Research Report
410

IDENTIFICATION OF HAZARDOUS RURAL HIGHWAY LOCATIONS

by

John A. Deacon
Associate Professor of Civil Engineering
University of Kentucky
Lexington, Kentucky

Charles V. Zegeer
Research Engineer
Division of Research
Kentucky Bureau of Highways
Lexington, Kentucky

and

Robert C. Deen
Assistant Director of Research
Kentucky Bureau of Highways
Lexington, Kentucky

accepted for publication by the
Transportation Research Board

November 1974

IDENTIFICATION OF HAZARDOUS RURAL HIGHWAY LOCATIONS

by
John A. Deacon, Charles V. Zegeer, and Robert C. Deen

ABSTRACT

An effective procedure was determined for identifying hazardous rural highway locations based on accident statistics. Multiple indicators of accident experience that are necessary include the number of fatal accidents, the total number of accidents, the number of effective-property-damage-only accidents, and the accident rate. Critical levels of these four indicators should vary from state to state depending on the nature of the local safety improvement program as well as local traffic and roadway conditions and prevailing attitudes toward highway safety. Specific recommendations are given for use in Kentucky. Critical accident rates are established using quality control procedures.

To identify hazardous highway locations, it is necessary to distinguish between short highway segments (spots) and large segments (sections) and to further classify spots as intersection and non-intersection locations. Intersection spots should include a distance of 0.15 mile (0.24 km) along all approaches; non-intersection spots should be 0.3-mile (0.48-km), floating segments; and sections should be 3-mile (4.8-km), floating segments. Both spots and sections should be classified by highway type and location. The use of dual time intervals of 1 and 2 years for accumulating and evaluating accident statistics was found to be desirable.

INTRODUCTION

Efforts to reduce the large toll of highway accidents include the identification and subsequent improvement of locations which are "dangerous" or "hazardous". The Kentucky Bureau of Highways has maintained a formal program for improving hazardous locations since 1968. Hazardous locations have been identified as 0.1-mile (0.16-km) segments having three or more accidents in a 12-month period. These locations are screened monthly in the central office to identify those most amenable to improvement under the spot-improvement program. The approximately ten percent identified for further study are 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.

This spot-improvement program 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 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 are high since approximately 35 percent of the locations investigated in the field do not warrant improvement.

The primary purpose of this study was to define and evaluate alternate methods for identifying hazardous rural highway segments based on accident statistics.

BACKGROUND AND SCOPE

Highway Safety Improvement Programs

Highway safety improvement programs have proliferated in recent years partly as a result of federal assistance to state and local governments made available through the Highway Safety Act of 1966 *(2)*. Essential components of these programs include (1) identification of potentially hazardous locations, (2) office investigations, (3) on-site investigations, (4) design studies, (5) programming, (6) implementation of improvements, and (7) continuous review and evaluation.

Safety improvement programs require an effective means for identifying hazardous or potentially hazardous highway locations. Hazardous locations are those for which the accident patterns are abnormally severe when compared with similar locations elsewhere and for which improvements, such as superior operational control and safer roadside appurtenances, can be made through techniques available to the highway management agency.

Input to the process of identifying hazardous locations is generated from several sources including citizens, enforcement agencies, legislative bodies, and the highway management agency. Citizen input often takes the form of complaints from individuals, the news media, and automobile and trucking associations. Enforcement agencies provide very important input through accident reports and files. In addition, individual patrolmen may identify hazardous sites before serious accident patterns develop. Hazard reports, such as those used in Virginia, represent a good way to formally solicit input from enforcement agencies *(3)*. Legislative bodies can effectively identify classes of hazards by making appropriations for specific types of improvements such as the rail-highway crossings provision of the Federal-Aid Highway Act of 1973 *(4)*. Finally, input from within the highway management agency derives from several sources including hazard indices, skid resistance and roughness studies, sufficiency ratings, routine surveillance by maintenance and traffic personnel, special safety programs and studies, and accident records.

Another important component of highway improvement programs are office investigations of the hazardous locations during which traffic data, accident reports, and other data are assimilated. Locations that can be corrected or improved under the available programs are identified, and an improvement priority is tentatively established. On-site investigations are used to confirm or modify office findings, to gather additional field data, and to identify specific measures for alleviating hazards. The design study embraces final improvement design and cost estimates. Improvements are programmed in the next component based on monies available and improvement priorities of all hazardous locations. The final two components of highway improvement programs include implementation of improvements (installation, reconstruction, etc.) and a continuous evaluation of program effectiveness.

Scope of Study

This study was restricted to an examination of one component of highway safety improvement programs, namely, the identification of hazardous rural highway locations. It was further restricted to an examination of those identification methods based on the use of accident statistics. It must be emphasized, however, that techniques other than those based on accident statistics are very useful in preventing the occurrence of accidents. In fact, their use is required by federal directives *(5, 6)*. Therefore, a balanced highway safety improvement program must contain definite, formalized procedures for identifying potentially high-accident locations before unacceptable accident patterns emerge.

Assumptions

The following assumptions form the foundation on which this study was based:

1. the purpose of identifying hazardous locations is to support a highway safety improvement program;

2. the highway safety improvement program encompasses a large, rural highway system;

3. the computerized accident data file contains as a minimum the location, date, and severity of each accident occurring during the prior 2 years;

4. accidents are located to the nearest 0.1 mile (0.16 km) from a known location or reference along each route in the system;

5. potentially hazardous locations are identified monthly;

6. all locations which are identified as potentially hazardous are subjected to a preliminary office investigation; and

7. individual accident reports are available for use in the office investigation.

Criteria for Evaluating Alternate Identification Methods

A number of criteria are useful in evaluating alternate methods for identifying hazardous locations. These include (1) maximizing utility of the results, (2) maximizing program efficiency, (3) maximizing reliability in identifying hazardous locations, and (4) minimizing administrative costs.

To assure that the identification method has maximum utility, interactions between the identification procedures and the safety improvement program must be recognized. The identification method must be fully compatible with available financial and personnel resources. For example, little would be gained by identifying a hazardous 10-mile (16-km) highway section if monies were available only for minor spot improvements. In addition, the identification method must be sensitive to functional differences among highway types and the nature of traffic. Five accidents on a low-volume highway might be indicative of the presence of a very severe hazard while five accidents on a high-volume highway might be quite acceptable. Safety standards vary with highway type and smaller accident rates are expected, for example, on controlled-access highways than on other types. Finally, both accident patterns and prevailing attitudes toward their acceptability change with time. It is important to be able to easily update the identification method to reflect these continuing changes.

The second criterion is that the identification method should maximize program efficiency. Locations should be identified that are most likely to be "correctable" by techniques available to the highway management agency through the safety improvement program. Furthermore, locations should be identified for which corrections are likely to yield the maximum benefits per dollar invested.

The third criterion is that the identification method should maximize reliability in identifying hazardous locations. The probability of identifying a truly hazardous location as being hazardous should be maximized and the probability of identifying a safe location as being hazardous should be minimized. Accident patterns vary from time to time in a somewhat random manner and the accident pattern observed during any particular period may or may not be indicative of the long-term accident experience at a given location.

Finally, the fourth criterion is that the identification method should minimize administrative costs of the safety improvement program. Thus, the identification method must be fully compatible with the highway, accident, and traffic records systems. Manual requirements and personal judgments should be minimized. The number of locations which are incorrectly identified as being hazardous or which are not correctable under the improvement program should be minimized so as to reduce the costs of office and on-site investigations.

TREATMENT OF RANDOMNESS

A major problem in using accident data to identify locations warranting improvement is randomness of the data. Accidents frequently result from a multitude of factors, such as vehicle defects and driver error, unrelated to specific deficiencies of the roadway or traffic control elements. When the number of such accidents is large at a particular location during a given time period, that location may erroneously be identifed as being hazardous, thus, necessitating needless and expensive office and on-site investigations.

The problem may be alleviated in two ways. First, accident records may be scrutinized in the office to ascertain if roadway and traffic control elements contributed significantly to the excessive accident pattern. Second, the length of highway segments and the time interval for assimilating accident data may be carefully selected to minimize the undesirable effects of randomness.

The latter procedure requires some knowledge of the probability distribution of accidents. The number of accidents occurring at a given location during a given time period can be closely approximated by the Poisson distribution *(7)*:

$$P(n) = e^{-a} a^n/n! \qquad (1)$$

in which P(n) = the probability that n accidents will occur at a given location during a given time period, e = base of natural logarithms, and a = expected number of accidents at the given location during the given time period. Equation 1 may also be expressed as

$$P(n) = e^{-\lambda m}(\lambda m)^n/n! \qquad (2)$$

in which λ = expected accident rate in accidents per million vehicle miles (kilometers) and m = number of vehicle miles (kilometers) in millions.

As is shown subsequently, Equation 1 is helpful in selecting optimal segment lengths and time intervals for assimilating accident data. It is also useful in so-called quality control methods for identifying hazardous locations. In these methods, a location is considered hazardous if the observed number of accidents exceeds a previously determined critical number (CN) or if the observed accident rate exceeds a previously determined critical rate (CR). The critical number or critical rate is chosen for a particular type of highway such that the probability that a normal location of that type will be judged to be hazardous is a small, predetermined quantity, p. Satisfactory approximations used to determine CN and CR are as follows *(8, 9)*:

$$CN = a + k \sqrt{a} + 1/2 \quad (3)$$

and

$$CR = \lambda + k \sqrt{\lambda/m} + 1/2m \quad (4)$$

in which k = a constant related to the probabilities, p, as follows:

p	0.0001	0.0005	0.0010	0.0050	0.0100	0.0500	0.1000
k	3.719	3.290	3.090	2.576	2.326	1.645	1.282

A location which experiences a larger number of accidents than the critical number or a larger accident rate than the critical rate is said to be hazardous since the severe accident pattern cannot be reasonably attributed to random occurrences.

TEST SAMPLE AND MEASURES OF MERIT

As a part, of the spot-improvement program in Kentucky, approximately 100 rural locations are identified each month as hazardous, that is, they exceed the criterion of three accidents per 0.1-mile (0.16-km) segment in the previous 12 months. All locations so identified are examined in the office and approximately 10 percent warrant on-site investigations. A sample of 170 of these locations was chosen for detailed evaluation in this study. Eighty-six of these were locations for which improvements were recommended and completed (IR locations) while the remaining 84 were no-improvement-recommended (NIR) locations.

Benefits and costs were computed for each of the 170 locations. For IR locations, benefits were defined to be the difference between average annual accident costs for the 2 years immediately prior to the date of identification and the accident costs for the first year following completion of improvements. Costs were defined to include the sum of a fixed administrative cost of $500 per location and the actual cost of the improvements. For NIR locations, benefits were set equal to zero and costs were set equal to the fixed administrative cost of $500 per location. The following accident costs were used: $9,880 for a fatal accident, $4,570 for an A-type injury accident, $2,635 for a B-type injury accident, $1,525 for a C-type injury accident, and $585 for a property-damage-only (PDO) accident *(1)*.

The two measures of merit included net benefits and benefit-cost ratio. Net benefit is the difference between total benefits and total costs (including both improvement and administrative costs). The benefit-cost ratio is the ratio of benefits to costs.

COMPONENTS OF IDENTIFICATION METHODS

Segment Length

Certainly one of the more important considerations in selecting an identification method is the length of highway segments for which accident data are to be accumulated. A distinction must be made between spots and sections. Spots are short segments of highway used for the purpose of identifying hazardous point locations such as a dangerous bridge, grade, curve, or intersection or an improperly designed or located control device. However, longer lengths of roadway (sections) can also be hazardous, usually as a result of the cross section, geometrics, or pavement surface being insufficient to safely accommodate increased traffic volumes, weights, and speeds.

Spots - Kentucky, as well as a number of other states including Virginia, Florida, Idaho, Oklahoma, California, and Connecticut *(1, 3, 10-14)*, defines spot locations to be 0.1-mile (0.16-km) segments. Other states, however, define spot locations differently: Michigan uses a 0.2-mile (0.32-km) segment *(14)*; Alabama, a 0.4-mile (0.64-km) segment *(15)*; and North Carolina, a variable 0.1-mile (0.16-km) to 1-mile (1.6-km) segment *(16)*.

Several considerations are of paramount importance in determining an appropriate spot length. First, the spot length can be no smaller than the minimum distance increment for reporting accident locations. If accidents are reported to the nearest 0.1 mile (0.16 km), then the spot length can be as small as 0.1 mile (0.16 km). However, if the locations of accidents are reported to the nearest 0.5 mile (0.80 km), then the spot length can obviously be no smaller than 0.5 mile (0.80 km).

Second, the spot length should influence errors that will occur in reporting accident locations. Such errors are inevitable due to the field conditions surrounding accident investigations, the fact that field reference markers are often located no more frequently than one per mile (kilometer), and the fact that an accident "scene" may extend several hundred yards (meters) in length. A spot length of 0.3 mile (0.48 km) is adequate to accommodate reporting errors if markers are placed every mile and if enforcement personnel are well trained.

Third, spot length should be at least as large as the area of influence of a highway hazard. An inadequate control device, a slippery bridge, or a dangerous curve may contribute to accidents that occur over a range of several hundred yards (meters). A spot length of at least 0.3 mile (0.48 km) better approximates the area of influence of a hazard than does the commonly used 0.1-mile (0.16-km) length.

Fourth, reliability in identifying hazardous locations is directly related to the spot length. As spot length is increased, the probability of identifying a truly hazardous location as being hazardous is increased and the probability of identifying a safe location as being hazardous is decreased. A simple example, based on the Poisson distribution of Equation 1, serves to illustrate this point.

Assume that a hazardous segment for a particular class of highway has been defined as one having a "long-term" average of 30 or more accidents per mile (1.6 km) per year. In Figure 1, the probability that a given spot has 30 or more accidents per mile (1.6 km) during a particular 12-month period is shown as a function of both spot length and the average "long-term" accident experience. The probability of correctly identifying truly hazardous locations (such as those represented by the curves for expected accidents of 50, 40, and 35 per mile (1.6 km) per year) as being hazardous is generally increased as spot length increases. Furthermore, the probability of incorrectly identifying "safe" locations (such as those represented by the curves for expected accidents of 25, 20, and 10 per mile (1.6 km) per year) as being hazardous is decreased as spot length increases. It is apparent, therefore, that errors in identifying hazardous locations caused by the random nature of accident occurrences can be minimized by the use of longer spots.

Fifth, the effect of spot length on computation of benefits derived from safety improvements is another consideration in the selection of an appropriate spot length. Table 1 shows summary results for the 170-location test sample. As is plainly evident, computed benefits increase with an increase in spot length from 0.1 mile (0.16 km) to 0.3 mile (0.48 km). As some larger spot length is approached, the computed benefits become stabilized about a constant value representative of actual benefits achieved. As large a spot length as is practical should, therefore, be used in evaluating the benefits of safety improvements.

Sixth, if spots as small as 0.1 mile (0.16 km) are used, there is little discrimination among them by numbers of accidents since most such spots have at most one accident. This difficulty can be overcome by using spot lengths of at least 0.3 mile (0.48 km) *(17)*.

Even though prior considerations suggest that spot length should be as large as possible, a practical constraint is the ability of office and field personnel to readily discern the hazardous condition within the given spot length. If the spot length is excessive, it may become difficult and time consuming to isolate the hazard so that suitable corrective action can be taken. For this reason, spot length should probably be limited to a maximum of about 0.5 mile (0.80 km) and preferably to 0.3 mile (0.48 km).

Finally, spots may be considered to be either fixed or floating locations. To illustrate the difference, consider that spot length has been chosen to be 0.3 mile (0.48 km). One spot might be located within an interval along a route of 9.0 to 9.2 miles (14.4 to 14.7 km) from the reference point. The next spot would then be located from 9.3 to 9.5 miles (14.9 to 15.2 km), the next from 9.6 to 9.8 miles (15.4 to 15.7 km), etc. A difficulty with this fixed scheme arises when a hazard is located near the boundary of two spots, for example, at 9.5 miles (15.2 km). Some accidents associated with this hazard would be reported as occurring within one spot length and the remainder would be reported as occurring within the adjacent spot length. Conceivably, neither of the two spots might be identified as being hazardous and the hazardous condition might remain undetected. This situation can be easily prevented by using floating rather than fixed spots. Spots would then be defined as 0.3-mile (0.48-km) segments centered on points 9.0, 9.1, 9.2 miles (14.4, 14.6, 14.7 km) etc. from the reference point. Use of floating spots is highly recommended as a means for avoiding the necessity for a priori determinations of the locations of hazardous conditions.

Sections -- Kentucky presently does not systematically identify highway sections which are unusually hazardous primarily because it does not have a highway improvement program funded at a level sufficient to make necessary improvements. However, hazardous sections are identified by several other states including Virginia, Florida, Idaho, Oklahoma, Oregon, North Carolina, and Ohio *(3, 10-12, 14, 16, 18)*.

There is little agreement as to what constitutes an acceptable section length although 1 mile (1.6 km) seems to be a reasonable minimum. Preferably, each section should be defined such that it contains a pavement of uniform type and condition, a roadway of homogenous design, and traffic of constant type and volume. Sections so defined would be of variable length and fixed by the locations of intersections and other roadway and traffic conditions. However, traffic, accident, and highway records systems may make it difficult to designate sections in this way. Additionally, the interpretation of accident data is complicated for variable-length sections since observed accident rates are dependent on section length: high accident rates have been observed on short sections and low accident rates on long sections *(17)*. This dependency is related to the way in which sections are designated: long sections tend to have lower traffic volumes and fewer factors of traffic interference such as intersections, changes in the number of lanes, and access points.

For these reasons, it is recommended that section length be constant. A length within the range of 2 to 5 miles (3.2 to 8.0 km) which is allowed to "float" along the route appears to be acceptable. Under conditions encountered in Kentucky, a 3-mile (4.8-km) section appears to be near optimal since sections identified for maintenance purposes average about 3 miles (4.8 km) in length and since most major intersections in rural areas are spaced at least 3 miles (4.8 km) apart. Use of the floating procedure minimizes incompatibilities between section designations and the physical features of the roadway.

Time Interval

The time interval for accumulating accident statistics varies among the states from a minimum of 1 month in Michigan *(14)* to a maximum of 3 years in North Carolina *(16)*. The most common period, 1 year, is used in Kentucky, Virginia, Florida, Idaho, California, Utah, and Ohio *(1, 3, 10, 11, 14, 18)*. Oregon uses 2 1/2 years *(14)* and Illinois *(14)*, Oklahoma *(12)*, and North Carolina *(16)* use a combination of two or more time periods.

Several factors must be considered in selecting an optimal time interval. The time interval should preferably be an integer multiple of 1 year to avoid complexities occasioned by seasonal influences on accident patterns. It should be as short as possible for identifying locations where sudden changes have occurred which warrant immediate correction. These two considerations suggest that the time interval should be set at 1 year.

At the same time, a desirable characteristic of any identification procedure is the reliability with which hazardous locations are identified. Reliability is generally increased as the time interval is increased. This can be illustrated using, once again, the Poisson distribution to calculate the probability of identifying a spot as being hazardous given its true expected accident experience and varying the time interval. Figure 2 depicts the results of such an analysis assuming the spot length is 0.1 mile (0.16 km) and the hazardous criterion is 30 or more accidents per mile per year. The probability of correctly identifying truly hazardous locations (such as those corresponding to 50, 40, and 35 annual expected accidents per mile (1.6 km)) as being hazardous generally increases as the time interval increases. The probability of incorrectly identifying safe locations (such as those corresponding to 25, 20, and 10 annual expected accidents per mile (1.6 km)) as being hazardous generally decreases as the time interval increases.

May *(19)* has also studied the effect of time interval on the reliability with which truly hazardous locations can be isolated from those exhibiting severe short-term accident patterns as a result of the chance occurrence of many unexplained accidents. Based on an analysis of accident statistics accumulated over a 13-year period at 433 intersections, he concluded that the minimum time interval should be 3 years and that little would be gained by increasing the interval beyond 3 years.

Thus, it is well established that time intervals in excess of 1 year should be used to improve reliability. At the same time, excessively long intervals should be avoided to reduce data storage requirements and to minimize the likelihood that substantial changes in traffic volumes, pavement surfaces, etc. may alter the accident pattern. While recognizing that others may prefer a 3-year interval, the authors have concluded that 2 years is a reasonable maximum time interval.

In summary, it is recommended that dual time intervals be used to identify hazardous locations. One year is recommended to assure responsiveness to sudden changes in accident patterns and 2 years to assure maximum reliability.

Accident Data

Accident data can be presented in various ways to reflect not only the number of accidents but also their severity and rate. Indicators that might be used for the purpose of identifying hazardous locations include (1) total number of accidents, (2) number of fatal accidents, (3) number of equivalent-property-damage-only (EPDO) accidents, (4) total accident rate, (5) fatal accident rate, and

(6) EPDO accident rate. These indicators may be used singly or in combination to determine whether a location is hazardous based on a comparison of the observed accident pattern with the established critical limit(s).

A number of states including Kentucky, California, Utah, Michigan, and Alabama have used total number of accidents as the primary indicator of accident experience *(1, 13, 14, 15)*. This indicator is advantageous since the degree of hazard is directly related to the total number of accidents and since the number of accidents can be obtained very simply from accident files without supplementary identifications (such as accident type) or calculations (such as EPDO) or without the use of traffic data (such as rates). On the other hand, it is insensitive both to traffic exposure and to accident severity.

Another indicator, the number of fatal accidents, is attractive since fatal accidents are most costly and evoke wide publicity and concerned public reaction. However, due to the relative rarity of fatal accidents, statistics based thereon are somewhat unstable. Another disadvantage is that hazardous conditions may exist at locations which have experienced a large number of accidents but no fatalities.

The EPDO indicator combines the primary advantages of the above two indicators by reflecting not only the total number of accidents but also their severity. For purposes of this study, the number of EPDO accidents was calculated from *(1)*

$$EPDO = 9.5\ (F + A) + 3.5\ (B + C) + PDO \qquad (5)$$

in which 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. Other attempts to combine the number and severity of accidents into a single index have been made as exemplified by Oklahoma's assignment of a severity number of two to each PDO accident and four to each fatal or injury accident *(12)*.

The above three indicators fail to distinguish among locations based on traffic exposure. This difficulty is circumvented by using accident rates such as the total number of accidents per million vehicle miles (vehicle kilometers), the number of fatal accidents per million vehicle miles (vehicle kilometers), or the number of EPDO accidents per million vehicle miles (vehicle kilometers). Virginia, Florida, Idaho, Oregon, and Ohio are among those using total accident rate to identify hazardous locations *(3, 10, 11, 14, 18)*. All of these, with the exception of Oregon, use quality-control techniques to establish the critical rate. North Carolina *(16)* uses the EPDO rate to assign improvement priorities.

In comparing various indicators of accident experience, another factor of importance is the desire to identify locations for which corrections will yield the maximum benefit per dollar invested. The 170-location test sample provides a mechanism through which various indicators can be compared in this respect. The 170 locations were ranked by each of four indicators (total accidents, total accident rate, EPDO accidents, and EPDO accident rate) in order from highest (rank of 1) to lowest (rank of 170) accident experience. For each indicator, the average net benefit for 0.3-mile (0.48-km) spots was plotted as a function of rank number as shown in Figure 3. The average net benefit was computed for any location rank by averaging the difference between the sum of benefits and the sum of the costs for all locations of equal or more severe accident experience.

The curves of Figure 3 converge at a rank of 170. The best accident indicator is the one which has the largest average net benefit for ranks less than 170. The best indicator in this respect is EPDO accidents followed in turn by EPDO rate, total number of accidents, and accident rate. This conclusion was also verified using cumulative benefit-cost ratio as the measure of merit.

From this brief analysis, it was concluded that the best indicator for assuring the maximum benefit per dollar invested was the number of EPDO accidents. This is logical since benefits are computed from accident costs and since the number of EPDO accidents is directly related to accident costs *(1)*.

Segment Classification

Although some states, such as Kentucky *(1)* and Idaho *(11)*, do not distinguish between locations based upon highway type or design features, many others do. Oklahoma *(12)* and North Carolina *(16)* make the simple, but important, distinction between intersection and non-intersection locations. Florida *(10)* uses a slightly more complex scheme in which segments are classified by location (urban or rural) and by type (interstate, two-lane, four-lane divided, and four-lane undivided). Virginia *(3)* uses a classification of two-lane, four-lane divided, four-lane undivided, freeways, and intersections. Still more complex classification schemes are used by others such as Ohio *(18)*.

The basic questions regarding segment classification are two, namely, should segments be classified by type and, if so, what classification scheme should be used? The answer to the first question is affirmative simply because safety standards and expectations vary with highway type and location. The objective of safety improvement programs is to upgrade hazardous locations to conform with acceptable standards for locations of similar type. Thus, there is no expectation that two-lane, uncontrolled-access facilities can or should be upgraded to safety standards anticipated for freeways. Neither should similar accident patterns and safety standards be expected in both rural and urban areas.

The answer to the second question is more complex since it depends on the nature of the improvement program and on local conditions. A distinction should be made between rural and urban locations because of the different anticipated accident patterns. There should also be a distinction based on highway type which, as a minimum, should recognize number of lanes, median separation, and access control. A minimum classification based on highway type would include two-lane, uncontrolled access;

multilane, undivided, uncontrolled access; multilane, divided, uncontrolled access; and multilane, divided, controlled access. Depending on the local situation, other classifications might also be added.

A classification scheme based on location and highway type is sufficient for the analysis of highway sections. As a minimum, spots must also be classified according to location and highway type using the same scheme as for sections. However, further classification is often added based on the predominant roadway feature within the spot segment. Features that have been used include curves, grades, structures, intersections, visibility restrictions, railroad crossings, etc.

It is highly desirable to distinguish between spots located at intersections and those located on open stretches of highway. Accident patterns are generally different for these two types of locations and exposure to traffic at intersections is normally measured in terms of the number of vehicles which enter the intersection from all approaches rather than the number of vehicle miles (kilometers). However, there is little justification for further classification of spots by predominant roadway feature. Resources must be allocated to those spots having the most severe accident experiences; the nature of the predominant roadway feature only affects the type of corrective action required.

RECOMMENDATIONS FOR IDENTIFYING HAZARDOUS ROADWAY SEGMENTS

On the basis of the foregoing analysis, specific recommendations have been formulated for the identification of hazardous highway locations. However, it is necessary to point out once again that identification procedures must vary from state to state depending on local traffic and roadway conditions and the nature of the improvement program as reflected primarily by money, time, and manpower available for investigation and improvement of hazardous locations.

General Scheme

If the improvement program will permit, both hazardous spots and sections should be identified. Non-intersection spots should be floating, 0.3-mile (0.48-km) segments centered on successive 0.1-mile (0.16-km) locations. If accident reporting errors are felt to be excessively large, a spot length of 0.5 mile (0.8 km) is preferred. Highway sections should be floating segments having a constant length of 2 to 5 miles (3.2 to 8.0 km) and generally centered on successive 1-mile (1.6-km) locations. A length of 3 miles (4.8 km) is recommended for conditions similar to those encountered in Kentucky. As a minimum, both spots and sections should be classified according to location and highway type. Spots should be further classified as intersection or non-intersection locations. Intersection spots should be defined to include a distance of 0.15 mile (0.24 km) along all approaches to the intersection. The measure of traffic exposure at an intersection should be the number of vehicles entering the intersection.

Two time intervals for accumulating accident statistics are recommended both for spots and for sections. One year is recommended for assuring maximum responsiveness to changing conditions while minimizing difficulties associated with seasonal accident patterns. Two years is recommended as an additional interval to maximize reliability in identifying locations with longer term accident problems.

The overall procedure for identifying and investigating hazardous highway segments is diagrammed in Figure 4. Four accident indicators are used to determine whether any particular segment of highway is hazardous. These include the number of fatal accidents, the total number of accidents, the number of EPDO accidents, and the accident rate.

The first warrant for a hazardous segment is an excessive number of fatal accidents. Concern for the number of fatal accidents is based on their large cost as well as public reaction to highway fatalities. It is the opinion of the authors that each fatal accident site should be investigated in the office by competent highway personnel. In applying this warrant, different critical numbers of fatal accidents need not be applied for different highway classes.

The second warrant is an excessive total number of accidents. This warrant provides a rapid means for screening a very large number of segments. Locations declared to be potentially hazardous by this warrant are further tested by the third and fourth warrants before an office investigation is initiated. Locations judged to be safe by this warrant are not examined further. To add further simplicity, the same critical number of accidents can be used for all highway classes.

The third warrant is an excessive number of EPDO accidents. The economic efficiency of an improvement is better related to the number of EPDO accidents than any other indicator of accident experience. All segments having a large number of EPDO accidents should, therefore, be investigated in the office. Again it is recommended that the critical number of EPDO accidents be the same for all highway classes.

The fourth warrant is an excessive accident rate. Segments not identified by the EPDO warrant should be further examined to ascertain if they have excessive accident rates when compared to other locations of similar type. This is the only point where segments need be classified by location, highway type, and, possibly, predominant roadway characteristic. It is also the only point at which traffic volume and accident data must be merged, thereby minimizing manual operations required for those agencies that do not have compatible, computerized accident and traffic data files. Total accident rate is recommended for use as the final warrant because of the desirability for incorporating a measure of traffic exposure and because of the ease by which critical rates can be established using quality control techniques (Equation 4). Quality control techniques easily enable refinement and updating of the identification method to reflect changing accident patterns and changing attitudes toward the acceptability of various accident histories. Different critical rates can be easily established for different highway classifications and the critical rates can be simply adjusted to assure compatibility between the identification method and the resources available through the safety improvement program.

Critical Values

Critical values of accident indicators reflect not only the traffic and roadway conditions existing in a given state but also the resources available under the safety improvement program. Furthermore, they change in time not only as roadway and traffic conditions and the improvement program change but also as experience accumulates and attitudes toward highway safety change. The following critical values are recommended for conditions similar to those in Kentucky. Unfortunately data were not available with which to establish critical values for intersection spots.

Critical Number of Fatal Accidents -- Each fatal accident site should be identified as a potentially hazardous site and should be subjected to an office investigation. Thus, the critical number of fatal accidents for the spot identification procedures is one during the prior 12 months. A second critical number is not required for the 2-year period. For the identification of potentially hazardous 3-mile (4.8-km) sections, the critical number of fatal accidents for the prior 12 months should be two with no additional specification for the 2-year period.

Critical Total Number of Accidents – The total-number-of-accidents warrant is recommended as a screening procedure to reduce the total number of spots or sections to a manageable size. Critical values need to be set sufficiently low to minimize the chance of overlooking a truly hazardous location while at the same time being sufficiently high to avoid identifying too many locations for further processing. Recommended values are (1) for 0.3-mile (0.48-km), non-intersection spots, five accidents in the prior year or seven accidents in the prior 2 years and (2) for 3-mile (4.8-km) sections, 17 accidents in the prior year or 25 accidents in the prior 2 years.

These critical values were chosen to identify slightly more spots (and the corresponding number of sections) than have been formerly identified monthly in Kentucky. Equation 3 was used to select these values. The expected number of accidents, a, was based on an observed statewide accident pattern of one accident per mile per year *(20)*. The value of a in Equation 3 was thus taken to be 0.1 for 0.1-mile (0.16-km) spots in 1 year, 0.3 for 0.3-mile (0.48-km) spots in 1 year, 0.6 for 0.3-mile (0.48-km) spots in 2 years, 3.0 for 3-mile (4.8-km) sections in 1 year, and 6.0 for 3-mile (4.8-km) sections in 2 years. The value of k was determined from Equation 3 by using a critical number of three accidents for 0.1-mile (0.16-km) spots in 1 year (corresponding to the current Kentucky criterion). Once k had been determined, Equation 3 was used to derive the critical numbers for the other segment lengths and time intervals.

As a brief check on the reasonableness of these critical numbers, the ratio of the total number of accidents on 0.3-mile (0.48-km) segments to the total number on 0.1-mile (0.16-km) segments for 578 locations included in the spot-improvement program in Kentucky was computed to be 1.67. Applying this ratio to the current Kentucky criterion of three accidents per 0.1 mile (0.16 km) per year yields the recommended limit of five accidents per 0.3-mile (0.48-km) spot per year. These critical numbers can and should be altered as necessary depending upon local conditions and experience gained through the safety improvement program.

Critical Number of EPDO Accidents – The EPDO warrant identifies locations for which improvements are likely to yield the maximum benefit per dollar invested. To select critical numbers for the EPDO warrant, the 170 locations of the test sample were first ordered with respect to decreasing numbers of EPDO accidents within a 0.3-mile (0.48-km) segment (rank 1 has the highest EPDO and rank 170 the lowest). The cumulative net benefits were then computed for any location rank by adding the net benefits for that location to those for locations of lower rank (higher EPDO). Figure 5 summarizes the results of these computations. For location ranks beyond rank 70, the cumulative net benefit does not increase. Thus, investments in the improvement program for these locations failed to yield a return greater than the investment cost and, hence, were not profitable. Recommended critical levels for the EPDO warrant were, therefore, selected as those corresponding to rank 70, namely, 16.0 EPDO accidents for 0.3-mile (0.48-km), non-intersection spots for the 1-year period and 23.0 EPDO accidents for the 2-year period.

These critical levels for the EPDO warrant must not be used indiscriminately. Their use is justified only for the kinds of improvements made possible under the Kentucky spot-improvement program.

Since Kentucky has little experience with a safety program for improving hazardous highway sections, it is difficult to justify the selection of critical numbers of EPDO accidents for 3-mile (4.8-km) sections. However, such numbers may be derived by applying the ratio of the critical values for the EPDO warrant and the total accidents warrant for 0.3-mile (0.48-km) spots to the critical numbers of accidents for 3-mile (4.8-km) sections. Such a computation yields critical numbers of EPDO accidents for 3-mile (4.8-km) sections of 55 and 80 for 1 and 2 years of accident data, respectively. These limits are suggested only as guidelines for initiating a section improvement program.

Critical Accident Rate -- The accident-rate warrant identifies hazardous locations not previously selected by the fatal-accident and EPDO warrants. If the critical accident rate is a fixed quantity for a given highway type, that is, it does not vary with traffic volume, the accident-rate warrant can yield misleading information. For example, a low-volume location with only one or two accidents per year can have a relatively high accident rate while a high-volume location with many accidents can have a low accident rate. This potential difficulty can be circumvented by using the quality-control procedure to establish critical rates. Using this procedure, low-volume locations must have larger accident rates than high-volume locations to be considered critical.

Critical rates established by this procedure (Equation 4) are dependent on the expected accident rate, λ, for locations of like characteristics; a measure of traffic exposure, m, (the number of vehicle miles or vehicle kilometers of travel normally expressed in millions); and a predetermined small probability, p, that a normal location will have an accident rate in excess of the critical rate. The probability parameter is selected at a level which will identify the desired number of locations. It may also be set at different levels for different classes of highways if it is desired to concentrate improvement funding on particular highway types. Florida, Ohio, and Oklahoma have used probabilities of 0.005, 0.005, and 0.05, respectively *(10, 18, 12)*. The expected accident rate, λ, may be recomputed periodically from routine accident data for whatever classification of highways may be desired.

Based on Kentucky experience, a probability of 0.001 is acceptable for use with the recommended identification system. The following statewide average accident rates (per million vehicle miles (1.6 million vehicle kilometers)) are used: two-lane routes -- 2.39; three-lane routes -- 2.44; four-lane, undivided routes -- 3.13; four-lane, divided routes -- 1.56; and interstate and parkway routes -- 0.84 *(20)*. Critical accident rates are presented as functions of average daily traffic volumes (ADT) in Figures 6 and 7. Figure 6 applies to 0.3-mile (0.48-km), non-intersection spots and Figure 7 to 3-mile (4.8-km) sections. Similar curves can be readily constructed using Equation 4 for other probability levels, highway classifications, and average accident rates. Examination of Figures 6 and 7 reveals that the critical accident rate is reduced as traffic volume, time interval, and segment length are increased.

To test whether a segment is hazardous by the accident-rate warrant, the appropriate figure is first selected. A point is then located on the figure using the observed accident rate and the observed ADT. If the point lies above the critical curve for the appropriate highway classification, the segment is judged to be hazardous; otherwise, it is judged to be safe.

Validation

To further validate the recommended identification method, it was applied to the 170-location test sample to ascertain the number of spots that would have been identified as being hazardous by the new procedure and to determine the resulting economic efficiency of the spot-improvement program. Of the 170 spots, 28 were identified as being hazardous by the new fatal-accident warrant, 61 were identified by the combined total-number-of-accidents and EPDO warrants, and 21 were identified by the combined total-number-of-accidents and accident-rate warrants. Sixty of the 170 locations were not identified as being hazardous by the new procedure.

The remaining 110 spots yielded an average net benefit of $1548 per location as compared to an average of $582 per location using present identification procedures. It is concluded, therefore, that the economic efficiency of the spot-improvement program would be enhanced through adoption of the identification procedure recommended herein.

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop an efficient procedure for identifying hazardous rural highway locations based on accident statistics. An optimal procedure must be compatible with the nature of the attendant safety improvement program and should identify those locations where improvements will result in the maximum reduction in accident costs per dollar invested. In addition, administrative costs should be minimal and the reliability with which locations are identified as being safe or hazardous should be maximal. These and other considerations led to the following conclusions:

1. An important distinction must be made between segments that are classified as spots and those that are classified as sections. The purpose of identifying hazardous spots is to locate and correct hazardous point locations such as a dangerous bridge or intersection. The purpose of identifying hazardous sections is to locate and correct dangerous conditions such as a slippery surface or an inadequate shoulder that exist over a sizable distance. Hazardous spots and sections should be identified separately for the purpose of programming corrective actions.

2. The lengths of non-intersection spots and sections should be constant but both should be allowed to float along a given route with overlapping of adjacent segments. The optimal non-intersection spot length is 0.3 mile (0.48 km) under most conditions. Intersection spots should include a distance of 0.15 mile (0.24 km) along all approaches to the intersection. The constant section length should be within the range of 2 to 5 miles (3.2 to 8.0 km), depending on local conditions. A section length of 3 miles (4.8 km) was found to be optimal for conditions similar to those encountered in Kentucky.

3. Accident statistics should be accumulated and evaluated both for 1-year and 2-year periods. The shorter period is necessary to assure maximum responsiveness to rapid changes in roadway and traffic conditions while the longer period is necessary to assure maximum reliability in identifying hazardous segments.

4. Significant advantages accrue by the use of multiple indicators of accident experience in the identification of hazardous locations. Recommended indicators include the number of fatal accidents, the total number of accidents, the number of equivalent-property-damage-only (EPDO) accidents, and the accident rate. The number-of-fatal-accidents warrant assures that locations of these costly and well-publicized accidents are thoroughly investigated. The total-number-of-accidents warrant is useful as

an initial screening device to reduce the very large number of potentially hazardous locations to manageable size. The EPDO warrant flags locations that offer the greatest possible improvement benefit. Finally, the accident-rate warrant identifies locations having abnormally severe accident patterns when compared with those of similar characteristics and traffic volumes.

5. Critical levels of these four indicators will vary from state to state, depending on the nature of the local safety improvement program as well as local traffic and roadway conditions and prevailing attitudes toward highway safety. Specific recommendations are contained herein for use within Kentucky.

6. Critical accident rates should be established using the so-called quality control procedures. Such procedures allow rapid adjustments for statewide changes in accident patterns as well as other changes such as in the funding level of the improvement program.

7. It is necessary to classify both spots and sections by location (urban or rural) and by highway type. The minimum classification based on highway type includes the following: two-lane, uncontrolled access; multilane, undivided, uncontrolled access; multilane, divided, uncontrolled access; and multilane, divided, controlled access. Such a classification is necessary simply because safety expectations and standards vary with highway type and location. Spots must be further classified as intersection or non-intersection locations.

8. Finally, input for identifying potentially hazardous highway segments is generated from numerous sources in addition to accident statistics. The safety improvement program should be structured in such a manner as to exploit these sources to the maximum possible extent. Unfortunately, accident statistics, while being very important indicators of hazardous conditions, are often accumulated after irreparable damage has been done.

REFERENCES

1. Agent, K. R., *Evaluation of the High-Accident Location Spot-Improvement Program in Kentucky,* Research Report No. 357, Kentucky Bureau of Highways, February 1973.
2. *Guidelines for Local Participation in the National Highway Safety Act of 1966,* Kentucky Department of Public Safety, June 27, 1967.
3. *Accident Studies and Analyses System and Highway Safety Improvement Program,* Chapters 60-61, Virginia Department of Highways, 1972.
4. **Federal-Aid Highway Act of 1973**, Public Law 93-87, 93rd Congress, S.502, August 13, 1973.
5. *Highway Safety Program Standards,* FHWA, Washington, D. C., June 27, 1967.
6. *Identification and Surveillance of Accident Locations -- Volume 9,* **Highway Safety Program Manual**, FHWA, Washington, D. C., January 17, 1969.

7. Norden, M., Orlansky, J., and Jacobs, H., *Application of Statistical Quality Control Techniques to Analysis of Highway-Accident Data,* **Bulletin 117**, Highway Research Board, 1956.

8. Morin, D. A., *Application of Statistical Concepts to Accident Data*, **Record Number 188,** Highway Research Board, 1967.

9. Rudy, B. M., *Operational Route Analysis,* **Bulletin 341**, Highway Research Board, 1962.

10. *Implementation Program for PPM 21-16 Highway Safety Program Projects,* Florida Department of Transportation, 1972.

11. *Explanation of Computations Performed by Computer,* Idaho State Department of Highways, January 20, 1973.

12. *Safety Program Selection,* Oklahoma Department of Highways, Traffic Engineering Division, December 1972.

13. Graves, R. A. and Hodges, R., *Development of a Traffic Accident Analysis System,* State Highway Department of Georgia, February 1972.

14. **Evaluation of Criteria for Safety Improvements on the Highway**, Roy Jorgensen and Associates, 1966.

15. Alexander, C. E., Traffic Engineer, Alabama Highway Department, Personal Letter, September 27, 1972.

16. **Rural Highway Safety Program -- 1972,** Volume I, North Carolina State Highway Commission, 1972.

17. Kihlberg, J. K. and Tharp, K. J., *Accident Rates as Related to Design Elements of Rural Highways,* **NCHRP Report 47**, Highway Research Board, 1968.

18. *Identification of High Accident Locations and Sections,* Ohio Department of Transportation, Bureau of Traffic, October 1972.

19. May, J. F., *A Determination of an Accident Prone Location,* **Traffic Engineering,** February 1964, Vol 34, No. 5.

20. Agent, K. R., *Relationships between Roadway Geometrics and Accidents (An Analysis of Kentucky Records),* Research Report No. 387, Kentucky Bureau of Highways, February 1974.

TABLE 1

COMPARISON OF MEASURES OF MERIT FOR 0.1- AND 0.3-MILE (0.16- AND 0.48-km) SPOTS

MEASURE OF MERIT	SPOT LENGTH	
	0.1 MILE (0.16 km)	0.3 MILE (0.48 km)
Average Annual Net Benefit	$146	$582
Cumulative Annual Benefit-Cost Ratio	1.20	1.80

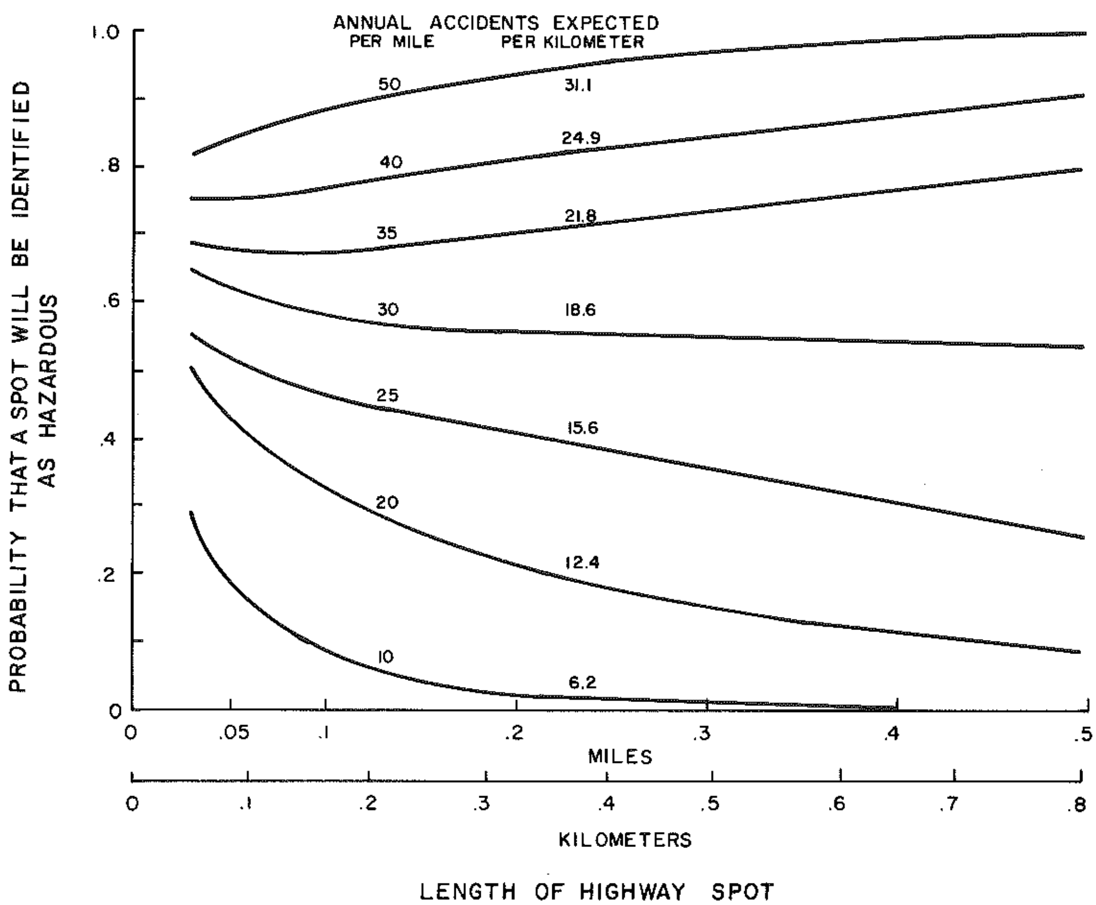

Figure 1. Effect of Spot Length on the Probability of Identifying a Spot as Hazardous

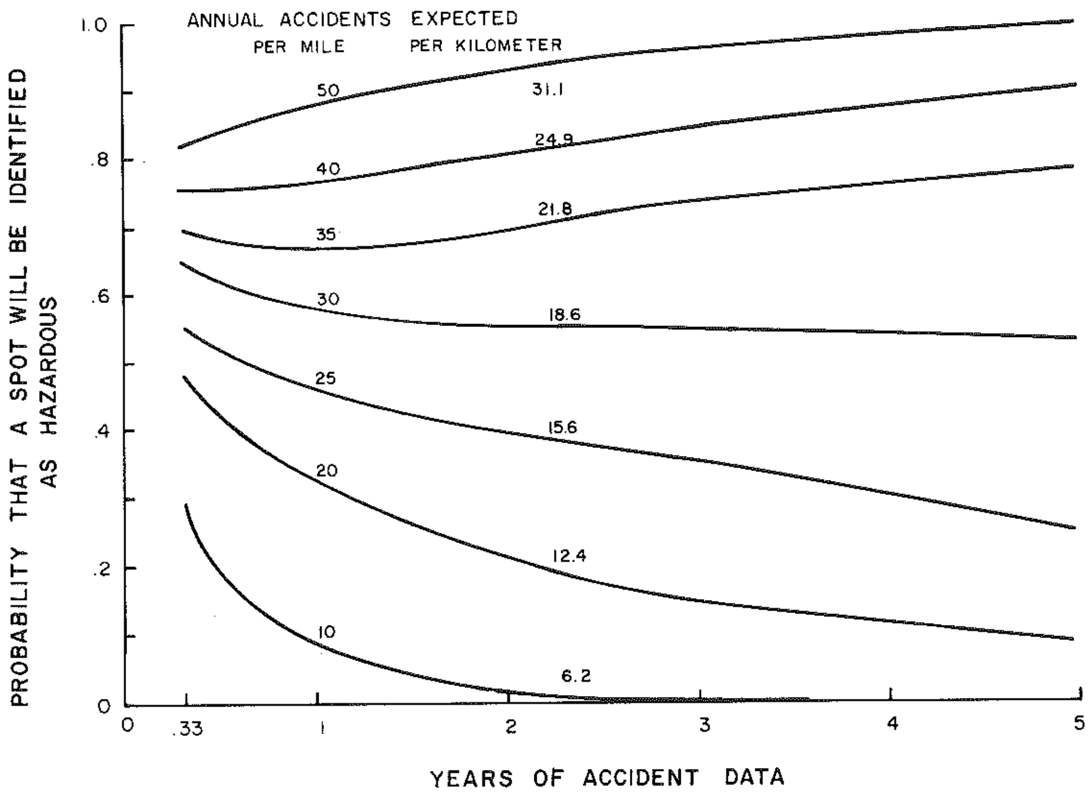

Figure 2. Effect of Time Periods on the Probability of Identifying a Spot as Hazardous

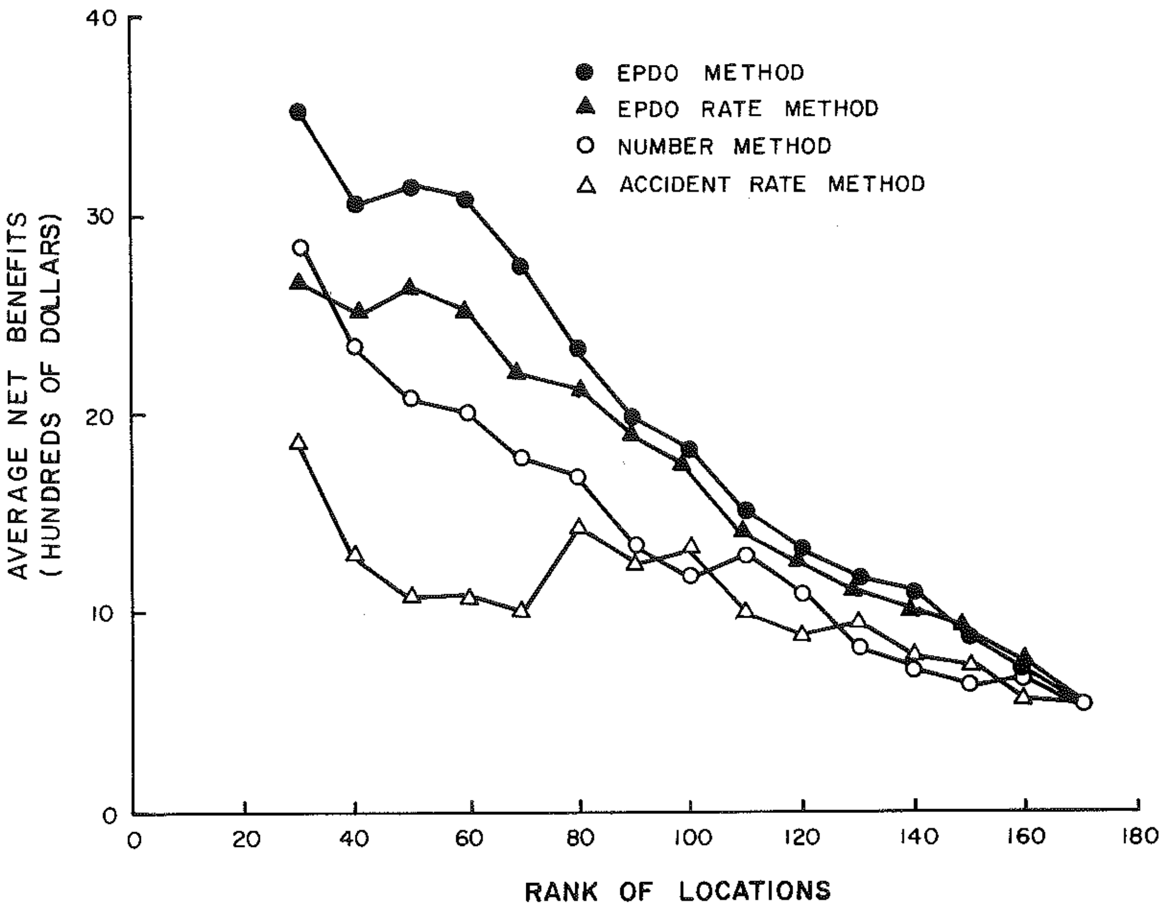

Figure 3. Comparison of Four Accident Indicators by Average Net Benefits

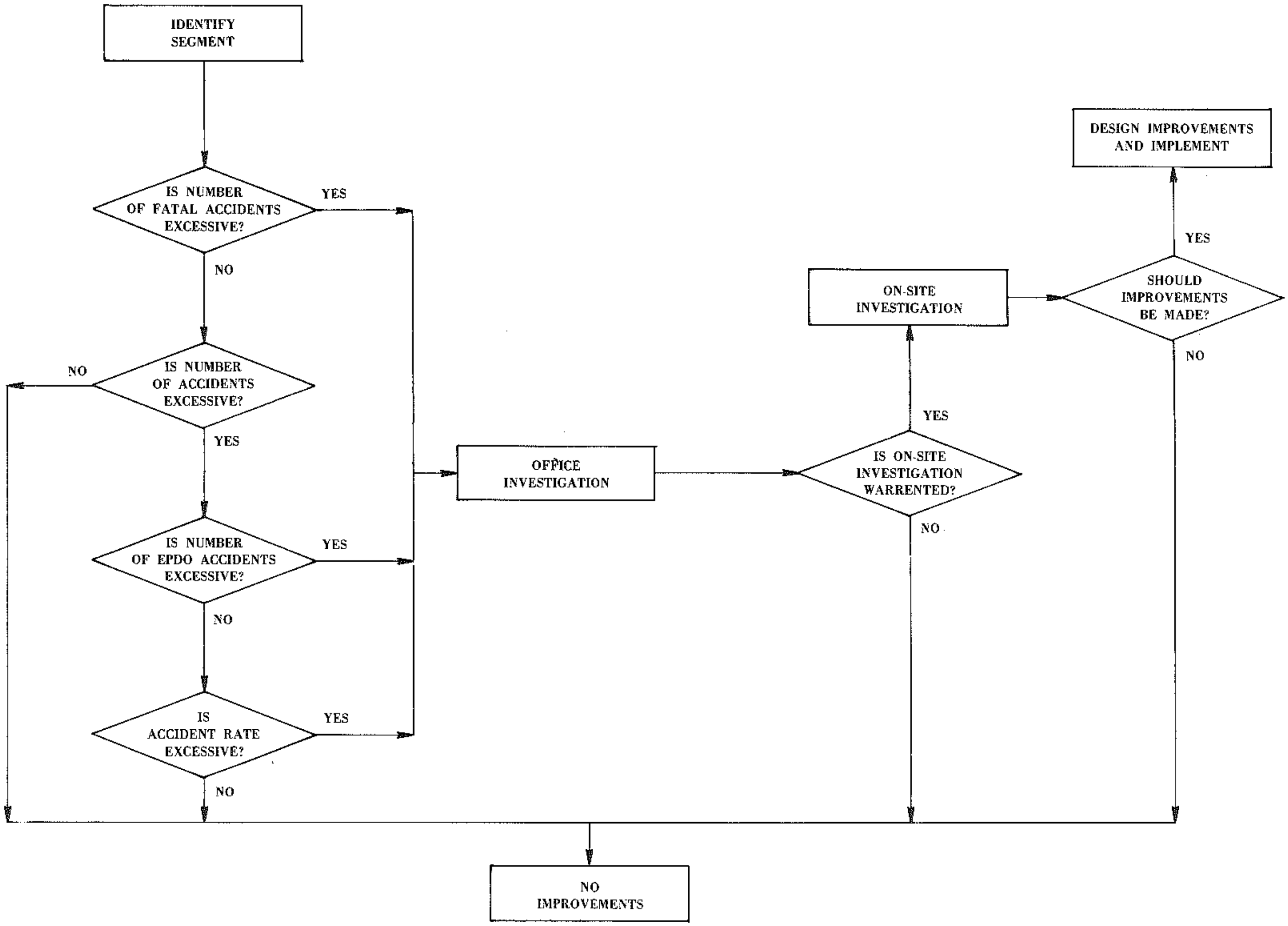

Figure 4. Recommended Procedure for Identifying and Investigating Hazardous Highway Segments

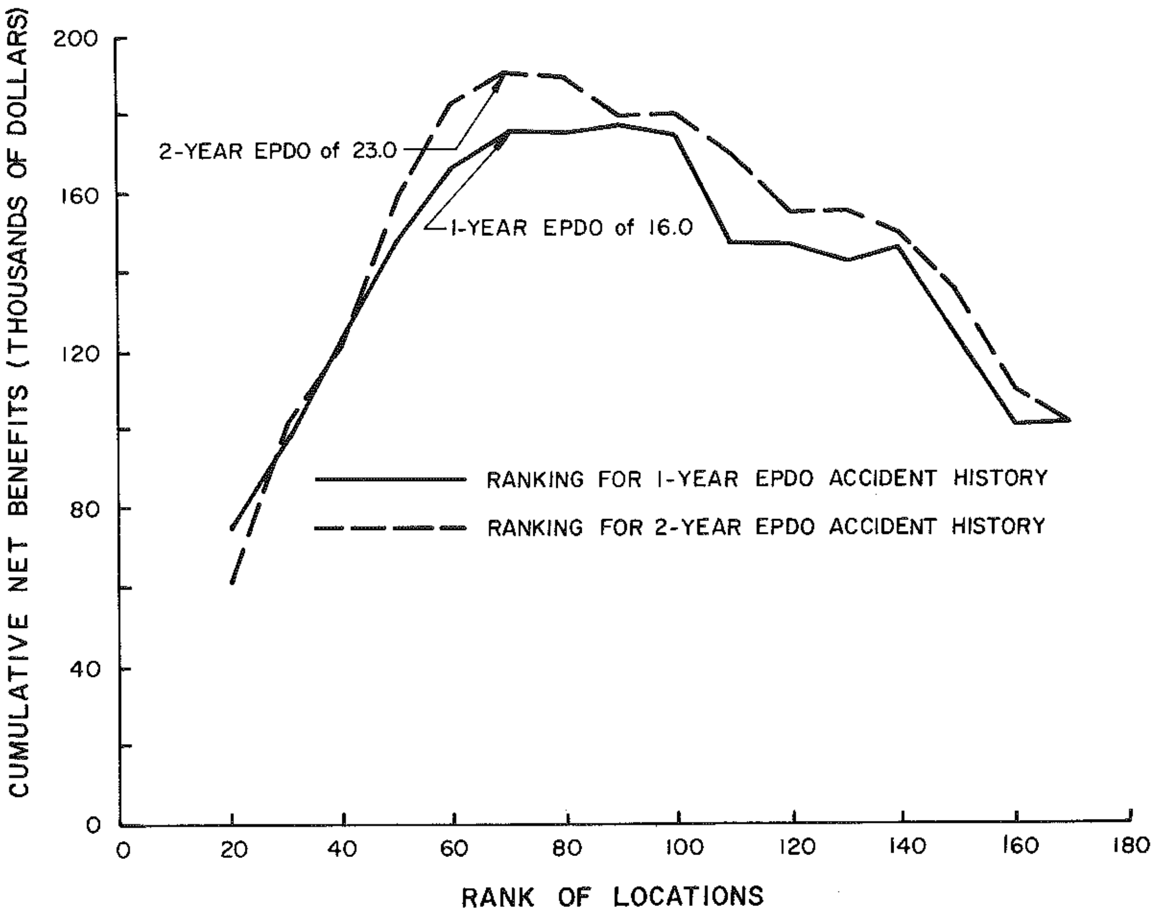

Figure 5. **Determination of Critical Number of EPDO Accidents for 0.3-Mile (0.48-km) Spots**

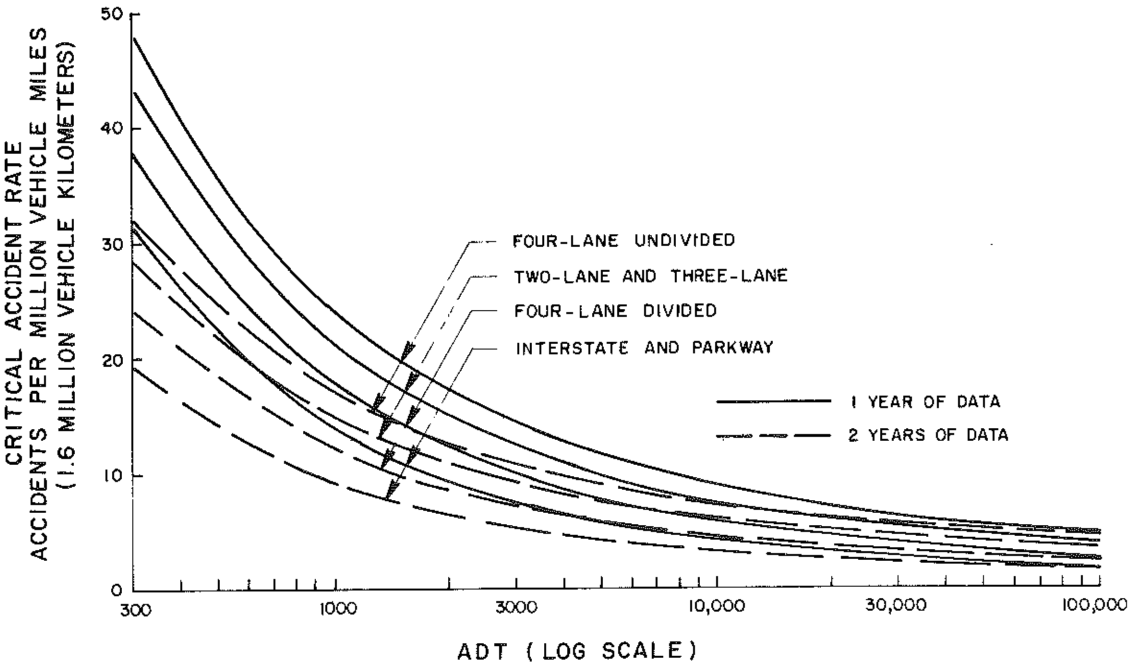

Figure 6. Critical Accident Rates for 0.3-Mile (0.48-km), Non-Intersection Spots, p = 0.001

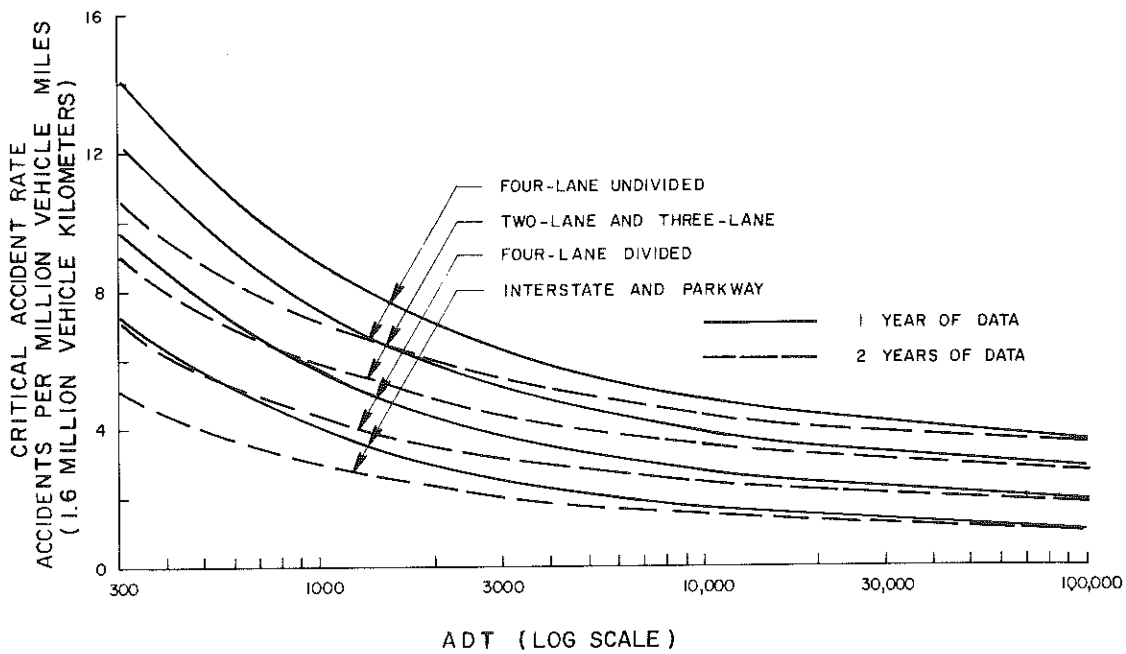

Figure 7. Critical Accident Rates for 3-Mile (4.8-km) Sections, p = 0.001