committee
The purpose of this study was to determine the most effective method of identifying hazardous locations for on-site investigations. To decrease the possible effect of random or spurious accidents on the identification of hazardous locations, a 0.3-mile (0.48-km) segment was chosen along with 1- and 2-year periods for accumulating and comparing accident data. An optimal method for identifying hazardous locations and sections was determined to be one which (1) maximizes benefits from improvements, (2) identifies locations with critically high accident rates, and (3) identifies potential hazards. A sample of 170 locations was used to compare several location-identification methods. The procedure recommended combines a Number Method, EPDO Method, Rate-Quality Control Method, and objective input from citizens and state police. This procedure should be used to identify hazardous spots 0.3 mile (0.48 km) long and sections 1 and 3 miles (1.61 and 4.83 km) long which should be investigated in the field. A detailed plan for implementing such a procedure is also proposed.
IDENTIFICATION OF HAZARDOUS LOCATIONS
ON RURAL HIGHWAYS IN KENTUCKY

KYP-72-45, HPR-1(9), Part III

by

Charles V. Zegeer
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Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

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the author who is responsible for the facts and
the accuracy of the data presented herein. The
contents do not necessarily reflect the official
views or policies of the Bureau of Highways.
This report does not constitute a standard,
specification, or regulation.

June 1974
INTRODUCTION

Efforts to reduce the large toll of highway accidents include the identification and subsequent improvement of highway locations which are "dangerous" or "hazardous". The Kentucky Bureau of Highways has maintained a program for improving hazardous locations since 1968. Potentially hazardous locations have been identified as 0.1-mile (0.1-km) segments having three or more accidents in a 12-month period. A computer printout of these locations is prepared each month and screened in the central office to identify those locations most amenable to improvement under the spot-improvement program. The approximately ten percent identified for further study are then investigated more thoroughly in the field by teams composed of traffic engineers, maintenance engineers, and police personnel. Improvements recommended by the teams are then implemented through the spot-improvement program. Figure 1 summarizes the procedure for identifying and improving highway locations.

The current spot-improvement program in Kentucky has resulted in significant reductions in accidents and favorable benefit-cost ratios at locations where improvements have been made (1). However, despite the effectiveness of the overall program, the method for identifying hazardous locations has some potentially serious weaknesses:

1. considerable personal judgment is required in the preliminary office screening,
2. errors in accurately determining accident locations and the random or chance nature of accident occurrences are not properly taken into account, and
3. administrative costs may be excessive because approximately 36 percent of the locations investigated in the field from January 1, 1968, to June 30, 1971, did not warrant improvement.

The primary purpose of this study was to define and evaluate alternate methods for identifying hazardous highway locations. The lengths of highway segments and time periods to be used to define a hazardous location and for securing accident data must be selected. Warrants are recommended for the selection of highway locations and sections to investigate. In addition to accident records, human judgments should be considered as a possible warrant for highway improvements.
Figure 1. Current Spot-Identification-and-Improvement Program of the Kentucky Bureau of Highways.
BACKGROUND AND SIGNIFICANCE OF IDENTIFICATION METHODS

Federal assistance to state and local governments for improvement and expansion of local highway safety programs is a major aspect of the Highway Safety Act of 1966 (2). Uniform standards for highway safety program performance were released by the Secretary of Transportation on June 27, 1967 (3). A portion of these standards deals with identification and surveillance of accident locations:

"Each state, in cooperation with county and other local governments, shall have a program for identifying accident locations and for maintaining surveillance of those locations having high accident rates or losses."

In 1969, the FHWA issued Volume 9 of The Highway Safety Program Manual (4) to provide guidance to state and local governments in a systematic collection and review of accident data. The goal of the program is to take corrective actions at highway sites which give the "...best likelihood of producing significant improvements..." (4). Several considerations, including number of accidents, accident rates, and accident severity, were recommended to identify locations to be investigated for possible improvements. Also, "...preventative surveillance is recommended on highway locations by examination of potentially high-accident locations before they contribute to significant accident losses" (4).

Defining the Spot Length

To identify hazardous locations, the length of the spot or location must be defined. Kentucky currently defines a spot location as a 0.1-mile (0.16-km) segment of roadway, and state police reports of rural accidents locate an accident to the nearest 0.1 mile (0.16-km). The 0.1-mile (0.16-km) segment is also used in Florida, Idaho, Oklahoma, Virginia, California, and Connecticut (5, 6, 7, 8, 9, 10). A variable 0.1-mile (0.16-km) to one-mile (1.6-km) length is used in North Carolina (11). Michigan uses a 0.2-mile (0.32-km) segment (10) and Alabama's accident spot is defined as 0.4-mile (0.64-km) in length (12) (see APPENDIX A).

Choosing a Method to Identify Hazardous Spots

Several criteria, including those based on accident history, hazard indices, personal opinions, traffic congestion, and highway sufficiency ratings, can be used to identify potentially hazardous locations. As recommended by the FHWA, accident history is widely accepted as a primary determinant of hazardous locations (3). Personal judgment is most useful in identifying potential high-accident locations. Citizen complaints and field surveillance are considered for evaluations in Connecticut (10). Michigan considers traffic congestion as one criterion in establishing priority listings for intersection improvements (10). Virginia utilizes state trooper "hazard reports" to locate potentially high-accident locations (8). Locations identified in this manner tend to take precedence over those identified from accident history. A "wrong-way driving accidents and incidents" report is also used in Virginia by state police to identify
locations on interstate and divided highways subject to head-on collisions. Copies of these two report forms are included in APPENDIX B.

Several methods are now used by state transportation agencies for identifying hazardous highway spots based on accident histories:

1. number of accidents method,
2. accident rate method,
3. number of equivalent property damage only accidents (EPDO) method,
4. equivalent property damage only accident rate (EPDO rate) method,
5. rate-quality control method, and
6. various combinations of one or more of the above methods.

To use any of the methods, a critical accident indicator is defined and all locations with accident histories above that value are considered for investigation. Each state sets its own critical value depending on the number of locations that can be handled under the spot-improvement program and on other considerations. The initial value is affected by money, time, and manpower available for investigation and improvement of locations.

The number of accidents method utilizes a listing of hazardous locations ranked by the numbers of accidents occurring during a given period of time (10). This method has been used in Kentucky and California (9) with a critical number of three accidents in a 12-month period. Alabama uses the same method but the critical number of accidents is six per 12 months (12). Utah designates intersections as critical if ten or more accidents have occurred in the past year (10). In Michigan, the critical number is three or four accidents per month, depending on the geographic location of the highway within the state (10).

Locations may be compared by their accident rates, a quantity incorporating not only accident experience but also traffic exposure. The accident rate method, as used in Oregon, requires 2 1/2 years of accident data to insure stability of rate values. Accident rates are computed semi-annually in Oregon for the purpose of identifying hazardous locations. The critical accident rate chosen depends on the number of locations which can be handled (10).

The equivalent property damage only (EPDO) method combines accident experience at a particular location into a form that will reflect not only the number but also the severity of accidents. For purposes of this study, the number of EPDO accidents was determined from (1):

\[
\text{EPDO} = 9.5 (F + A) + 3.5 (B + C) + \text{PDO}
\]

where \(\text{EPDO} = \) number of equivalent property damage only accidents,

\(F = \) number of fatal accidents,
A number of A-type injury accidents, 
B = number of B-type injury accidents, 
C = number of C-type injury accidents, and 
PDO = number of property damage only accidents.

In addition to the EPDO method, other schemes for considering accident severity in the identification of hazardous locations have been used. Connecticut lists locations by numbers of accidents, but only counts accidents involving either a fatality or an A- or B-type injury (10). Oklahoma assigns a severity number of two for each PDO accident and a number of four to each fatal or injury accident and uses a "severity index" of eight or greater as the minimum value for including a location in its safety program (7).

The EPDO rate is computed by dividing the EPDO number by the corresponding traffic volume at a location. In North Carolina, all locations for which the numbers of accidents exceed a critical number are placed on the improvement program. However, priorities are assigned to these locations on the basis of EPDO rate (11).

A variation of the rate method is the rate-quality control method, which utilizes a statistical test to determine whether the accident rate at a particular location is abnormally high in relation to a predetermined mean rate for locations of similar characteristics (13). The statistical tests are based on the commonly accepted assumption that accident occurrences are approximated by the Poisson distribution (14). The critical rate or upper control limit is calculated as (15, 16)

$$U. C. L. = \lambda + k \sqrt{\frac{\lambda}{m}} + \frac{1}{2}m$$

where

- $U. C. L.$ = upper control limit (i.e., critical rate) for a particular highway location in accidents per million vehicles (or hundred million vehicles),
- $\lambda$ = overall average accident rate for locations of like characteristics in accidents per million vehicles (or hundred million vehicles),
- $m$ = number of vehicles traversing the location in million vehicles (or hundred million vehicles),
- and
- $k$ = probability factor determined by the level of statistical significance desired for the equation.

The $k$ value is determined by the level of probability, $P$, that an accident rate above $\lambda$ is abnormal, that is, sufficiently large and such that the high accident rate cannot be reasonably attributed to random occurrences. The prime determinant of the constant, $k$, is the number of hazardous locations that can be handled by a particular spot-improvement program. Selected values of $k$ are (15):

<table>
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<tr>
<th>$P$</th>
<th>0.995</th>
<th>0.975</th>
<th>0.950</th>
<th>0.925</th>
<th>0.900</th>
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<tr>
<td>$k$</td>
<td>2.576</td>
<td>1.960</td>
<td>1.645</td>
<td>1.440</td>
<td>1.282</td>
</tr>
</tbody>
</table>
States now using the rate-quality control method include Ohio, Florida, Idaho, and Virginia (13, 5, 6, 8).

The number-rate method is a combination of the number and the rate methods. It is usually applied by selecting either a number or a rate as the initial criterion and then ranking the resulting locations in order by the other accident indicator. Locations in Illinois are considered hazardous if they meet either a number criterion of 15 or more accidents per year or an annual accident rate exceeding three accidents per million vehicle miles (1.6 million vehicle kilometers) (10).

**Time Considerations for Choosing Hazardous Locations**

Of primary importance to hazardous location-identification schemes is the time period for accumulating accident statistics. The most commonly used period is one year. States using 1 year are Ohio, Florida, Idaho, Oklahoma, Virginia, Kentucky, California, and Utah (13, 5, 6, 7, 8, 1, 10). Michigan identifies hazardous locations based on the number of accidents in 1 month (10). States using longer accident histories include Oregon, using 2 1/2 years, and North Carolina, using 3 years (10, 11). Illinois bases priorities on either a 1-year or 2-year period (11).

**Classification of Locations**

Many states differentiate among various types of locations in their spot-improvement programs. In this manner, each location is compared to locations of similar geometric or functional features. Florida classifies route segments by location (urban or rural) and by type (interstate, two lanes, four or more lanes -- divided, and four or more lanes -- undivided) (5). Virginia classifies locations as two lanes, four or more lanes -- divided, four or more lanes -- undivided, freeways, and intersections (8). The detailed classification scheme used in Ohio follows (13):

1. Interchanges
   (a) diamond
   (b) full cloverleaf
   (c) three-leg
   (d) partial cloverleaf
   (e) full cloverleaf with collector-distributor road
   (f) half interchange
   (g) other
   (h) combination diamond and cloverleaf

2. Intersections by Control Sophistication
   (a) flashing device
   (b) fixed-time signal
2. cumulative net benefit,
3. average gross benefit,
4. average net benefit, and
5. benefit-cost ratio.

Cumulative gross benefit is the sum of accident costs after the improvements subtracted from the sum of accident costs before the improvements at all locations considered. Cumulative net benefit is equal to the cumulative gross benefit minus the sum of the costs of improvements (including administrative program costs) at all locations. Average gross benefit is the cumulative gross benefit divided by the number of locations. Average net benefit is computed by dividing the cumulative net benefit by the number of locations. Benefit-cost ratio is the ratio of the gross benefits to the cumulative costs for all locations.
SELECTION OF A TEST SAMPLE

To evaluate various methods for identifying hazardous locations, it is convenient and desirable to test a sample of hazardous locations representative of locations previously investigated in Kentucky. This sample should make it possible to compare various location-identification methods.

Since 1968, approximately 100 rural locations each month have exceeded the hazardous criterion (three accidents per 0.1-mile (0.16-km) segment of highway in the previous 12 months). An average of 10 percent of these were investigated in the field and about 60 percent of the investigated locations were later improved. A total of 613 field investigations were made at 578 locations from January 1, 1968, to June 30, 1971. Of these locations, 349 were improved and no improvements were recommended at 207 locations. There were 22 locations where improvements were recommended but not completed prior to June 30, 1971 (1).

These 578 locations were considered an appropriate set from which to choose a test sample. Each of the 578 locations was classified as either an IR location (one or more improvements made), a NIR location (improvement neither recommended nor made), or a NC location (improvements recommended but not completed).

To decide which of these 578 locations should be used to test identification methods, dates relating to the spot-improvement program must be understood:

1. "flagged" date -- date on which the location was initially considered to be a high-accident location (three or more accidents in the previous 12 months),
2. "memo to district" date -- date the location was brought to the attention of the highway district which had responsibility for initiating the field investigation (approximately 3 months after the flagged date),
3. "investigation" date -- date on which the location was investigated in the field by an investigating team (approximately 1 to 2 months after the memo-to-district date),
4. "start of construction" date -- date on which construction was started to improve a location, and
5. "completion" date -- date on which one or more improvements were completed at the location (approximately 10 months after the investigation date).

IR locations had dates corresponding to each of the five dates above. However, NIR and NC locations had no construction or completion dates.

To determine a practical "before" interval for the purpose of assessing benefits, it is important to select a period which would be representative of the long-term accident experience. It is also necessary to determine whether the before period should include the period between the flagged date and the
(c) semi-actuated signal
(d) fully-actuated signal
(e) stop sign

3. Other Locations
   (a) railroad crossing
   (b) bridge
   (c) curve
   (d) grade
   (e) restricted sight distance

Locations are classified as intersections or non-intersections in North Carolina and Oklahoma (11, 7). Idaho considers all spot locations together (6).

Highway Sections

Hazardous sections (long lengths of roadway) are identified in many states to supplement the identification of hazardous spots (short lengths of roadway). In many situations, an accident problem exists over a section of highway several miles (kilometers) in length. Hazardous sections are often not identified by a spot-identification method when accidents are spaced uniformly over several miles (kilometers). A hazardous section identification method would be needed to identify such situations.

Kentucky presently does not systematically identify highway sections which are unusually hazardous. However, highway sections are often studied at the request of district engineers or other people when long lengths of a highway appear to have unusually large numbers of accidents. Highway sections are often investigated when several closely spaced high-accident spot locations are identified.

Several other states identify hazardous highway sections based on accident data. Oregon identifies a section by a fixed 1-mile (1.60-km) length (10). Sections are also identified as a length greater than 0.5 mile (0.80-km) in Ohio (13), greater than 0.11 miles (0.18 km) in Virginia (8), greater than 1.0 mile (1.60-km) in Florida (5), greater than 1.1 miles (1.76 km) in North Carolina (11), and "variable" in Oklahoma (7) (see APPENDIX A).

Methods of identifying hazardous sections also vary widely in different states. Warrants for hazardous sections in Oregon, Florida, and Idaho require the accident rate to exceed the critical rate of a particular roadway classification (10, 5, 6). Number criteria for sections include five accidents per year in Virginia (8) and eight accidents per year in Oklahoma (7). In North Carolina, a section must have 25 accidents per year and exceed the critical rate (11). A hazardous section in Ohio is identified by having more than four accidents, more than 1.5 times the average accident rate, and accidents no greater than 0.5 miles (0.80 km) apart (13).
No specific categories of sections are used for identifying hazardous sections in North Carolina, Idaho, Illinois, and Oregon (11, 6, 10). Classification by numbers of lanes are made in Oklahoma, Virginia, and Florida (7, 8, 5). Ohio (13) classifies sections as total-accident sections, wet-pavement sections, inadequate-shoulder sections, and conflict-of-right-of-way sections.

Use of Benefit Data for Evaluating Methods

A major consideration for choosing a preferred program to identify hazardous locations is the potential of deriving maximum benefits at locations where improvements are made. The term "benefits," as used in this report, is defined as the monetary savings incurred after improvements are made at a location. It is computed by subtracting accident costs after an improvement from accident costs before the improvement. One to three years of accident data are generally used for the "before" period and at least 1 year is considered for the after period. However, accident data used for the before period must be converted to a time period equal to the after period to express benefits.

Benefits derived from highway improvements may be expressed as either direct benefits or total benefits. Direct benefits are computed from direct accident costs. Direct costs of motor vehicle accidents include property damage, medical costs, loss of vehicle use, value of work time lost, legal costs, and others.

Values of direct costs used in this report are (1):

<table>
<thead>
<tr>
<th>INJURY TYPE</th>
<th>DIRECT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDO-type accident</td>
<td>$585 per accident</td>
</tr>
<tr>
<td>A-type accident</td>
<td>$4570 per accident</td>
</tr>
<tr>
<td>B-type accident</td>
<td>$2635 per accident</td>
</tr>
<tr>
<td>C-type accident</td>
<td>$1525 per accident</td>
</tr>
<tr>
<td>F-fatal accident</td>
<td>$9880 per accident</td>
</tr>
</tbody>
</table>

Total costs include both direct and indirect costs of an accident. Indirect costs consist mainly of losses of future earnings. The following total accident costs for 1970, as determined by the National Safety Council, were used in this report (17):

<table>
<thead>
<tr>
<th>INJURY TYPE</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDO-type accident</td>
<td>$400 per accident</td>
</tr>
<tr>
<td>Non-fatal injury</td>
<td>$2,700 per injury</td>
</tr>
<tr>
<td>Fatality</td>
<td>$45,000 per fatality</td>
</tr>
</tbody>
</table>

There are several possible measures of merit that can be used to express direct or total benefits for a combination of two or more locations:

1. cumulative gross benefit,
To gain insight into this question, letters were sent to representatives of four states -- Virginia, North Carolina, Florida, and Idaho -- with relatively advanced accident analysis techniques. Idaho, North Carolina, and Florida base "before" data on the date construction begins and "after" data on the date construction is completed (18, 19, 20). Virginia uses the date of improvement completion as a reference date for both before and after periods (21).

It was felt, however, that a more meaningful and representative "before" period would be referenced from the "flagged" date. Accident data preceding this date was that which initiated action to be taken at the location. A period of 2 years was selected for gathering accident data before the flagged date. An interval of 1 year after the completion date was then chosen to represent the after experience at each location. Because of the limitations in available accident records and the history of the spot-improvement program (it began January 1, 1968), locations were chosen for inclusion in the test sample that had a flagged date and a completion date between January 1, 1969, and June 30, 1971.

Only 170 locations included in the spot-improvement program fit the date requirements of this study. Eighty-six of these were IR locations and 84 were NIR's. Pertinent data for the 170 locations are summarized in APPENDIX C. Detailed comparison of accident data revealed that the 170 locations chosen for the test sample were in fact representative of all 578 locations investigated under the spot-improvement program from July 1, 1968, to June 30, 1971.
TREATMENT OF RANDOMNESS IN LOCATION IDENTIFICATION

A problem in identifying locations which need improvement (based on accident data) has to do with the occurrence of random accidents. Accidents may occur as a result of vehicle defects or driver error and are thus unrelated to physical deficiencies of the roadway. When the number of such random accidents is large at a particular highway location for any given time period, the spot may erroneously be identified as hazardous. Thus, needless and expensive field investigations may be made at such locations.

A careful study of all accident reports may help the traffic engineer to label certain accidents as random. However, many accident reports are not detailed enough to permit such conclusions. Also, accidents reported as resulting from driver inattentiveness may or may not have been related to roadway deficiencies. While it may be virtually impossible to determine whether every accident is related to roadway deficiencies, it is possible to minimize the effect of random occurrences of accidents on identifying hazardous locations (1) by carefully defining the length of highway segments for use in assimilating accident data and (2) by carefully choosing a time interval (or intervals) to use for accident data collection.

Optimal Spot Length

A major factor to consider in developing an optimal system of location identification involves the selection of the length of roadway to be used to define a location. A 0.1-mile (0.16-km) segment is currently used in Kentucky to identify hazardous sites (intersections and non-intersections). The location of an accident is provided on each accident report relative to milepost markers, which are located every mile (1.6 km) on interstates and parkways and at irregular intervals on other state-maintained roads.

Because the distance between adjacent milepost markers on many non-interstate rural roads in Kentucky is sometimes several miles (kilometers), reporting of an accident location to the exact 0.1-mile (0.16-km) point is often impossible. Even on interstate routes, distances between milepost markers are 1 mile (1.6 km) and reporting errors of at least 0.1 mile (0.16 km) could easily occur. A 0.3-mile (0.48-km) segment would allow for reporting errors of 0.1-mile (0.16 km) on either side of a 0.1-mile (0.16-km) location.

A second advantage of using segment lengths of greater than 0.1 mile (0.16 km) relates to the area of influence of an accident location. For example, accidents on a dangerous curve usually do not occur at the same 0.1-mile (0.16-km) point. A slippery bridge could cause an accident on the bridge itself; another accident may occur several hundred feet (meters) beyond the bridge. Thus, the area of influence of a particular highway hazard is often greater than 0.1 mile (0.16 km). A segment of 0.3 mile (0.48 km) would more closely approximate the area of influence of a highway hazard than a length of 0.1 mile (0.16 km).
Another consideration affecting determination of an optimal segment length is the effect of segment length on the computation of benefits derived from safety improvements. Table 1 shows summary results useful in comparing 0.1-mile (0.16-km) and 0.3-mile (0.48-km) segments. As is plainly evident, computed benefits increase with increases in segment length from 0.1 mile (0.16 km) to 0.3 mile (0.48 km). As some larger segment length is approached, the computed benefits should become stabilized about a constant value representative of actual benefits achieved as a result of safety improvement. It is, therefore, essential to use as large a segment length as is practical in evaluating safety improvements.

Probability considerations can also be used to compare segment lengths. Assume the number of accidents closely approximates a Poisson probability distribution \( P(n = x) = e^{-a} a^x / x! \)

where \( P(n = x) \) = probability that the number of accidents \( (n) \) occurring at a location during a given time period is equal to \( x \),

\( e = \) constant = base of natural logarithms = 2.7183, and

\( a = \) average number of accidents at a particular location.

One objective in selecting a technique for identifying hazardous locations is to minimize the probability of identifying a safe location as being hazardous. The following example, which is based on the Poisson distribution, serves to illustrate that this objective can be achieved by using longer segment lengths.

The critical number of accidents used in the example is three accidents per 0.1-mile (0.16-km) segment per year, or for the purpose of comparing segment lengths, 30 accidents per mile (1.6 km). Thus, if a segment has a "long-term" average of 30 or more accidents per mile (1.6 km), it is by definition a hazardous segment. In Figure 2, the probability that a location has 30 or more accidents per mile (1.6 km) during a given 12-month period is plotted against segment length. Individual curves are shown for locations having different "long-term" average accident histories. The probability of correctly identifying truly hazardous locations (such as those represented by the curves for averages of 50, 40, 35, and 30 accidents per mile (km)) as being hazardous is generally increased as segment length increases. Furthermore, the probability of incorrectly identifying "safe" locations (such as those represented by the curves for averages of 25, 20, and 10 accidents) as being hazardous is decreased as segment length increases. It is apparent, therefore, that errors in identifying hazardous locations caused by the random nature of accident occurrences can be minimized by using longer segment lengths.

On the basis of the above considerations, it was concluded that the optimal segment length for identifying hazardous locations is greater for 0.3 mile (0.48 km) than 0.1 mile (0.16 km). While other segment lengths may also be acceptable, the 0.3-mile (0.48-km) segment appears to be the best for use
TABLE 1

COMPARISON OF BENEFIT DATA FOR 0.1- AND 0.3-MILE (0.16- AND 0.48-km) SEGMENTS

<table>
<thead>
<tr>
<th>MEASURE OF BENEFITS&lt;sup&gt;a&lt;/sup&gt;</th>
<th>SEGMENT LENGTH (mile)</th>
<th>SEGMENT LENGTH (km)</th>
<th>DIRECT BENEFITS&lt;sup&gt;b&lt;/sup&gt;</th>
<th>TOTAL BENEFITS&lt;sup&gt;b&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.1</td>
<td>0.16</td>
<td>$874</td>
<td>$2167</td>
</tr>
<tr>
<td>Gross Benefits</td>
<td>0.3</td>
<td>0.48</td>
<td>1310</td>
<td>2799</td>
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<tr>
<td>Average</td>
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<td>0.16</td>
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<tr>
<td>Net Benefits</td>
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<td>0.48</td>
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<tr>
<td>Benefit-Cost Ratio</td>
<td>0.1</td>
<td>0.16</td>
<td>1.20</td>
<td>2.98</td>
</tr>
</tbody>
</table>

<sup>a</sup> For one year.

<sup>b</sup> Computations based on 2 years of "before" data and 1 year of "after" data.

---

**ANNUAL ACCIDENTS EXPECTED**

**PER MILE**

<table>
<thead>
<tr>
<th>Length of Highway Segment</th>
<th>Probability</th>
<th>Probability</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>0.104</td>
<td>0.902</td>
</tr>
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<td>20</td>
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<td>0.948</td>
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<td>30</td>
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<tr>
<td>40</td>
<td>0.009</td>
<td>0.991</td>
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</table>

**PER KILOMETER**

<table>
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<th>Length of Highway Segment</th>
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**LENGTH OF HIGHWAY SEGMENT**

Figure 2. Effect of Length on the Probability of Identifying Hazardous Locations.
EVALUATION OF OPTIMAL METHODS FOR LOCATION IDENTIFICATION

To determine which method(s) should be used to identify hazardous highway locations, the objectives of a desirable method needed to be carefully formalized. An optimal method should

1. minimize administrative costs of the spot-improvement program by reducing the number of locations identified but for which improvements are not warranted,
2. increase the efficiency of the program by better identifying those locations for which improvements will yield the maximum benefit per dollar spent,
3. identify locations which are geometrically or functionally hazardous:
   a. locations which have critically high accident rates
   b. locations which do not have a high accident occurrence but are potential high-accident locations, and
4. minimize time and expense of implementation and operation.

Critical Number of Accidents Criterion

The use of a number-of-accidents warrant is practiced in several states as a preliminary screening technique for choosing hazardous locations. Some states then apply another method (such as EPDO rate or rate-quality control) to determine which locations to investigate in the field. Other criteria, such as EPDO or accident rate, could be used as an initial warrant. However, use of a number criterion permits easy determination of locations for the spot-improvement program without calculating accident rates or EPDO numbers for every location in the state each month.

Kentucky’s number criterion of three or more accidents per 0.1-mile (0.16-km) segment per 12 months identifies approximately 100 locations per month. Accident reports at these locations are manually reviewed to determine accident causes, and about ten of these locations are investigated each month. Although the method of choosing the ten locations may have certain disadvantages, use of the initial accident criterion has several advantages. The criterion of three accidents per 12 months per 0.1 mile (0.16 km) is low enough so that a large sample of locations will be chosen each month. Thus, the chances of overlooking hazardous locations are minimized. The criterion is high enough to limit the number of locations to a manageable number (≈ 100 per month).

Since the 0.3-mile (0.48-km) segment has been suggested as being more desirable, the accident criterion might be changed to yield approximately the same number of locations each month. The number of accidents for a 0.1-mile (0.16-km) segment can be compared to the number of accidents for a 0.3-mile (0.48-km) to convert the number criterion to a 0.3-mile (0.48-km) segment. Since 1968, the 578 locations investigated had 2080 accidents for the 0.3-mile (0.48-km) segment and 1244 accidents for the 0.1-mile (0.16-km) segment in the 1-year before period. The ratio of 0.3-mile (0.48-km) accidents to 0.1-mile
(0.16-km) accidents was 1.672. The three accidents criterion for the 0.1-mile (0.16-km) segment is approximately equivalent to 3 x 1.672 = 5.02 or five accidents per 0.3-mile (0.48-km) segment per year. Thus, an initial accident criterion for the 0.3-mile (0.48-km) segment would be five accidents per 12 months.

Since the 2-year period has been proposed for use in identifying locations with high long-term accident occurrences, a number criterion should also be used based on a 2-year period. The 2-year accident criterion is intended to identify locations not flagged by the 1-year criterion. A location with nine or more accidents in 2 years would be flagged by the 1-year criterion. Thus, a 2-year number of accidents around six to eight appears to be a good choice. The number seven is recommended for use as an initial 2-year number criterion.

Values chosen for the number criterion for 1- and 2-year time intervals are important only for the number of locations they identify each month. Thus, they can and should be altered periodically to identify a manageable number of locations. Because of the recommended expansion of spot length and use of a 1- and 2-year period, the number of locations expected to be identified each month is more than 100.

**Benefit Analysis of Methods**

Another major factor in choosing an optimal method(s) for identifying hazardous highway locations is the consideration of potential benefits. The four major location-identification methods were compared for benefit potential as determined from the test sample (170 locations). To determine the optimal manner of expressing benefits (measures of merit), three criteria were established. The measure of merit should exhibit stability and data sensitivity and be philosophically sound. Applying these criteria to choose between various benefit alternatives, the following conclusions were reached:

1. Direct benefits are preferable to total benefits for comparing location-identification methods.
2. The average of the first and the second year of accident data before the flagged date is preferable to using only one of the two years to represent the "before" accident history of a location.
3. For the purpose of comparing location-identification methods, the benefit-cost ratio and average net benefits are preferable to cumulative net, cumulative gross, and average gross benefits.

A detailed description of the evaluation of measures of economic efficiency is given in APPENDIX D.

Benefits were expressed as direct benefits; the benefit-cost ratio and average net benefits were used as the measures of merit. Average annual benefits were used to compute benefit-cost ratios and average net benefits. They were calculated by subtracting accident costs 1 year after the completion date from the average accident costs before the flagged date. Two years of accident data was available for calculation of the annual "before" cost.
in Kentucky for identifying hazardous locations. This length is sufficiently short that qualified field teams should have no difficulty in identifying accident-causeative features within the segment. For optimal efficiency, a "floating" 0.3-mile (0.48-km) segment should be used.

**Optimal Time Interval**

The choice of the length of accident history to use is important in selecting an optimal identification method. Methods used in several states (see APPENDIX A) show a range of from 1 month in Michigan to 3 years in North Carolina \(10, 11\). A short accident history is useful in identifying locations which have sudden rashes of accidents and may need immediate improvements. However, a minimum of 1 year of data is preferred because of seasonal variations associated with shorter time periods. Use of a longer time period gives a better long-term accident comparison of locations and may minimize the effect of randomness. States such as Illinois, Oklahoma, and North Carolina use a combination of two or more time periods to identify hazardous locations. This has the advantage of identifying locations with long-term accident histories and as well as those sites with sudden increases in accident occurrences.

Assuming accidents fit the Poisson distribution over time, a set of curves was drawn to show the probability of a location having three or more accidents per year (per 0.1 mile (0.16 km)) for periods of 0.33 years to 5 years. The shapes of the curves in Figure 3 are similar to those in Figure 2 and use the Poisson formula given previously. The curves show that probability levels increase as the time interval increases for most locations having over three accidents in any particular year. The use of 2 to 5 years of accident data will give from a 93-percent to 99-percent probability (respectively) that a location will be identified as being hazardous for locations having a long-term average of five accidents per year.

The advantage of using several years of accident data for identifying hazardous locations is the stability achieved. Some disadvantages are the practical limitations of keeping accurate accident data for all accident locations for several years. Also, sudden changes in conditions of locations may require immediate improvements so further accidents can be minimized. Thus, some form of a dual time period is preferred. A combination of a 1-year with a 2-year period is proposed for use in Kentucky. The 1-year period would "flag" locations with sudden rises in accident occurrence. A 2-year period would identify locations with serious, long-term, high accident experiences. An advantage of the 2-year period over a longer interval is that accident records would not have to be maintained for an excessively long time. Also, highway surfaces, environment, volumes, and other driving factors are likely to change substantially after several years, so that accident data more than 2 years in the past may not be representative of present conditions.
Figure 3. Effect of Time Period on the Probability of Identifying Hazardous Locations.
Figures 4 and 5 show the four location-identification methods plotted for benefit-cost ratio and for average net benefits, respectively. To plot the points, the 170 locations were ranked by each of the four methods in order from highest to lowest accident experience. Benefits corresponding to the rank of locations for each method were then plotted. In each graph, all curves must converge to one point since the benefits of all 170 locations were used in each method. The best method in this type of analysis is the one which assumes the highest benefit level for all the locations, particularly at high ranks (low numbers on the "Rank of Locations" scale).

In Figure 4, the EPDO Method claims the largest benefit-cost ratio at nearly every point. The EPDO Rate Method is clearly the second best method with the Number Method and Accident Rate Method placing third and fourth, respectively. The average net benefit analysis (Figure 5) also shows the EPDO Method to be superior. The ordering of the other three methods shows the EPDO Rate Method to be second best for the first 140 locations after which it narrowly surpasses the EPDO Method for the last 30 locations. The Number Method is again the third best method, and the Accident Rate Method is fourth.

The benefit analysis shows the EPDO Method to be the best of the four methods. This conclusion is logical since benefits are computed from accident costs, and the EPDO number for a location is directly related to its accident costs. Thus, to identify locations having the maximum potential for deriving benefits (reducing accident costs), the EPDO Method should be used.

**Cutoff Value for EPDO Method**

Since the EPDO Method was chosen as the best for choosing locations with high benefit potentials, it was necessary to establish a cutoff EPDO value which would be used to warrant a field investigation at a location. The prime determinant in the choice of an EPDO cutoff value was what minimum value will identify locations which yield positive benefits if improved.

To select such a cutoff EPDO value, Figures 6 and 7 were drawn using cumulative net direct benefits for 1 year and 2 years of data, respectively. Cumulative benefits are used instead of average benefits for this evaluation because the cumulative curve should initially increase as locations are ranked in order from highest EPDO. When the curve peaks, the EPDO corresponding to that point represents the value above which locations have positive benefits. Using 1 year of data, the EPDO cutoff value corresponding to positive benefits was 12.5. For the 2-year case, the approximate EPDO value was 21.5.

To assure maximum benefits, the EPDO Method should be used with cutoff values of 12.5 and 21.5 for 1 and 2 years of accident data, respectively. With the limited number of locations used in this evaluation, these EPDO cutoff values are recommended as a guide to use until they can be further
Figure 4. Comparison of Benefit-Cost Ratios for Four Methods.
Figure 5. Comparison of Average Net Benefits for Four Methods.
Figure 6. Determination of an Optimal EPDO Cutoff Value for 1 Year.
Figure 7. Determination of an Optimal EPDO Cutoff Value for 2 Years.
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Consideration of Other Methods

Besides maximizing benefits, there are several other objectives of a good method (or methods). Although the EPDO Method is good for maximizing benefits, it is not necessarily sensitive to locations with abnormally high accident rates as are the various accident rate methods. However, methods using only a pure accident rate for comparing locations may give undesirable results because locations with only one or two accidents per year with very low traffic volumes (less than 1000 AADT) will have very high accident rates. Locations with heavy volumes (over 20,000 AADT) and high numbers of accidents will often have low accident rates. Thus, the Accident Rate Method often indicate low-volume locations should have highest priority for investigation.

The Rate-Quality Control Method uses accident rates but applies a statistical test to determine whether the accident rate is significantly abnormal (critical) for sites of like characteristics. Low-volume sites must have larger accident rates than high-volume locations to be considered critical. As stated earlier, the formula for determining critical locations with this method is

\[ \text{U.C.L.} = \lambda + k \sqrt{\frac{\lambda}{m}} + \frac{1}{2m}. \]

To apply the Rate-Quality Control Method in Kentucky, statewide average accident rates were computed for five major highway classes for 0.3-mile (0.48-km) rural segments (22):

- \( \lambda(\text{two-lane}) = 0.72 \) accidents/million vehicles,
- \( \lambda(\text{three-lane}) = 0.73 \) accidents/million vehicles,
- \( \lambda(\text{four-lane, undivided}) = 0.94 \) accidents/million vehicles,
- \( \lambda(\text{four-lane, divided}) = 0.47 \) accidents/million vehicles,
- \( \lambda(\text{interstate and parkway}) = 0.25 \) accidents/million vehicles.

Values of \( k \) are chosen depending on the probability level, \( P \), that a location has a critical accident rate with a given volume. As the probability level (\( P \)) decreases to 50 percent, the value of \( k \) approaches zero. As the traffic volume increases and the probability decreases, the upper control limit (U.C.L.) for a location approaches the overall average accident rate (\( \lambda \)) for that type of highway. Thus, all locations with an accident rate greater than average would be considered critical. The \( k \) value selected for use in the equation depends upon the number of locations desired for investigation. Florida (5) and Ohio (13) use a \( k \) of 2.576 and Oklahoma's is 1.645 (7). As more time, money, and manpower become available, the \( k \) value can be reduced to allow consideration of locations which have a lower probability of being identified as hazardous.

For each highway class, an upper control limit (U.C.L.) curve can be derived by substituting different
values of annual volume (m) into the rate-quality control equation and plotting the points on a graph. If annual volume or AADT is plotted on the X-axis and accident rate on the Y-axis, a set of upper control limit curves can be derived for each highway class and probability level for 0.3-mile (0.48-km) spots.

Figure 8 illustrates the upper control limit curves for five probability levels on two-lane roads. Points lying above an upper control limit curve are considered critical. As the probability level increases, the accident rate required for a location to be critical also increases. The important point is that locations with low volumes require higher accident rates than high-volume locations to be critical (above the upper control limit).

Since the probability level to use for the Rate-Quality Control Method depends on the number of locations that can be considered for field investigations, a reasonable approach to the problem is to initially choose a high probability level like 99.5 percent. All locations meeting the number criterion (five accidents per year or seven accidents in 2 years) would be tested by the EPDO Method. All locations meeting these criteria would be placed on the list of locations to investigate. Locations meeting the number criteria but not the EPDO criteria would be tested by the Rate-Quality Control Method. Locations with critical accident rates would then be placed on the list of locations to be investigated.

To most easily apply the Rate-Quality Control Method, each location should be placed into one of five roadway classifications. A set of curves has been drawn for quick and easy analysis of each type of location. Figure 9 shows these curves for a P of 99.5 percent. Accident rate is plotted against AADT (converted from annual volume) for locations of 0.3-mile (0.48-km) segments. To use the curves, the accident rate of a location and its AADT must be known for the previous year. The point is found on the graph and the location is considered hazardous if it lies above the appropriate upper control limit curve.

Similar curves for a probability level of 99.5 percent for 2 years of data were plotted in Figure 10. They are similar in shape to curves in Figure 9, except the accident rate required to exceed the upper control limit is less demanding. They were derived using the same k and λ as the 1-year curves. However, the m values used for the 2-year curves are twice as large as those for 1 year (approximately twice the total volume). In Figures 9 and 10, the four-lane, undivided roadway curve is the highest, followed by two- and three-lane roads which have nearly equal statewide accident rates. Four-lane, divided segments require the third highest accident rates, and interstate and parkways are the lowest.

One important advantage of the Rate-Quality Control Method over other methods is the built-in technique to update it whenever desired. The λ value can be easily determined for each roadway classification annually since total numbers of accidents and total vehicle miles (kilometers) are annually
Figure 8. Upper Control Limit Curves for 0.3-Mile (0.48-km) Spots on Two-Lane Rural Kentucky Roads for Five Probability Levels.
Figure 9. Upper Control Limit Curves for Five Highway Classifications of 0.3-Mile (0.48-km) Spots on Rural Kentucky Roads for 1 Year ($P = 99.5$).
Figure 10. Upper Control Limit Curves for Five Roadway Classifications of 0.3-Mile (0.48 km) Spots on Rural Kentucky Roads for 2 years (P = 99.5).
calculated by computer. Also, a rate method is of little practical use without critical values expressed as a function of volume.

Although the Rate-Quality Control Method is used in several states, there are possibilities for the use of other quality control methods. It is also conceivable to apply control techniques to EPDO and number criteria. The use of a Number-Quality Control Method can easily be derived from the U.C.L. formula by multiplying both sides of the equation by traffic volume and expressing the upper control limit in terms of number of accidents. This equation would give identical results as the other form of the equation. The meaning and use of an EPDO-quality control equation is somewhat unclear at this time, but such applications of the upper control limit equation should be studied in more detail.

**Intuitive Judgments in Identifying Hazardous Locations**

Locations may become geometrically or functionally dangerous as traffic or roadway conditions change. Such locations cannot always be identified by accident data. However, if they are not improved, a rash of accidents may result. To avoid such occurrences, it is often helpful to identify potential high accident locations by methods in addition to analysis of accident records.

One method of identifying potential high accident locations without using accident records is by citizen input. This may sometimes be unreliable, but accurate records of complaints could be helpful if several complaints are directed toward the same location. Another method is to use state police input. As stated before, Virginia utilizes information from police hazard reports. Although a small number of locations are identified each year by Virginia police, these locations usually take precedence over locations identified by accident experience. State police in Kentucky are usually assigned to patrol the same county for several years, so they are usually quite familiar with unsafe highway conditions.

Reports concerning unsafe locations could be made by police to engineers by telephone or by written report. Advantages of each method should be carefully considered. The important thing is to have some form of continuing input from police. The careful consideration of citizen input could also be a very helpful mechanism in identifying locations for field inspection.

Another occurrence that should warrant consideration of an investigation is a fatal accident. Under the recommended method for identifying locations, five accidents in 1 year or seven accidents in 2 years are required to initially flag a 0.3-mile (0.48-km) location. Thus, the occurrence of four fatalities in a sample location in a year would not justify inspection under this warrant. Because of the great tragedy of a fatal accident, a special report is completed by state troopers for every highway fatality. This report includes comments as to possible highway hazards that might have contributed to the accident.

Fatal accident reports should be studied in the office to identify locations which need improvements. Many fatalities will occur as a result of obvious human or vehicle error such as drinking, speeding, tire
blowout, brake failure, etc. These fatalities may have no practical solution from a highway improvement point of view. However, fatalities caused by possible highway deficiencies such as sharp curves, slick pavements, narrow bridges, and others should be strongly considered for investigation. Thus, a single fatal accident at a location should warrant consideration of a field inspection.

**Spot Identification Procedure**

An optimal spot identification procedure has been suggested in stages in this report. The first step is to define a spot a 0.3-mile (0.48-km) long segment of highway. All spots with five accidents in the past 12 months or seven accidents in the past 2 years should be initially flagged. Locations so identified would be considered by two other methods. Each location should be tested first by the EPDO Method using a cutoff value of 12.5 for 1 year or 21.5 for 2 years. Locations meeting either of these warrants will be placed on a list of locations to be investigated in the field.

Locations not meeting the EPDO warrant should be tested by the Rate-Quality Control Method. This can be done quickly by locating the point representing the accident rate and AADT of the location on Figure 9 or 10 (for 1 or 2 years of data, respectively). Locations exceeding the appropriate curve should also be placed on the list of locations to be investigated.

All locations identified by police input, citizen input, or the occurrence of a fatality should be carefully reviewed. Locations believed to be hazardous should also be added to the investigation list. Locations meeting any one of the warrants should be screened in the office to eliminate locations previously investigated or improved. (Reinvestigations may be desired for certain problem locations.) All remaining locations should then be investigated in the field by the state investigation team.

Past improvements by Kentucky's spot-improvement program have proven to be very beneficial in accident reduction (1). However, this new procedure should help to decrease administrative costs by using a quick procedure for identifying locations to consider for improvement. The method used now involves study of each accident report at all locations meeting the three accident (per 12 months per 0.1-mile (0.16-km) segment) criteria to find related accident trends. The new program should save many hours in obtaining an investigation listing, and there will be more administrative time and money to be used for considering an additional number of locations each month.

Since recommendation of corrective measures at a location may often be quite difficult, a guideline, recommended by Pignataro (23), of possible improvements for eight different types of accidents is given in APPENDIX E. This list is not meant as a set of rules or procedures that must be done but only as a guideline to use in addition to engineering judgment by an investigation team.
IDENTIFICATION OF HAZARDOUS HIGHWAY SECTIONS

Highway sections are essentially no different from locations (spots) except that they are defined by a greater length. Thus, there is no real justification for identifying them by methods different from those used to identify spots. An efficient way of identifying hazardous sections based on accident data is to let one or more fixed section lengths "float" through accident records to pick out areas of high accident experience. Several states use a fixed 1-mile (1.6-km) section which has been found to be reasonable for locating problem areas. However, to identify sections which are hazardous over a greater length, a 3-mile floating section appears to be a good length. Maintenance sections used in Kentucky are typically about 3 miles in length. This is because highway sections of 3 miles or less usually can be associated with homogenous geometries and traffic volumes. Thus, the use of floating 1-mile and 3-mile sections is practical.

Continuing the logic of a number cutoff for sections as for spots, warrants need to be made for initial section identification. Considering average accident densities on Kentucky roads, judgment would favor the use of a cutoff number of accidents of approximately 10 per mile (6.3 per kilometer) per year and 20 per 3 miles (12.5 per 3 kilometers) per year. Warrants of 15 accidents in 2 years for 1-mile (1.6-km) sections and 30 for 2 years for 3-mile (4.8-km) sections are proposed and were derived from the approximate ratios of 1-year accident warrants to 2-year accident warrants for spots.

After identifying sections which meet the 1- or 2-year warrants for 1-mile (1.6-km) or 3-mile (4.8-km) sections, the EPDO criterion should then be applied. Again using judgment with consideration given to the ratio of (EPDO warrant)/(number warrant) for spots, recommended EPDO criteria for 1-mile (1.6-km) sections are 25 and 40 for 1 and 2 years, respectively, and 50 and 75 for 3-mile (4.8-km) sections. Thus, sections identified by the number criterion should be tested by the EPDO criterion. Sections meeting these warrants should be placed on a list of sections to be investigated. Sections meeting the number criterion but not the EPDO criterion should then be tested by the Rate-Quality Control Method.

To apply the Rate-Quality Control Method to sections, the same formula is used as with spots:

$$U.C.L. = \lambda + k \sqrt{\lambda/m} + 1/2m,$$

where m is expressed here as accidents per million vehicle miles (1.6 million vehicle kilometers). Average accident rates for each of five highway classifications in Kentucky are (22):

- \(\lambda\) (two-lane) = 2.39 accidents/million vehicle miles (1.6 million vehicle kilometers),
- \(\lambda\) (three-lane) = 2.44 accidents/million vehicle miles (1.6 million vehicle kilometers),
- \(\lambda\) (four-lane, undivided) = 3.13 accidents/million vehicle miles (1.6 million vehicle kilometers),
- \(\lambda\) (four-lane, divided) = 1.56 accidents/million vehicle miles (1.6 million vehicle kilometers), and
- \(\lambda\) (interstate and parkway) = 0.84 accidents/million vehicle miles (1.6 million vehicle kilometers).
Values of k are identical to those shown for spots. They depend on the level of probability (P) that accident rates above λ are abnormal. The level of probability chosen is again dependent on the number of sections which can be investigated.

Upper control limit curves were drawn for the five classes of highways for a P of 99.5 percent. Figures 11 through 14 show these curves for highway sections ranging from 1 mile (1.6 km) to 20 miles (32.2 km) for 1 year of accident data. Because of the similarity of two-lane and three-lane roads (2.39 and 2.44), a λ of 2.40 was used for both roadway types and were represented by the same curves. Knowing the section length, annual average daily traffic (AADT), and accident rate of a section, the graph indicates whether the accident rate of the section is critical. This is done by moving up on the graph from the appropriate AADT until it crosses the correct curve for section length. If the accident rate corresponding to that point is exceeded by the actual accident rate, the section should be investigated.

Figures 15 through 18 show these curves for 2 years of accident data. The only difference in the two sets of curves is that m is approximately twice as large for 2 years as for 1 year. This increase in m produces curves having less demanding upper control limits for a location to meet the 2-year warrant.

Input from citizens and state police should be considered just as they should for spot locations. Requests are commonly made by citizens and local officials to evaluate certain highway sections. With Figures 11 through 18, a section of any length from 1 to 20 miles (1.6 to 32.0 km) can be tested quickly to determine whether it exceeds the upper control limit. Sections of non-integer lengths can be tested by interpolation between appropriate curves.

It should be mentioned that the magnitude of the number cutoff, the EPDO cutoff, and the probability level (P) for identifying hazardous sections should depend solely on the number of sections that are identified as compared to the number that can be investigated and improved. Values for these warrants are being recommended in this report for use until better values can be determined.
Figure 11. Upper Control limit Curves for Rural Interstate and Parkway Sections for 1 Year (P = 99.5).
Figure 12. Upper Control Limit Curves for Rural Four-lane, Divided Highway Sections for 1 Year (F = 99.5).
Figure 13. Upper Control Limit Curves for Rural Two- and Three-Lane Highway Sections for 1 Year ($P = 99.5$).
Figure 14. Upper Control Limit Curves for Rural Four-Lane, Undivided Highway Sections for 1 Year ($P = 99.5$).
Figure 15. Upper Control Limit Curves for Rural Interstate and Parkway Sections for 2 Years (P = 99.5).
Figure 16. Upper Control Limit Curves for Rural Four-Lane, Divided Highway Sections for 2 Years (P = 99.5).
Figure 17. Upper Control Limit Curves for Rural Two- and Three-Lane Highway Sections for 2 Years ($P = 99.5$).
Figure 18. Upper Control Limit Curves for Rural Four-Lane, Undivided Highway Sections for 2 Years (F = 99.5).
CONCLUSIONS

In summary, the following conclusions are highlighted:

1. The 0.3-mile (0.48-km) roadway segments were found to be more suitable for defining spots than 0.1-mile (0.16-km) segments.

2. Direct benefits were found to be a more appropriate index for determination of improvement benefits than total benefits.

3. Use of 2 years of accident data before an improvement date is preferred to only 1 year for calculation of annual benefits from an improvement.

4. Use of an accident history of several years at a location gives a higher probability that the location will be correctly identified as hazardous or non-hazardous than if a short accident history of 1 year or less is used.

5. The EPDO Method proved to be better for identifying locations with the greatest benefit potential than did the Number Method, Accident Rate Method, or EPDO Rate Method.

6. The Rate-Quality Control Method is better than other accident rate methods for identifying locations having critically high accident rates.

7. Classifications of spot locations and highway sections by highway type is useful for testing by the Rate-Quality Control Method.

8. Hazardous highway spots and sections should be identified on the basis of both accident experience and input from citizens and state police.
RECOMMENDATIONS AND IMPLEMENTATION

The recommended program for identification of hazardous highway spots and sections will have several advantages over the existing system. It would (1) identify locations with critically high accident rates, (2) identify locations with high benefit potentials, (3) identify hazardous sections of various lengths and compare their accident rates with critical rates, (4) save time and money by providing quick, easy methods of identifying hazardous spots and sections, and (5) allow more spots and sections to be considered each month because of the rapidity that locations can be tested.

To implement the proposed system, all highway locations (spots) 0.3 mile (0.48 km) long with a minimum of five accidents during the past year or seven accidents in the past 2 years would be flagged. These locations should then be tested by the EPDO method using cutoff values of 12.5 for 1 year and 21.5 for 2 years. Locations meeting one or more of the EPDO method criteria should be placed on the list of locations to be investigated. The locations not meeting the EPDO criteria should be tested by the Rate-Quality Control curves (Figures 9 and 10). Locations exceeding their respective upper control limits should also be placed on the investigation listing. Locations should also be considered for investigation by making use of input from citizens and state police. Fatality locations should be studied to determine possible improvements. Highway locations meeting any of the above warrants should then be screened to eliminate (optional) locations previously investigated or improved.

Hazardous sections (longer lengths of highway) should be identified by the same basic methods as locations (or spots). Sections 1 mile (1.6 km) long should be identified initially by scanning accident records for sections exceeding 10 accidents per year or 15 accidents per 2 years. Three-mile (4.8-km) sections exceeding 20 or 30 accidents for 1 and 2 years, respectively, should also be flagged. The EPDO Method should then be used to test these sections using an EPDO cutoff value of 25 (for 1 year) and 40 (for 2 years) for 1-mile (1.6-km) sections. EPDO criteria for 3-mile (4.8-km) sections should be 50 and 75 for 1 and 2 years, respectively. Sections not meeting any EPDO warrants should be tested by the Rate-Quality Control curves (Figures 11 through 18) to determine which sections exceed the upper control limits. Sections meeting these warrants should be investigated along with consideration of citizen and police input. Improvements may be made at spot locations and highway sections after investigation if they are recommended by the investigation team. Locations needing major reconstruction should be placed on a priority program. Dynamic programming is a suggested technique to determine optimal improvements for these locations under budget limitations. The proposed hazardous spot- and section-identification program for the Kentucky Bureau of Highways is shown in Figures 19 and 20.
Figure 19. Proposed Spot-Identification-and-Improvement Program for the Kentucky Bureau of Highways.
Figure 20. Proposed Section-Identification-and-Improvement Program for the Kentucky Bureau of Highways.
REFERENCES


APPENDIX A

SUMMARY OF METHODS USED
IN SEVERAL STATES TO
IDENTIFY HAZARDOUS SPOTS AND SECTIONS
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<th>Intersections</th>
<th>Sport</th>
<th>Sections</th>
<th>Intersections</th>
<th>Sport</th>
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<th>Intersections</th>
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<table>
<thead>
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<th>Spot Length</th>
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<th>0.1 mile (0.16 km)</th>
<th>0.2 mile (0.32 km)</th>
</tr>
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<tbody>
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<td>1966</td>
<td>1966</td>
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</tr>
<tr>
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<td></td>
<td>Four or More Lanes, Divided</td>
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<td></td>
<td>(Urban and Rural)</td>
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<td>Four or More Lanes, Divided</td>
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<td>Spot</td>
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<th>Accident Rate</th>
<th>More Than Critical Accident Rate</th>
<th>More Than Critical Accident Rate</th>
<th>More Than Critical Accident Rate</th>
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</thead>
<tbody>
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<td>1966</td>
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<td>1966</td>
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<tr>
<td>Date</td>
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<th>Yes</th>
<th>Yes</th>
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<table>
<thead>
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<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1966</td>
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<th>Sport</th>
<th>Sections</th>
<th>Intersections</th>
<th>Sport</th>
<th>Sections</th>
<th>Intersections</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>1966</td>
<td>1966</td>
<td>1966</td>
<td>1966</td>
</tr>
<tr>
<td>Method Used</td>
<td>OFFO Rate</td>
<td>Rate Quality Control</td>
<td>Accident Rate</td>
<td>Number of Accidents</td>
<td>Number of Accident Rate</td>
</tr>
<tr>
<td>-------------</td>
<td>------------</td>
<td>----------------------</td>
<td>---------------</td>
<td>---------------------</td>
<td>------------------------</td>
</tr>
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<td>Basis of Method</td>
<td>Critical Accident Severity Rate</td>
<td>Critical Accident Rate</td>
<td>Accident Rate</td>
<td>Number of Fatal and 4 and 5 Injury Accidents</td>
<td>Number of Accidents</td>
</tr>
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<td>Time Period</td>
<td>3 Years</td>
<td>1 Year</td>
<td>2 1/2 Years</td>
<td>1 Year</td>
<td>1 Year</td>
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<td>Major Location</td>
<td>Bridges</td>
<td>Spans</td>
<td>Urban Sections</td>
<td>Spans</td>
<td>Spans</td>
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<td>Classifications</td>
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<td>Sections</td>
<td>Rural Sections</td>
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<td>Sections</td>
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<td>Spur Length</td>
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<td>0.1 mile (0.16 km)</td>
<td>0.1 mile (0.16 km)</td>
<td>0.1 mile (0.16 km)</td>
<td>0.3 mile (1.44 km)</td>
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<td>Primary Highway System</td>
<td>Secondary Highway System</td>
<td>None</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
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<td>Spot Warrants</td>
<td>Existed Critical Accident Rate</td>
<td>Existed Critical Accident Rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Existed Critical Accident Rate</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>1</td>
<td>15 or More Accidents Per Year</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>2 Years for Same or More Accidents Per Year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Length</td>
<td>Over 1 mile (1.61 km)</td>
<td>0.1 mile (0.16 km)</td>
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<td>0.3 mile (0.48 km)</td>
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<td>None</td>
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</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Spot Warrants</td>
<td>Critical</td>
<td>Critical</td>
<td>Existed Critical Rate</td>
<td>Existed Critical Rate</td>
<td>On Request</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Critical</td>
<td>Existed Critical Rate</td>
<td>Existed Critical Rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>At Least 15 Accidents Per Year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>For 3 Years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADAMS (M)</td>
<td>OREGON (M)</td>
<td>CONNECTICUT (M)</td>
<td>KENTUCKY (M)</td>
<td>KENTUCKY (P)</td>
<td></td>
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<td>No</td>
<td>No</td>
<td>No</td>
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<td>Categories of Intersection</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

VIRGINIA'S
WRONG-WAY DRIVING REPORT FORM
AND
HAZARD REPORT FORM
INTERSTATE AND PRIMARY (DIVIDED) SYSTEMS

WRONG WAY DRIVING ACCIDENTS
AND INCIDENTS

Route ______ County or City _________ Location ____________________________

Direction Wrong Way Vehicle Traveling ____________________________

Date _______ Day _______ Hour ____ Dawn ___ Daylight ___ Dusk ___ Darkness _____

Weather

Condition: Clear ___ Cloudy ___ Rain ___ Snow ___ Sleet ___ Fog ___ Hail ___ Other ___

Surface Condition: Dry ___ Wet ___ Snowy ___ Icy ___ Muddy ___ Oily ___ Other ______

Did Crash Result? Yes ___ No ___ If so, No. Persons Killed ______ Injured ______

Type of Wrong Way Vehicle Involved: ____________________________

Estimated Speed of Wrong Way Vehicle at Time of Crash: _______________________

Describe Accident or Incident Briefly: _______________________________________

Indicate Where Wrong Way Driver Entered the Wrong Lane and Why, if Possible:

Approximately How Far Did the Vehicle Travel the Wrong Way Before the Accident or Apprehension? _______

Give the Sex, Race, Age, and Condition of Wrong Way Driver: ____________________________

*Residence of Operator: Local _______ Adjacent _______ State _______ Foreign _______

What Suggestions Do you Have For Preventing This Type of Accident or Incident? _______________________

Other Comments: _______________________________________________________

Trooper ____________________________ Date ____________________________

*Local (within county or municipality in which incident happened)
Adjacent (within adjoining county or municipality)
State (within state but not within local or adjacent areas)
Foreign (out of state)
DEPARTMENT OF STATE POLICE
Highway Hazard and Information Report

No. 20922

Results:

DEPARTMENT OF STATE POLICE
Highway Hazard and Information Report

No. 20922

Date

To:
Resident Eng.
Highway Dept.
(town)

From:
Dept. of
State Police
(station)

Subject:

******************************************************************************

Information

State Property Damaged: (check appropriate box)

Nature of Damage:

Date ______ Time -------- Route ______ Location __________________

Vehicle Involved: Make ______ Model ______ License ____ State______

Liability Insured By:

Driver: (name) ________________________________ (address) ________________

Owner: (name) ________________________________ (address) ________________

*********** Hazard Information and Request ***********

The following highway conditions were observed while on routine patrol:

Rt. No. ______ Intersection ______ Location __________________

Explain: ____________________________________________________________

Request: ____________________________________________________________
APPENDIX C

DATA SUMMARIES FOR 170 TEST LOCATIONS
### TABLE C-1

**SUMMARY OF LOCATIONS** by number of lanes

<table>
<thead>
<tr>
<th></th>
<th>IR LOCATIONS</th>
<th>NIR LOCATIONS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Lane</td>
<td>73</td>
<td>53</td>
<td>126</td>
</tr>
<tr>
<td>Four-Lane Undivided</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Four-Lane Divided</td>
<td>10</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Interstate and Parkway</td>
<td>3</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>Totals</td>
<td>86</td>
<td>84</td>
<td>170</td>
</tr>
</tbody>
</table>

*For 0.3-mile (0.48-km) segments.

### TABLE C-2

**SUMMARY OF ACCIDENT DATA** by year

<table>
<thead>
<tr>
<th>TIME PERIOD</th>
<th>AVERAGE NUMBER OF ACCIDENTS</th>
<th>AVERAGE ACCIDENT RATE (Accidents/Million Vehicles)</th>
<th>AVERAGE EPDO</th>
<th>AVERAGE EPDO RATE (EPDO Accidents/Million Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Year Before</td>
<td>5.8</td>
<td>4.4</td>
<td>15.5</td>
<td>11.7</td>
</tr>
<tr>
<td>Second Year Before</td>
<td>2.9</td>
<td>1.6</td>
<td>7.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Two-Year Average</td>
<td>4.3</td>
<td>3.0</td>
<td>11.7</td>
<td>8.2</td>
</tr>
</tbody>
</table>

*For 170 locations (0.3-mile (0.48-km) segments).
### TABLE C-3

**SUMMARY OF LOCATIONS**

<table>
<thead>
<tr>
<th>TYPE OF LOCATION</th>
<th>IR LOCATIONS</th>
<th>NIR LOCATIONS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Intersections</td>
<td>33</td>
<td>25</td>
<td>58</td>
</tr>
<tr>
<td>Non-Intersection Spots</td>
<td>33</td>
<td>37</td>
<td>70</td>
</tr>
<tr>
<td>Driveway Intersections</td>
<td>15</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>Interstate Interchanges</td>
<td>5</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>86</strong></td>
<td><strong>84</strong></td>
<td><strong>170</strong></td>
</tr>
</tbody>
</table>

*For 0.3-mile (0.48-km) segments.*

### TABLE C-4

**SUMMARY OF ACCIDENT DATA**

<table>
<thead>
<tr>
<th>TIME PERIOD</th>
<th>AVERAGE NUMBER OF ACCIDENTS PER LOCATION</th>
<th>AVERAGE ACCIDENT RATE (Accidents/Million Vehicles)</th>
<th>AVERAGE EPDO ACCIDENT RATE (EPDO Accidents/Million Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Lane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Year Before</td>
<td>5.6</td>
<td>5.3</td>
<td>14.4</td>
</tr>
<tr>
<td>Second Year Before</td>
<td>2.6</td>
<td>1.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Two-Year Average</td>
<td>4.1</td>
<td>3.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Four-Lane Undivided</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Year Before</td>
<td>7.7</td>
<td>2.0</td>
<td>23.3</td>
</tr>
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<td>Second Year Before</td>
<td>6.7</td>
<td>2.6</td>
<td>22.2</td>
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<td>Two-Year Average</td>
<td>7.2</td>
<td>2.2</td>
<td>22.7</td>
</tr>
<tr>
<td>Four-Lane Divided</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>First Year Before</td>
<td>6.8</td>
<td>2.3</td>
<td>20.7</td>
</tr>
<tr>
<td>Second Year Before</td>
<td>4.5</td>
<td>1.7</td>
<td>11.4</td>
</tr>
<tr>
<td>Two-Year Average</td>
<td>5.7</td>
<td>1.9</td>
<td>16.1</td>
</tr>
<tr>
<td>Interstate and Parkway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Year Before</td>
<td>0.0</td>
<td>2.7</td>
<td>14.5</td>
</tr>
<tr>
<td>Second Year Before</td>
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<td>6.7</td>
</tr>
<tr>
<td>Two-Year Average</td>
<td>4.4</td>
<td>2.0</td>
<td>16.6</td>
</tr>
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</table>

*For 0.3-mile (0.48-km) segments.*
### TABLE C-5

**SUMMARY OF ACCIDENT DATA\(^a\) BY YEAR AND BY TYPE OF LOCATION**

<table>
<thead>
<tr>
<th>TYPE OF LOCATION</th>
<th>TIME PERIOD</th>
<th>AVERAGE NUMBER OF ACCIDENTS PER LOCATION</th>
<th>AVERAGE ACCIDENT RATE (Accidents/Million Vehicles)</th>
<th>AVERAGE EPDO</th>
<th>AVERAGE EPDO RATE (EPDO Accidents/Million Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Intersections</td>
<td>First Year Before</td>
<td>5.7</td>
<td>3.2</td>
<td>14.8</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>Second Year Before</td>
<td>3.0</td>
<td>1.6</td>
<td>8.1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Two-Year Average</td>
<td>4.4</td>
<td>2.4</td>
<td>11.5</td>
<td>6.7</td>
</tr>
<tr>
<td>Non-Intersection Spots</td>
<td>First Year Before</td>
<td>5.6</td>
<td>5.6</td>
<td>15.7</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td>Second Year Before</td>
<td>2.5</td>
<td>1.5</td>
<td>7.0</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>Two-Year Average</td>
<td>4.1</td>
<td>3.6</td>
<td>11.4</td>
<td>9.5</td>
</tr>
<tr>
<td>Driveway Intersections</td>
<td>First Year Before</td>
<td>6.4</td>
<td>5.3</td>
<td>17.0</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>Second Year Before</td>
<td>3.8</td>
<td>2.1</td>
<td>10.9</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>Two-Year Average</td>
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<td>3.7</td>
<td>13.9</td>
<td>10.9</td>
</tr>
<tr>
<td>Interstate Interchanges</td>
<td>First Year Before</td>
<td>5.3</td>
<td>1.7</td>
<td>14.6</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>Second Year Before</td>
<td>2.1</td>
<td>0.7</td>
<td>5.9</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Two-Year Average</td>
<td>3.7</td>
<td>1.2</td>
<td>10.3</td>
<td>2.9</td>
</tr>
</tbody>
</table>

\(^a\)For 0.3-mile (0.48-km) segments.
APPENDIX D

EVALUATION OF MEASURES OF ECONOMIC EFFICIENCY
EVALUATION OF MEASURES OF ECONOMIC EFFICIENCY

One attribute of a good scheme for identifying hazardous locations is that locations should be identified which will yield the maximum benefits in accident-cost reduction per dollar spent on improvements. Thus, it is necessary to compare various location-identification methods in term of the benefits that can be anticipated. Several questions must be addressed before such a comparison is possible:

1. Should benefits be derived from direct or total accident costs?
2. What is the best measure of merit - cumulative gross benefits, cumulative net benefits, average gross benefits, average net benefits, or benefit-cost ratios?
3. Should the before accident costs be calculated from accident experience accumulated for (a) the 12-month period ending at the flagged date, (b) the 12-month period ending 1 year in advance of the flagged date, (3) the 24-month period ending at the flagged date, or (4) some other period?

To help determine what measure of economic efficiency should be used to compare location-identification methods, the following criteria were established:

1. the measure of merit should exhibit stability,
2. the measure of merit should be sensitive to the available data, and
3. the measure of merit should be philosophically sound.

Figure D1 is useful for demonstrating graphically the significance of the first criterion. If several hazardous locations are ranked in order from the most hazardous to the least hazardous (based on accident experience), the line representing the average benefits should be as smooth as possible. Figure D2 demonstrates the importance of the second criterion. The potential for deriving benefits should be greatest for the most hazardous locations and should decrease as the degree of hazard decreases. The best measure of merit is that most sensitive to the ranking of the locations.

Direct Versus Total Benefits

To compare direct and total benefits by the three criteria, benefits were calculated for the 170 test locations. For each location, the number of accidents, accident rate, EPDO, and EPDO rate were computed for the 1-year period and the 2-year period before the flagged date. Total and direct benefits were computed for each location using the first year, second year, and both years of accident costs before the flagged date.

The 170 locations of the test sample were ranked in order of accident occurrence by the Number Method, the Accident Rate Method, the EPDO Method, and the EPDO Rate Method using accident data accumulated at the 0.3-mile (0.48-km) segment during the 12-month period preceding the flagged
date. The Accident Rate Method referred to here is essentially a Number-Rate Method since all 170 locations were initially selected by a number criterion of three accidents.

Four figures were prepared to compare direct and total benefits using average net values for the 170 locations. These locations were ranked by the Number Method (Figure D3), Rate Method (Figure D4), EPDO Method (Figure D5), and EPDO Rate Method (Figure D6).

Data stability (Criterion 1) is better for direct benefits than total benefits in all four figures. The points represented by the direct benefits can be closely approximated by a smooth line with little deviation from this line. The plots of total benefits show far greater deviation from a smooth line representing the data set. Large upward jumps in the total benefit plots are a result of the elimination of one or more fatalities at a location after improvement. Thus, for Criterion 1, direct benefits are more favorable than total benefits.

A comparison of data sensitivity in Figures D3 through D6 indicates that total benefits are preferred to direct benefits for each of the four methods. However, both direct and total benefits are favorably sensitive inasmuch as a line representing both choices of benefits decreases from the highest location ranks to the lowest (from most hazardous locations to least hazardous). Thus, either benefit choice is acceptable from the standpoint of data sensitivity for comparison of location-identification methods, but total benefits are slightly better than direct benefits.

The third criterion requires that the benefit form be philosophically sound. Use of direct benefits appears to be a better choice than total benefits because of the large cost ($45,000) placed on a fatality by the total costs technique. In many accidents, the particulars of the accident will determine whether a fatality or an injury will result. Positions of the passengers, ages of the occupants, and type of accident are major determinants. For example, an accident involving a pedestrian is more likely to cause a fatality than a rear-end vehicle accident under similar vehicle speeds and at the same location. Use of total benefit comparisons for choosing hazardous locations would support the investigation of all fatal accident locations before any other locations. Even though fatal accidents deserve careful consideration, many fatalities are not indicative that the locations are always worthy of top priorities for improvements.

From a comparison of direct and total benefits, total benefits are slightly better than direct benefits for data sensitivity, although both benefit choices are adequately sensitive for comparing location-identification methods. Direct benefits have considerably better data stability than total benefits, and direct benefits are preferred over total benefits from a philosophical standpoint. Thus, direct benefits were used in this study to compare the four basic location-identification methods.
Methods of Expressing Direct Benefits

Inasmuch as direct benefits are preferred to total benefits, the next decision is how to express direct benefits in the evaluation of location-identification methods. Possibilities include cumulative net benefits, average net benefits, cumulative gross benefits, average gross benefits, and benefit-cost ratios.

A major objective of a location-identification method is to maximize benefits per dollar spent on operation of the program (administrative costs) and improvements made. Net benefits and benefit-cost ratios satisfy this requirement (although they are not necessarily proportional); gross benefits do not. Therefore, benefit-cost ratios and net benefits are preferred to gross benefits.

Cumulative and average benefits may both be useful for certain evaluations. For comparing location-identification methods, average benefits indicate the benefit per location. This may be more meaningful in interpretation than cumulative benefits because the level of cumulative benefits is greatly influenced by the number of locations under consideration. With average benefits, benefits of any sample of locations can be compared without any conversions. Also, in an ordering of locations by accident occurrence for various location-identification methods, an average benefit comparison is easier to interpret for comparing methods. Thus, benefit-cost ratios and average net benefits are two forms of direct benefits proposed to compare the location-identification methods.

Time Period Considerations for Benefit Calculations

The final decision that must be made in selecting benefit expressions is choosing a time period to use in benefit calculations. Because of limitations in the availability of accident data, only 2 years of accident data was obtained for the 170 locations. As a result of seasonal variations in accidents, at least 1 full year of accident data is preferred to be compared with 1 year of "after" data. Thus, the three possible time periods of "before" data that can be used for computing benefits are the first year, the second year, and both years before the flagged date. The three benefit criteria will be applied to test the three time periods.

The time periods were compared in Figures D7, D8, D9, and D10. Only the EPDO Method was used to rank the locations because of the direct relationship of EPDO number and benefit potential. The average direct net benefits for each time period is plotted on the Y axis in Figures D7 and D8. Benefit-cost ratios are plotted in Figures D9 and D10. Locations can be ranked by a method using either 1 or 2 years of "before" accident data. Figures D7 and D9 make use of 1 year of "before" accident occurrence to rank the locations by the EPDO Method. Figures D8 and D10 make use of 2 years of "before" data to order the locations by the EPDO Method. Thus, two different forms of direct benefits (average net benefits and benefit-cost ratios) and two different sizes of data sets (1 and 2 years) are used to compare the first, second, and both years of benefits.
Data stability (Criterion 1) is fairly good for each time period in Figures D8 and D10. In Figures D7 and D9, the first- and both-years curves are quite stable while the second-year curves have undesirable humps and are not as smooth as the other curves. Thus, the first year or both years of data is preferred for stability.

Criterion 2 (data sensitivity) also indicates a preference for the first-year or both-years curves. All three time periods show good data sensitivity in Figures D8 and D10, but the second-year curves are nearly horizontal in Figures D7 and D9.

Philosophical arguments may be made for any of the three time periods. The first-year benefits may be useful in determining immediate gain from improvements. For example, new hazards at a location can cause a sudden rash of accidents. Relatively simple corrections may sometimes be made to eliminate the cause of the accident outbreak. First-year benefits would give values indicating the elimination of these accidents. First-year benefits would contain accident reductions at locations with a high number of random accidents. This is because locations are initially identified as hazardous due to a high number of accidents the first year before.

The second-year benefit technique largely eliminates this error. However, second-year benefits exclude the reduction of accidents caused by hazards such as sudden reduction of sight distance, damage or break in highway pavement, opening of a new entrance onto a highway, and sudden change in traffic patterns and volumes. Because of the flagged date used in this study, the second-year before data may not represent the long-term accident reduction at a location.

Use of 2 years of before accident experience would be a compromise. It would be influenced by random accidents, but it would include accidents due to new highway hazards. Although the both-year technique is not unquestionably the best, it has data stability and sensitivity and appears to be a good choice for comparing location-identification methods. It was, therefore, used for method evaluations.
GOOD MEASURE OF MERIT

POOR MEASURE OF MERIT

Figure D1. Effect of Measure of Merit on Data Stability.

GOOD MEASURE OF MERIT

POOR MEASURE OF MERIT

Figure D2. Effect of Measure of Merit on Data Sensitivity.
Figure D3. Comparison of Direct and Total Benefits for Locations Ranked by the Number Method.
Figure D4. Comparison of Direct and Total Benefits for Locations Ranked by the Rate Method.
Figure D5. Comparison of Direct and Total Benefits for Locations Ranked by the EPDO Method.
Figure D6. Comparison of Direct and Total Benefits for Locations Ranked by the EPDO Rate Method.
Figure D7. Comparison of Time Periods for Average Direct Net Benefits Using the EPDO Method and 1-Year Ranking.
Figure D8. Comparison of Time Periods for Average Direct Net Benefits Using the EPDO Method and 2-Year Ranking.
Figure D9. Comparison of Time Periods for Benefit-Cost Ratios Using the EPDO Method and 1-Year Ranking.
Figure D10. Comparison of Time Periods for Benefit-Cost Ratios Using the EPDO Method and 2-Year Ranking.
APPENDIX E

SUGGESTED CORRECTIONS FOR
HAZARDOUS LOCATIONS
Right-Angle and Rear-End Collisions at Intersections

1. Removal of view obstructions, such as foliage, bushes, billboards, or parking at curb
2. Installation of warning signs, if speeds are high and the element of surprise is present
3. Installation of stop signs, if view is obstructed to such an extent that safe approach speed is 8 miles per hour (3.6 m/s) or less, if one street is an approach street, or if no other remedy reduces accident frequency
4. Installation of traffic signals if minimum warrants are met
5. Continuing operation of traffic signals during certain light-traffic hours when signals are normally off
6. Provision of proper clearance interval in signal cycle
7. Relocation, repair, or other means of providing better visibility of signs or signals
8. Better street lighting
9. Provision of pedestrian crosswalk markings and/or pedestrian barriers
10. Re-routing of through traffic onto specially designated and protected through streets
11. Creation of one-way streets
12. Provision of traffic signal system time for progressive movement
13. Speed zoning to safe approach speed

Head-On, Left-Turn Collisions at Intersections

1. Provision of turning guidelines
2. Prohibition of left turns (provided such movement is of little importance)
3. Provision of channelizing islands
4. Provision of protected turning interval, via traffic signal control
5. Installation of STOP signs (provided no other remedy works)
6. Elimination of view obstructions
7. Creation of one-way streets
8. Routing of turning traffic via an alternate route (with proper signs) to eliminate left turns

Pedestrian-Vehicular Collisions at Intersections

1. Installation of pedestrian crosswalk lines
2. Erection of pedestrian barriers
3. Installation of traffic signals
4. Provision of pedestrian refuge islands
5. Prohibition of curb parking
6. Provision of adequate street lighting
7. Creation of one-way streets
8. Re-routing of through traffic to specially designated and protected through streets
9. Addition of pedestrian indications and pedestrian actuation features to existing traffic signals

Sideswiping Collisions
1. Installation of painted pavement lane lines
2. Installation of channelizing islands at intersections
3. Installation of advance warning signs to warn drivers of proper lane for certain destinations
4. Speed zoning
5. Provision of acceleration or deceleration lanes at intersections
6. Widening of pavement
7. Creation of one-way streets
8. Elimination of marginal obstructions such as caused by parked vehicles or other bottlenecks

Head-On Collisions
1. Same remedies as for sideswiping collisions
2. Installation of "no-passing" zones at curves or other points with restricted view
3. Installation of center dividing strip

Vehicles Running Off Roadway
1. Installation of pavement centerline
2. Installation of warning reflectors, guardrail, or white posts at curves
3. Installation of advance warning signs
4. Installation of roadside delineators
5. Speed zoning
6. Street lighting
7. Skid-proofing slippery pavements, improving shoulder maintenance, and prompt ice treatment and snow removal
Collision with Fixed Objects

1. Application of paint and reflectors to fixed object
2. Use of pavement guidelines to guide traffic around obstructions
3. Street lighting
4. Reduction of the number of fixed objects
   a. Place signs that must be in the median back-to-back wherever possible
   b. Remove unnecessary sign posts (consolidate signs)
   c. Combine signs and light poles where possible
   d. Utilize existing structures for posting signs
   e. Use sign bridges where possible rather than gore signs
5. Reduction of exposure to fixed objects
   a. Place signs and light poles on the right side of pavements rather than in the median or gore areas, reducing exposure to total traffic
   b. Use sign bridges where possible rather than gore signs
6. Minimizing hazards of fixed objects
   a. Provide guardrail in front of fixed objects
   b. Use prows and other methods wherever guardrail is not suitable
   c. Use breakaway sign support and light poles

Collisions with Parked Cars

1. Parking prohibitions
2. Change from angle to parallel parking
3. Re-routing of through traffic to less congested, specially protected through streets
4. Creation of one-way streets