IDENTIFICATION OF HAZARDOUS RURAL HIGHWAY LOCATIONS

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An effective procedure was developed for identifying hazardous rural highway locations based on accident statistics. Indicators of accident experience that are necessary include the number of fatal accidents, total number of accidents, number of equivalent-property-damage-only accidents, and the nature of the local safety improvement program, local traffic and roadway conditions, and prevailing attitudes toward highway safety. Specific recommendations are given for use of the procedure in Kentucky. Critical accident rates are established by using quality control procedures. In identification of hazardous highway locations, distinction is made between short highway segments (spots) and large segments (sections), and spots are further classified as intersection and nonintersection locations. Intersection spots should include a distance of 0.15 mile (0.24 km) along all approaches; nonintersection 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 1- and 2-year intervals for accumulating and evaluating accident statistics was found to be desirable.

EFFORTS to reduce the large toll of highway accidents include the identification and subsequent improvement of locations that are dangerous or hazardous. The Kentucky Bureau of Highways has maintained a formal program for improving hazardous locations since 1968. Hazardous locations are segments of 0.1 mile (0.16 km) that have three or more accidents in a 12-month period. These locations are screened monthly in the central office to identify those most suited to spot improvements. The approximately 10 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.

The 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: Personal judgment is required in the preliminary office screening, errors in accurately determining accident locations and the random or chance nature of accident occurrences are not properly taken into account, and administrative costs are high inasmuch as 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.

Publication of this paper sponsored by Committee on Traffic Records.

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 identification of potentially hazardous locations, office investigations, on-site investigations, design studies, programming, implementation of improvements, and continual reviews and evaluation.

Safety improvement programs require an effective means for identifying hazardous or potentially hazardous highway locations. Hazardous locations are those at 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 identification of 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, news media, and automobile and trucking associations. Enforcement agencies provide input through accident reports and files. In addition, 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 identify classes of hazards by making appropriations for specific types of improvements such as for rail-highway crossings (4). Finally, highway agency input includes hazard indexes, 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 is office investigations in which traffic data, accident reports, and other data for hazardous locations 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 encompasses final improvement design and cost estimates. Improvements are programmed based on available funds and improvement priorities of all hazardous locations. The final two components of highway improvement programs are implementation of improvements (installation, reconstruction, etc.) and continual evaluation of program effectiveness.

Scope of Study

This study examined one component of highway safety improvement programs: identification of hazardous rural highway locations. It was further restricted to identification methods based on the use of accident statistics. It must be emphasized, however, that other techniques are 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 of this study:

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 previous 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 that 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: maximizing utility of the results, maximizing program efficiency, maximizing reliability in identifying hazardous locations, and minimizing administrative costs.

The first criterion is that the utility of results be maximized. To ensure that the identification method has maximum utility requires that interactions between the identification procedures and the safety improvement program be recognized. The identification method must be compatible with available financial and personnel resources. For example, little would be gained by identifying a hazardous 10-mile (16-km) highway section if funds 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 a very severe hazard, whereas five accidents on a high-volume highway might be acceptable. Safety standards vary with highway type, and lower 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. The identification method must be updated to reflect these continuing changes.

The second criterion is that the identification method maximize program efficiency. Locations ahould be identified that are 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 maximize reliability in identifying hazardous locations. The probability of identifying a truly hazardous location as hazardous should be maximized, and the probability of identifying a safe location as hazardous should be minimized. Accident patterns vary in a somewhat random manner; the accident pattern observed during any particular period may or may not be indicative of the long-term accident experience at that location.

Finally, the identification method should minimize administrative costs of the safety improvement program and must therefore be fully compatible with the highway, accident, and traffic records systems. Manual requirements and personal judgments should be minimized. Minimizing the number of locations that are incorrectly identified as hazardous or that are not correctable under the improvement program will 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 are frequently caused by a multitude of factors, such as vehicle defects and driver error, that are unrelated to deficiencies of the roadway or traffic control elements. When many of these types of accidents occur at a particular location during a given time period, that location may erroneously be identified as 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 determine whether 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):

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

where

$P(n)$ = 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

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

where

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

As shown subsequently, equation 1 is helpful in selecting optimal segment lengths and time intervals for assimilating accident data. It is also useful in quality control methods for identifying hazardous locations, where 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 hazardous is a small, predetermined quantity, p. Satisfactory approximations used to determine CN and CR are as follows (8, 9):

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

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

where k = a constant related to the probability p as follows:

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

A location that experiences a larger number of accidents than the CN or a larger accident rate than the CR is said to be hazardous, for the severe accident pattern cannot be reasonably attributed to randomness.

TEST SAMPLE AND MEASURES OF MERIT

As 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 of these locations 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), whereas the remaining 84 were locations for which no improvement was recommended (NIR).

Benefits and costs were computed for each of the 170 locations. For IR locations, benefits were defined as 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 after completion of improvements. Costs were defined as the sum of a fixed administrative cost of $500 per location and the actual cost of the improvement. 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 of injury accident, $2,635 for a B type of injury accident, $1,525 for a C type of injury accident, and $585 for a property-damage-only (PDO) accident (1).

The two measures of merit were the benefit-cost ratio and net benefits, which are the difference between total benefits and total costs (including both improvement and administrative 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 to identify hazardous point locations such as a dangerous bridge, grade, curve, or intersection or an improperly designed or located control device. However, longer roadway sections can also be hazardous, usually because the cross section, geometrics, or pavement surface is insufficient to safely accommodate increased traffic volumes, weights, and speeds.

Spots

Kentucky, as well as other states including Virginia, Florida, Idaho, Oklahoma, California, and Connecticut (1, 3, 10-14), defines spot locations as 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; and North Carolina, a variable 0.1- to 1-mile (0.16- to 1.6-km) segment (15).

Several considerations are paramount to determining 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. However, if the locations of accidents are reported to the nearest 0.5 mile (0.8 km), then the spot length can obviously be no smaller than 0.5 mile.

Second, the spot length should influence errors that will occur in reporting accident locations. Such errors are inevitable because of the field conditions surrounding accident investigations and because reference markers are often located no more frequently than one per mile and an accident scene may extend several hundred yards 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. 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).

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

Assume that, for a particular class of highway, a hazardous segment is one having a long-term average of 30 or more accidents per mile per year. The probability that a given spot has 30 or more accidents per mile during a particular 12-month period is shown in Figure 1 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 per year) as hazardous generally increases 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 per year) as hazardous decreases 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, spot length affects the computation of benefits derived from safety improvements. The following table gives summary results for the 170-location test sample.

Spot Length (mile)	Net Benefit (dollars)	Benefit-Cost Ratio
0.1	146	1.20
0.3	582	1.80

As is plainly evident, computed benefits increase as spot length increases from 0.1 to 0.3 mile (0.16 to 0.48 km). As some larger spot length is approached, the computed benefits become stabilized about a constant value representative of actual benefits achieved. Therefore, the spot length used in evaluating the benefits of safety improvements should be as large as practical.

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) (16).

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 be difficult and time-consuming to isolate the hazard so that suitable corrective action can be taken. Therefore, 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 as either fixed or floating locations. For example, if the spot length is 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 14.8 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), and so on. 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 would be reported as occurring within one spot length and the remainder would be reported as within the adjacent spot length. Conceivably, neither of the two spots might be identified as 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, and 9.2 miles (14.4, 14.6, and 14.8 km) from the reference point. Use of floating spots avoids the necessity for a priori determinations of the locations of hazardous conditions.

Sections

Currently Kentucky does not systematically identify highway sections that 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, 15, 17).

There is little agreement on what constitutes an acceptable section length although 1 mile (1.6 km) seems to be a reasonable minimum. Preferably, each section should contain a pavement of uniform type and condition, a roadway of homogeneous 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 sections of variable length, for observed accident rates are dependent on section length: High accident rates have been observed on short sections, and low accident rates on long sections (16). 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) that is allowed to float appears to be acceptable. Under conditions encountered in Kentucky, a 3-mile (4.8-km) section is near optimal because sections identified for maintenance purposes average about 3 miles and because most major intersections in rural areas are spaced at least 3 miles 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, 17). Oregon uses 2½ years (14), and Illinois (14), Oklahoma (12), and North Carolina (15) 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 a multiple of 1 year to avoid complexities due to seasonal influences on accident patterns. It should be as short as possible to identify locations where sudden changes have occurred that warrant immediate correction. These two considerations suggest that the time interval should be set at 1 year.

At the same time, the reliability with which hazardous locations are identified is an important characteristic. Reliability is generally increased as the time interval is increased. This can be illustrated by using, once again, the Poisson distribution to calculate the probability of identifying a spot as hazardous given its expected accident experience and by varying the time interval. Figure 2 shows the results of such an analysis assuming that 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) as 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) as hazardous generally decreases as the time interval increases.

May (18) 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 due to 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, and the like may alter the accident pattern. Although others may prefer a 3-year interval, we 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 ensure responsiveness to sudden changes in accident patterns and 2 years to ensure 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 to identify hazardous locations include total number of accidents, number of fatal accidents, number of equivalent-property-damage-only (EPDO) accidents, total accident rate, fatal accident rate, and 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 limits.

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). The advantage of this indicator is that the degree of hazard is directly related to the total number of accidents and the number of accidents can be obtained very simply from accident files without supplementary identifications (such as accident type) or calculations (such as EPDO) and without the use of traffic data (such as rates). On the other hand, it is insensitive to both traffic exposure and accident severity.

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

Use of EPDO 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 (1) was calculated from

$$\mathrm{EPDO} = 9.5\,(F + A) + 3.5\,(B + C) + \mathrm{PDO} \tag{5}$$

where

F = number of fatal accidents,
A = number of A type of injury accidents,

Figure 1. Effect of spot length on the probability of identifying a spot as hazardous.

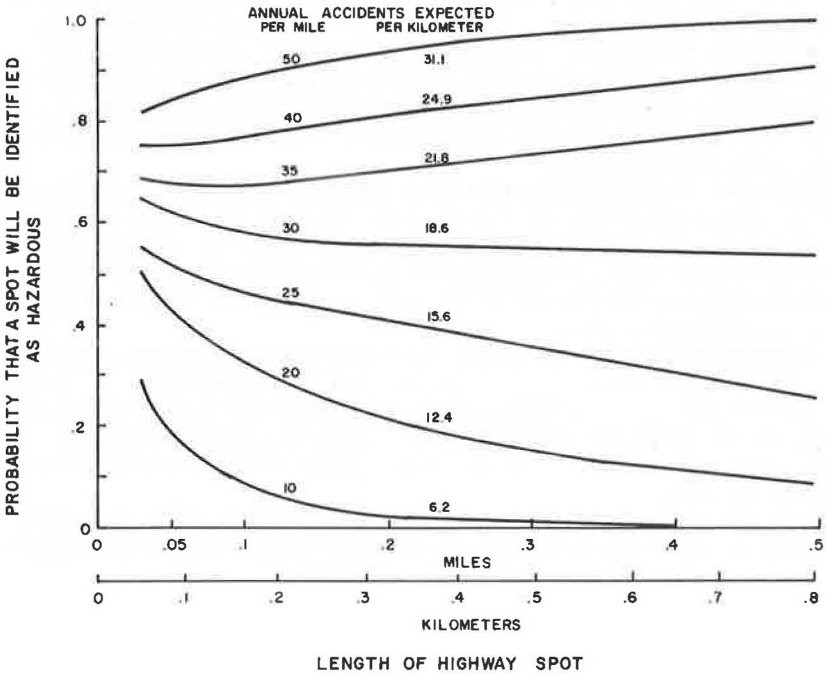
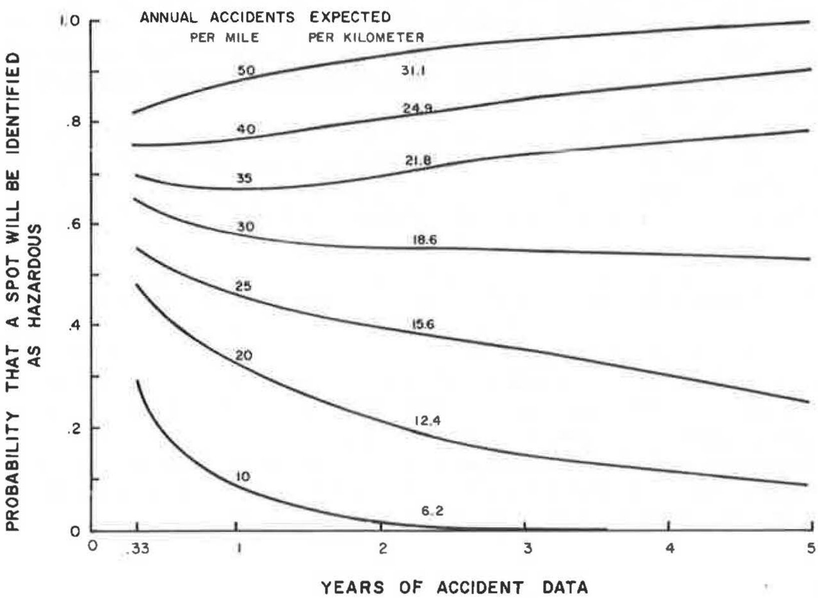


Figure 2. Effect of time periods on the probability of identifying a spot as hazardous.



B = number of B type of injury accidents,
C = number of C type of 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; for example, Oklahoma assigned 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, the number of fatal accidents per million vehicle miles, or the number of EPDO accidents per million vehicle miles. Virginia, Florida, Idaho, Oregon, and Ohio are among those using total accident rate to identify hazardous locations (3, 10, 11, 14, 17). All of these except Oregon use quality control techniques to establish the critical rate. North Carolina (15) uses the EPDO rate to assign improvement priorities.

In a comparison of 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 sample of 170 locations provides a mechanism through which various indicators can be compared. The locations were ranked by each of four indicators (total accidents, total accident rate, EPDO accidents, and EPDO accident rate) from highest (1) to lowest (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 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 that has the largest average net benefit for ranks less than 170. The best indicator in this respect is EPDO accidents followed by EPDO rate, total number of accidents, and accident rate. This conclusion was also verified by using the cumulative benefit-cost ratio as the measure of merit.

From this brief analysis, we concluded that the best indicator for ensuring 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 by highway type or design features, many others do. Oklahoma (12) and North Carolina (15) make the simple but important distinction between intersection and nonintersection 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 (17).

The basic questions regarding segment classification are, Should segments be classified by type, and, if so, what classification scheme should be used? The answer to the first question is yes 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 to 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 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, for 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

Figure 3. Comparison of accident indicators by average net benefits.

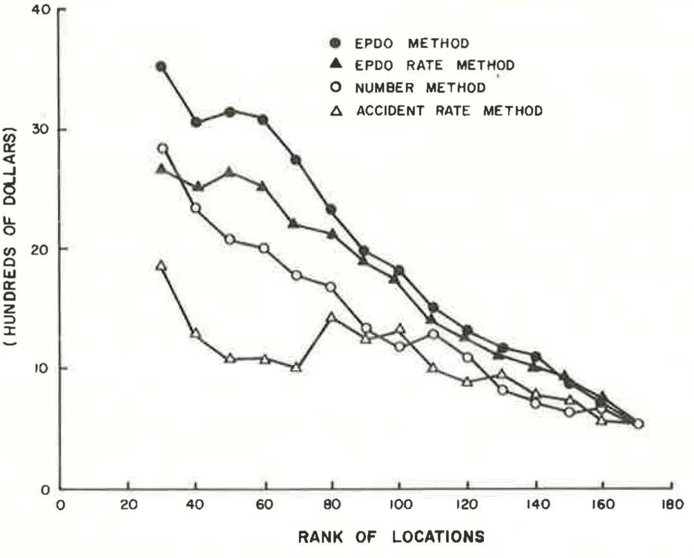
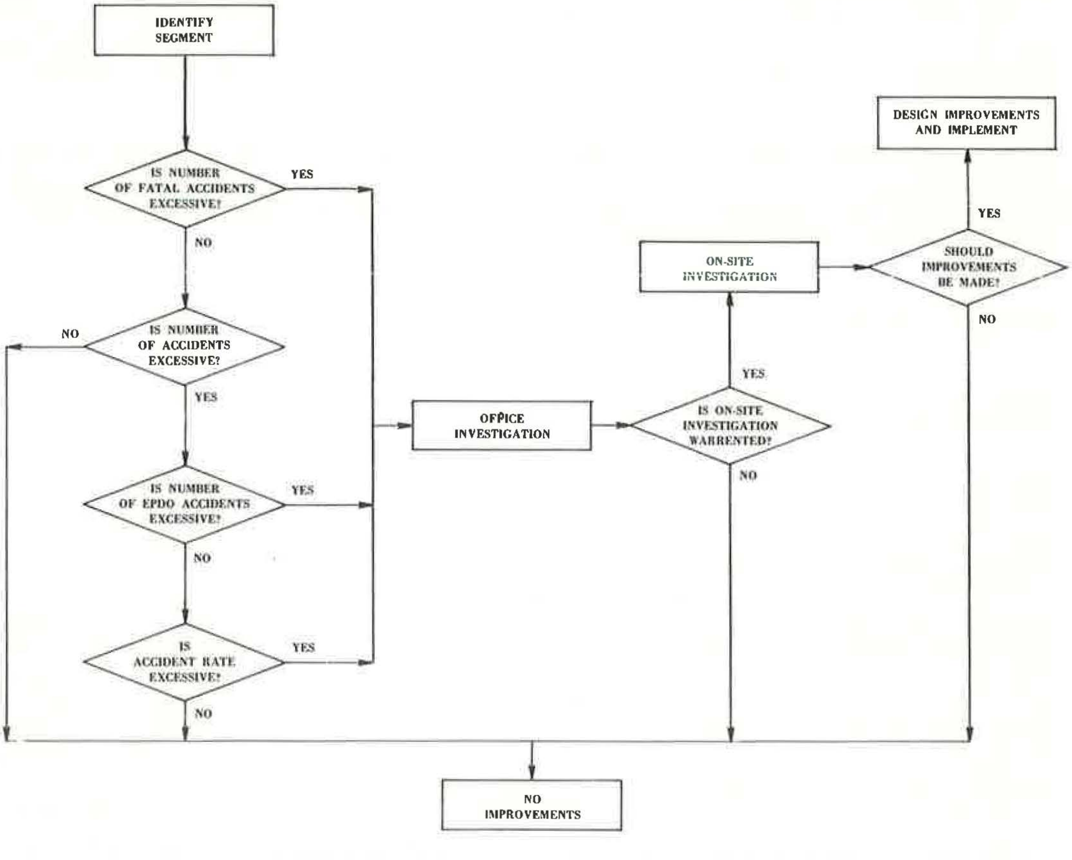


Figure 4. Recommended procedure for identifying and investigating hazardous highway segments.



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.

Classification 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 by using the same scheme as that used for sections. However, further classification based on the predominant roadway feature within the spot segment, such as curves, grades, structures, intersections, visibility restrictions, and railroad crossings, is often used.

Spots located at intersections should be distinguished from those located on open stretches of highway. Accident patterns are generally different for these two locations, and exposure to traffic at intersections is normally measured in terms of the number of vehicles that enter the intersection from all approaches rather than the number of vehicle miles. 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

Based on the foregoing analysis, specific recommendations have been formulated for identification of hazardous highway locations. However, identification procedures will 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. Nonintersection 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 appear 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 nonintersection 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 ensuring maximum responsiveness to changing conditions and minimum difficulties due to seasonal accident patterns. Two years is recommended to maximize reliability in identifying locations with longer term accident problems.

The overall procedure for identifying and investigating hazardous highway segments is shown in Figure 4. Four accident indicators are used to determine whether a particular segment of highway is hazardous: number of fatal accidents, total number of accidents, 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 and on public reaction. We believe that each fatal accident site should be investigated in the office by competent highway personnel; 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 as safe by this warrant are not examined further. As a further simplification, 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 determine whether they have excessive accident rates when compared to other locations of similar type. This is the only point where segments need to 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, so as to minimize manual operations for those agencies that do not have compatible computerized accident and traffic data files. Total accident rate is recommended as the final warrant because of the desirability for incorporating a measure of traffic exposure and because of the ease of establishing critical rates by using quality control techniques (equation 4). Through use of quality control techniques, the identification method can easily be refined and updated to reflect changing accident patterns and changing attitudes toward the acceptability of various accident histories. Different critical rates can be established for different highway classifications, and the critical rates can be simply adjusted to ensure 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 with which to establish critical values for intersection spots were not available.

Critical Number of Fatal Accidents

Each fatal accident site should be identified as potentially hazardous and should be subjected to an office investigation. Thus, the CN 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 warrant for total number of accidents 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 change of overlooking a truly hazardous location and sufficiently high to avoid identifying too many locations for further processing. Recommended values are (a) for 0.3-mile (0.48-km) nonintersection spots, five accidents in the prior year or seven accidents in the prior 2 years and (b) 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 (19). 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 on 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. Critical numbers for the EPDO warrant were selected by ranking the 170 test locations with respect to numbers of EPDO accidents within a 0.3-mile (0.48-km) segment (1 has the highest EPDO and 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 shows the results of these computations. For location ranks beyond 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 a rank of 70, i.e., 16.0 EPDO accidents for 0.3-mile (0.48-km) nonintersection 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.

Because Kentucky has little experience with a 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. 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, whereas

Figure 5. Determination of critical number of EPDO accidents for 0.3-mile (0.48-km) spots.

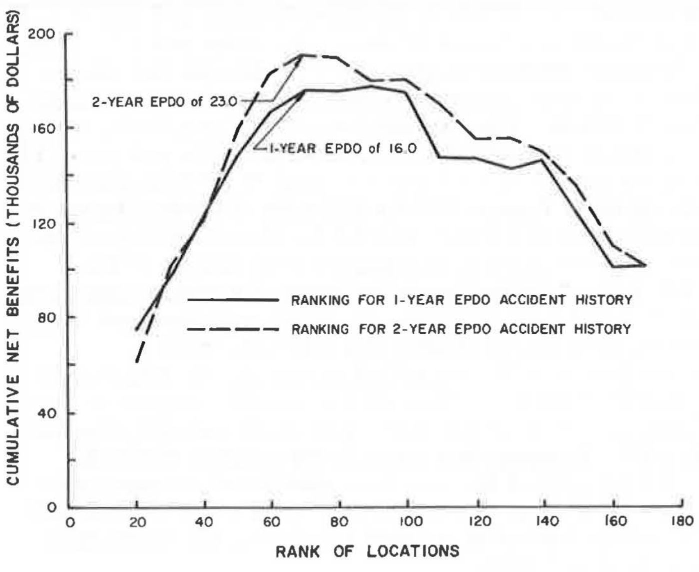
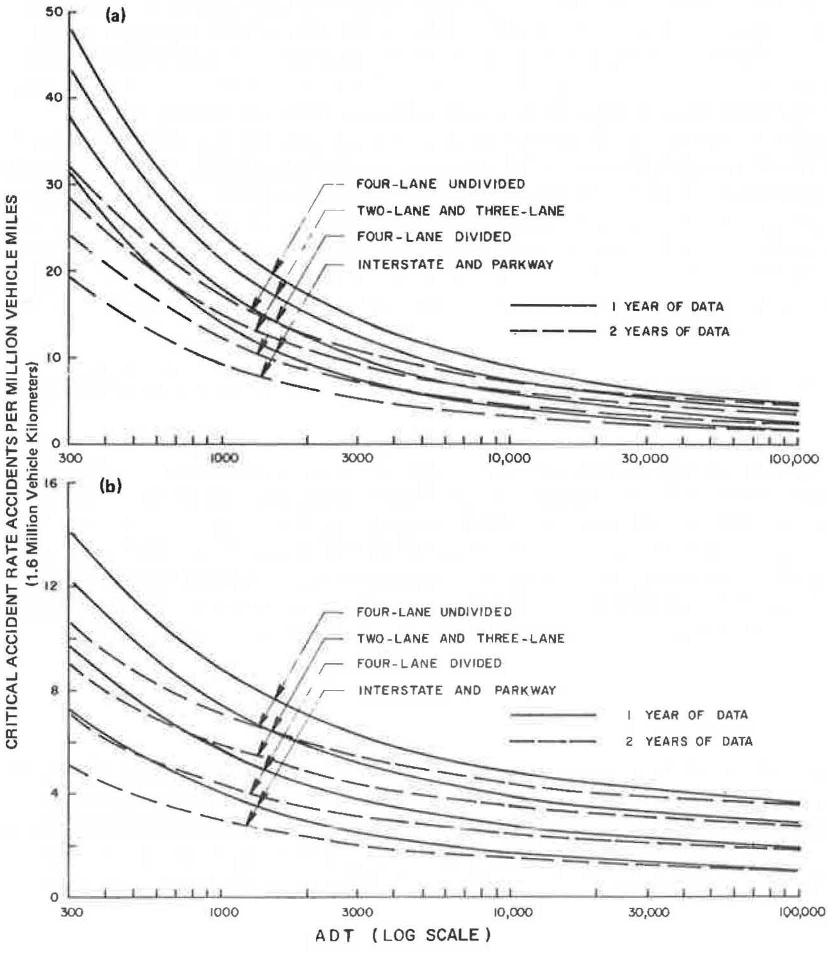


Figure 6. Critical accident rates for (a) 0.3-mile (0.48-km) nonintersection spots and (b) 3-mile (4.8-km) sections (p = 0.001).



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. With this procedure, the accident rate at low-volume locations must be larger than that at 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 of travel 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 that will identify the desired number of locations. It may 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, 17, 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) 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 (19). Critical accident rates are shown as functions of average daily traffic volumes in Figure 6. Similar curves can be constructed by using equation 4 for other probability levels, highway classifications, and average accident rates. Examination of Figure 6 reveals that the critical accident rate is reduced as traffic volume, time interval, and segment length increase.

To test whether a segment is hazardous by the accident rate warrant, a point is located on the appropriate figure by 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

The recommended identification method was further validated by applying it to the 170-location sample to ascertain the number of spots that would have been identified as 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 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 hazardous by the new procedure.

The remaining 110 spots yielded an average net benefit of $1,548 per location as compared to an average of $582 per location with present identification procedures. It is concluded, therefore, that the economic efficiency of the spot improvement program would be enhanced through adoption of the recommended identification procedure.

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 safe or hazardous should be maximal. These and other considerations led to the following conclusions.

1. An important distinction must be made between spots and sections. The purpose of identifying hazardous spots is to locate and correct point hazards 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

exists over a sizable distance. Hazardous spots and sections should be identified separately for the purpose of programming corrective actions.

2. The lengths of nonintersection spots and sections should be constant but both should be allowed to float along a given route with overlapping of adjacent segments. The optimal nonintersection 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 in Kentucky.

3. Accident statistics should be accumulated and evaluated for 1- and 2-year periods. The shorter period ensures maximum responsiveness to rapid changes in roadway and traffic conditions, whereas the longer period ensures 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 EPDO accidents, and the accident rate. The number of fatal accidents warrant ensures 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 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.

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.

6. Critical accident rates should be established by using quality control procedures, which allow rapid adjustments for statewide changes in accident patterns and other changes such as in the funding level of the improvement program.

7. Spots and sections should be classified 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 nonintersection 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. Although they are very important indicators of hazardous conditions, accident statistics are, unfortunately, often accumulated after irreparable damage has been done.

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