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CONTENTS

FOREWORD

The four papers in this RECORD are representative of several of the key elements of a highway safety evaluation system.

In the first paper, Weaver, Woods, and Post describe a formalized implementation procedure to program roadside safety improvements on controlled- and non-controlled-access highways. The procedure is based on an NCHRP project that presented a conceptual probabilistic model as a management tool to establish priorities for roadside safety improvements on freeways. Although that model was to be applicable on a national scale, the Texas Highway Department in cooperation with the Texas Transportation Institute developed the procedures described in this paper to suit Texas conditions.

Deacon, Zegeer, and Deen report in the second paper on a procedure for identifying hazardous rural highway locations by using the quality control technique to calculate critical accident rates. Specific recommendations are given for use by the Kentucky Bureau of Highways.

The identification of hazardous highway locations by processing accumulated accident experience is highly dependent on the particular methods that are used to locate accidents in the field. The paper by Goolsby and Yu describes the development of a quasi-coordinate link-node system for locating accidents. The paper discusses the use of the link-node system on urban and rural highways in Iowa. The flexibility of the location technique is illustrated in a brief description of the Iowa accident retrieval system.

The last paper, by Reiss, Berger, and Vallette, describes the creation of a motorcycle accident data base that was used to determine accident causation factors, to identify voids in motorcycle accident information, and to suggest a basis for future educational and public information programs. An accident typology was developed that identifies accident categories for which specific countermeasures can be designed.

—William T. Baker

COST-EFFECTIVENESS ANALYSIS OF ROADSIDE SAFETY IMPROVEMENTS

Graeme D. Weaver and Donald L. Woods,
Texas Transportation Institute; and
Edward R. Post, University of Nebraska

Roadside safety improvement programs must compete with other highway construction and maintenance programs for limited funds. As emphasis on roadside safety increases, the need for methods by which administrators may evaluate alternative safety improvements becomes apparent. This paper concerns the development of an implementable procedure for evaluating safety improvements for hazards along controlled- and non-controlled-access rural highways by using a general computerized analysis model to accommodate both. A cost-effectiveness conceptual model developed in a recently completed NCHRP research study provides the basic technique for comparing recommended safety improvements. The conceptual model, developed specifically for freeway evaluation, was extended to accommodate non-controlled-access roadways, and the implementation procedure was developed to fit the particular needs of the Texas Highway Department. The implementation procedure comprises three functions: conducting a detailed inventory of a highway to locate and define each roadside hazard, recommending feasible safety improvement alternatives for each hazard or group of hazards, and evaluating the recommended alternatives by using the computer model. A hazard inventory form on which to record information regarding the existing hazard and a hazard improvement form on which to record suggested improvements were developed. The data from these forms are transferred to computer cards to provide the necessary input information for cost-effectiveness analysis of the safety alternatives. Each phase of the procedure is discussed including composition of inventory team, methods to locate existing hazards, details of the two data forms, operation of the computer analysis model, and interpretation of the analysis results. Also included are case examples illustrating typical analysis results.

•HIGHWAY safety administrators currently are faced with the problem of attaining goals that are becoming increasingly more difficult to achieve in an inflated economy. Within these constraints and the stringent limitations on available safety funds, the choices of safety improvements are of necessity reduced to those that return the largest payoff for the safety dollar. The realistic approach becomes one of evaluating the safety improvement alternatives on a common basis, ranking them on a priority scale, and including in a safety program those that yield the greatest economic return.

The principle of economic efficiency to achieve the highest quality product is basic to good engineering practice. The product in roadside safety is hazard reduction. Alternatives must be evaluated and trade-offs must be made to reach an acceptable level of stability between the two elements in the economic principle. Further, if alternatives are to be evaluated uniformly across large regions, specific hazards and

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safety improvement alternatives must be identified, criteria must be selected to ensure commonality in analysis, and procedures must be developed to apply the principle in the real world.

Safety improvement programs generally have consisted of the following four steps:

1. Remove roadside obstacles,
2. Relocate those obstacles that cannot be removed (i.e., to a protected location or laterally),
3. Reduce the impact severity of those obstacles that cannot be removed (e.g., providing breakaway devices, turning down the ends of guardrails, and flattening roadside slopes), and
4. Protect the driver from those obstacles that cannot be improved otherwise by using impact-attenuation or redirection devices.

This approach would be ideal if sufficient funds were available to accomplish all four steps. Under ever-present economic constraints, trade-offs must be made, even within each of the four steps. Which obstacles should be removed? Should certain obstacles be relocated, or can redirection devices achieve the same safety benefit?

Highway safety engineers must evaluate many alternatives of this nature. Unfortunately, engineers have been handicapped by the lack of uniform objective criteria on which to evaluate viable safety alternatives.

As the emphasis on roadside safety has increased, the need for methods with which administrators may evaluate alternative safety improvements and program those to realize the greatest return on available safety improvement funds has become apparent.

The cost-effectiveness model developed in an NCHRP study (1) provides a basic technique for comparing recommended safety improvements. It relies on quantification of vehicle encroachment characteristics, physical dimensions and impact severity of the roadside obstacle, and cost information related to the existing and improved status. The conceptual model, developed specifically for freeway evaluation, was highly generalized and, therefore, was not readily implementable for specific needs. Further, it required expansion to accommodate roadways other than freeways. To implement the concept, each state would have to adapt the findings to its own specific needs and administrative structure.

The Texas Highway Department and the Texas Transportation Institute, through the cooperative research program, developed a formalized implementation procedure, compatible with Texas Highway Department policy, to program roadside safety improvements based on the generalized NCHRP research (2). In a follow-up study (3), the concept and procedure were adapted to include non-controlled-access roadways as well. The product of the two studies is a procedure that is applicable for the two types of highways and that uses a general computer program. This paper presents an overview of the procedure, which is undergoing statewide implementation in Texas.

RESEARCH APPROACH

Conceptual Design

Glennon's conceptual model (1) provides a basic foundation for a structured method with which to evaluate safety alternatives; however, it is not readily implementable in its current state. It requires much obstacle and traffic information that is unique to a particular roadway. To develop the model into an operational tool requires that a methodology be designed for acquiring and synthesizing the information and for presenting it in a form that is suitable for the conceptual model. Further, the concept must be extended for evaluating safety improvements not only along freeways but also on non-controlled-access roadways.

The objective of the research reported was to develop methodology to implement a roadside hazard improvement evaluation program by using Glennon's basic cost-effectiveness model as an analysis tool. The adaptation of the resulting procedure to computerized analysis techniques was a primary requisite.

The procedural concept was developed to achieve the following objectives:

1. Identify the information needs of the conceptual model (input data necessary for analysis), and determine which data may be obtained from previous studies and which data necessitate additional research;
2. Examine available information to determine which portion is usable in its current format and which portion requires modification or restructuring for input use;
3. Develop methods to obtain the information that is not currently available;
4. Develop computer techniques to incorporate necessary model data and permit evaluation of recommended safety improvements; and
5. Test the procedure under actual highway conditions.

Research Tasks

The research tasks for applying the theoretical concept to existing highways were as listed below:

1. Identify those obstacles that constitute a hazard to a vehicle encroaching on the roadside;
2. Assign a severity index value to each obstacle;
3. Define vehicle encroachment criteria under which a roadside obstacle can be expected to be impacted;
4. Develop a procedure for locating obstacles alongside roadways and a mechanism to record the information needed for analysis of the hazard;
5. Define viable safety alternatives for each hazard;
6. Develop a mechanism for selecting safety alternatives for each hazard or group of hazards and for recording the information for comparative analysis of the selected alternatives;
7. Develop computer techniques to incorporate the information collected in steps 1 through 6 and analyze the cost effectiveness of the alternatives.
8. Test the hazard identification list, the inventory procedure, the alternative selection procedure, and the computer analysis model.

These tasks are discussed below, and examples are presented to illustrate the safety improvement procedure and the analysis results from the computer analysis model.

IDENTIFICATION OF ROADSIDE HAZARDS

To computerize the safety improvement evaluation procedure required that all roadside hazards be specifically identified. Basic to identifying roadside hazards is defining what a hazardous roadside obstacle is. Hazard connotes severity of impact. Technically, any roadside obstacle projecting above the ground surface, any surface depression, or any terrain feature that produces a vector change in vehicle acceleration can be considered a hazard.

Roadside obstacles that met this general definition of hazard were included in the hazard inventory list. In the basic list, no regard was given to the severity of impact. The basic list contained approximately 10 categories for classifying obstacles.

Highway field trials were conducted to determine deficiencies in the basic list. These trial inventories revealed not only obstacles that had been omitted from the basic list but also the need for further subclassification of obstacles. Several extensions and refinements were made as a result of continued field trials. A list of roadside obstacles is given below; hazards were grouped under general identification code designations and, where necessary, were further subdivided:

1. Utility poles;
2. Trees;
3. Rigid signposts, including single-pole mounted, double-pole mounted, triple-pole mounted, cantilever support, and overhead sign bridge;
4. Rigid luminaire support base;
5. Curbs, including mountable design, nonmountable design (less than 10 in. high), and barrier design greater than 10 in. high;
6. Guardrail or median barrier, including W-section with standard 6-ft 3-in. post spacing (including departing guardrail at bridge), W-section with other than standard spacing, bridge approach guardrail with decreased post spacing (3 ft 1 in.) adjacent to bridge, bridge approach guardrail with post spacing not decreased, post and cable, metal beam guard fence (barrier) in median, and median barrier (concrete or equivalent);
7. Roadside slope, including sod, rubble rip-rap, or concrete-faced positive or negative slopes;
8. Ditches, including those formed by erosion but not those formed by intersection of front and back slopes;
9. Culverts, including headwall or exposed end of pipe, gap between culverts on parallel roadways, and sloped culverts with or without grate;
10. Inlets, including raised or depressed drop inlet and sloped inlet;
11. Roadway under bridge structure, including piers and vertical- and sloped-faced abutments;
12. Roadway over bridge structure, including open or closed gap between parallel bridges, rigid or semirigid bridge rail (smooth and continuous construction), other bridge rail (probable penetration, snagging, pocketing, or vaulting), and elevated gore abutment; and
13. Retaining wall, including face and exposed end.

For purposes of inventorying, all hazards were categorized as point hazards, longitudinal hazards, or slopes. This general classification system was selected so that inventory data could be recorded and the computer program logic organized.

SEVERITY INDEX ASSIGNMENT

The severity index is the relative measure of the effect on the vehicle or its occupants when a collision with an obstacle occurs. To quantify the severity of roadside hazards, we developed a two-part questionnaire and distributed it throughout the state of Texas to professionals in fields related to highway safety: design, operations, maintenance, law enforcement, and administration.

The first part of the questionnaire consisted of 98 hazard comparison statements with which respondents were requested to agree or disagree. The second part consisted of an evaluation of 52 roadside hazards and conditions; respondents were requested to numerically rate the potential hazard of each on a 0 to 10 linear rating scale. A rating of 0 indicated negligible injury to vehicle occupants, and 10 indicated probable fatality.

Although the linear scale is convenient for consistent ratings from field personnel, it has some inherent disadvantages in the cost-effectiveness model. In particular, a change in the severity index value means different things at each end of the scale. For example, a change from 9 to 7 represents a reduction from a highly probable fatal impact to one producing only injury, whereas a numerical change from 4 to 2 represents only minor significance, both being property-damage-only impacts. Therefore, the linear hazard indexes were adjusted on a nonlinear scale in proportion to cost relationships associated with property damage, injury, and fatal accidents; the cost of a fatal accident was set at $200,000.

VEHICLE ENCROACHMENT CHARACTERISTICS

The quantification of certain traffic operating characteristics is vital to Glennon's conceptual model. The specific information required includes roadside encroachment frequency, encroachment orientation, lateral displacement, and vehicle speed. The distribution of encroachment frequency and lateral displacement developed by Hutchinson and Kennedy (4) is included in the computer analysis model. The 11-deg encroachment angle selected by Glennon was also used in this research with a 60-mph vehicle speed.

DEFINITION OF SAFETY IMPROVEMENT ALTERNATIVES

An approach similar to that used in establishing the hazard list was used to define possible safety improvements for each hazard. An extensive list was developed of possible improvements for each obstacle on the hazard inventory list. The list was expanded to include improvements to groups of obstacles that occur along the roadside. During this phase, any improvement was included in the list without regard to cost, resulting severity, or, to a certain degree, the practicality of the improvement. The basic list was taken to the field repeatedly to determine deficiencies and was extended or refined as necessary until a final list was selected.

APPLICATION

General Procedure

The approach used to obtain hazard information involved conducting a detailed physical inventory of the highway. Although time-consuming, this method permitted accurate determination of all necessary roadside obstacle information. The inventory technique offered several other advantages also. On-site assessments of the hazard were made with respect to the roadway cross section and the relationship of one hazard to others in its immediate vicinity. In many cases, on-site inspection was necessary to fully evaluate potential remedial treatment. The need for precise hazard location, in conjunction with the on-site remedial evaluation, led to the decision to conduct a physical inventory of the total roadway. From this decision evolved the concept of a safety team simultaneously conducting the hazard inventory and making improvement recommendations.

The procedure to evaluate safety improvements for roadside hazards comprises three related functions:

1. Conducting a detailed inventory of the highway system to identify and locate each roadside hazard,
2. Recommending feasible safety improvement alternatives for each hazard or group of hazards, and
3. Evaluating the recommended safety improvement alternatives by using a computerized cost-effectiveness model.

In the inventory phase, the milepoint of each applicable hazard is identified by using a vehicle equipped with an odometer that records to one-thousandth of a mile (approximately 5 ft). As each hazard or group of hazards is located and evaluated, recommendations for remedial safety improvement are made. Hazard inventory information and improvement recommendations are recorded on forms described later in this paper. The hazard inventory information and improvement recommendations are the basic input for the cost-effectiveness model.

A primary consideration throughout this research was that the procedures developed be implementable on existing highways and within real-world constraints, primarily time constraints. Conducting an inventory requires a substantial expenditure of personnel and equipment. To minimize these costs, methods and measuring devices were designed to obtain the hazard information as easily and quickly as possible yet with the necessary accuracy.

Scope

The lateral boundaries within which safety improvements will be made are determined by the administrator, although in most roadside improvement programs the primary and secondary recovery areas (30-ft lateral clearance) are generally sufficient. Available information (4) indicates that safety improvements within this region benefit approximately 85 percent of drivers encroaching the roadside. The inventory procedure developed in this research includes all roadside hazards located in the median or within 30 ft of the outer edge of the traveled lane.

Inventory Team

The quality of the analysis depends to a very large degree on the quality of the input data. Inasmuch as the recommendations for alternative safety improvements govern to a great extent the cost-effectiveness results, the inventory team must have considerable experience in traffic operations, geometric design, maintenance, and cost estimating. Field trials of the inventory procedure indicated that a four-person team represents an efficient working force, to include as a minimum a driver, a data recorder, and two decision makers to recommend safety improvements. The more experienced the team members are, the more flexibility there is to rotate duties. The following procedure was found to work very efficiently. The driver assumed the responsibility of identifying each hazard as he drove along the highway at low speed; he stopped adjacent to each hazard to read the odometer. All hazard inventory data were recorded by a member of the team who was familiar with the hazard inventory form. The driver called out the hazard milepoint and identified the hazard by name. These were recorded, and necessary identification codes were assigned. Offset distances and other applicable data were recorded while two decision makers evaluated the hazard situation to select improvement alternatives. The decision makers completed the improvement form.

Recording Existing Hazard Information

Because there are so many hazards that must be inventoried along a section of roadway, the coding process must be systematic for eventual analysis by computer. The inventory team manually recorded all necessary information on each roadside obstacle included in the hazard inventory list on a one-page form. The hazard inventory form (Figure 1) was developed in several stages and reflects repeated field trials and modifications resulting therefrom. The form is applicable for both controlled- and non-controlled-access roadways; the analysis procedures are accommodated within the computer analysis model depending on the highway type and classification code entered on the form.

The form was developed to permit direct transfer of inventory data to computer card for entry to the cost-effectiveness program. Only those data within the numbered spaces in each box are entered on computer cards; the number below each space denotes the column number on the computer card.

Since any roadside obstacle encountered can be classified in only one of the three possible categories, only the information in the box containing the particular hazard type is recorded on the form to fully describe the hazard. Boxes 1 and 2 are completed on every form; only one of boxes 3, 4, or 5 is completed on each form.

Recording Safety Improvement Information

A roadside hazard improvement form was designed to provide a mechanism to record improvement information in a format acceptable for computer analysis. The hazard improvement form (Figure 2) was also developed as a result of repeated field trials.

Recorded on the hazard improvement form are the recommended safety treatments;

Figure 1. Roadside hazard inventory form.

Inventory Conducted by ____________ Date ________ Hazard Description ____________

HIGHWAY (BOX 1)

1 2 Highway Type
- 08 IH
- 01 US
- 02 SH
- 05 FM-RM

3 4 5 6 Highway Number

7 Classification
- Full Control Access
  - 1 Interstate
  - 2 Non-Interstate
- Non-Control Access
  - 3 Two-Lane
  - 4 Multilane Divided
  - 5 Multilane Undivided

8 9 10 County Code

11 12 13 14 Control Number — 15 16 Section Number

17 18 Total Width Center-Line to Shoulder on Inventory Side (Undivided Highway Only)

19 20 21 ADT (Total Both Directions 1000's)

22 Recording Direction
- 1 With Milepost
- 2 Against Milepost

HAZARD CLASSIFICATION (BOX 2)

23 24 25 26 Hazard Number

27 28 Identification Code — 29 30 Descriptor Code

31 Offset Code
- 1 Right
- 2 Median or Left Side

32 33 34 Median Width (ft) (Leave Blank if Median Inventoried on Near Side Only)

35 36 37 38 Grouping Number

MILE POINT AT HAZARD

39 40 41 42 43 44 Beginning

45 46 47 48 49 50 End (Except for Point Hazard)

POINT HAZARDS (BOX 3)

[1] 51

52 53 Hazard Offset, D (ft)

54 55 56 Width (W) (ft)

57 58 59 Length (L) (ft)

Drop Inlets Only: 60 61 62 Height (ft) or 63 64 65 Depth (ft)

LONGITUDINAL HAZARDS (Curbs, Bridgerails, Barriers, Guardrails, Ditches, and Retaining Walls) (BOX 4)

[2] 51

Hazard Offset, D (ft): 52 53 Beginning; 54 55 End

56 57 58 Height (ft) or Depth (ft)

59 60 Width (W) (ft)

END TREATMENT — Guardrail Only

61
1. Not Beginning at Structure - Safety Treated
2. Not Beginning at Structure - Not Safety Treated
3. Beginning at Structure - Full-Beam Connection
4. Beginning at Structure - Not Full-Beam Connection

62
1. Not Ending at Structure - Safety Treated
2. Not Ending at Structure - Not Safety Treated
3. Ending at Structure - Full-Beam Connection
4. Ending at Structure - Not Full-Beam Connection

SLOPES (BOX 5)

FRONT SLOPE

[3] 51

Hinge Point Offset, O_H (ft): 52 53 Beginning; 54 55 End

Steepness: 56 57 :1 Beginning; 58 59 :1 End

Distance "D_1" (ft): 60 61 Beginning; 62 63 End

64 Slope Face Erosion Code
1. Slight or None
2. Severe (Ruts > 1 ft)

65 Slope Direction
1. Positive
2. Negative

2nd or BACK SLOPE (Except for Level Terrain)

Steepness: 66 67 :1 Beginning; 68 69 :1 End

Distance "D_2" (ft): 70 71 Beginning; 72 73 End

74 Slope Face Erosion Code
1. Slight or None
2. Severe (Ruts > 1 ft)

75 Slope Direction
1. Positive
2. Negative

[1] Card Type 77

Recommendations: ____________

Figure 2. Roadside hazard improvement form.

BOX 1

Hazard Number (1 2 3 4) — Highway Number (5 6 7 8) — Country Code (9 10 11) — Control Number (12 13 14 15) – Section Number (16 17) — Hazard and Improvement Description

First Cost of Improvements ($) (18 19 20 21 22 23)

Repair Cost per Collision ($): Hazard (24 25 26 27); Improvement (28 29 30 31)

Normal Maintenance ($/yr): Hazard (32 33 34 35); Improvement (36 37 38 39)

BOX 2

POINT HAZARD IMPROVEMENTS

1 (40) 1 (41) Alleviate Hazard — (42)
1 Remove
2 Make Breakaway and/or Relocate
3 Reconstruct Inlet to Safe Design
4 Reconstruct Cross-Drainage System (Remove Headwalls, Extend Culvert, Grade, Etc.)

1 (40) 2 (41) Protect Hazard with Guardrail (Hazard Not on Critical Slope) — Lateral Offset (ft) Right or Median Near Side (42 43); Lateral Offset (ft) Median Far Side (44 45)

1 (40) 3 (41) Protect Hazard with Concrete Median Barrier (CMB) — Lateral Offset (ft) (42 43)

1 (40) 4 (41) Protect Hazard with Energy Attenuation System — Length (ft) (42 43 44); Width (ft) (45 46); Offset (ft) (47 48)

BOX 3

LONGITUDINAL HAZARD IMPROVEMENTS

2 (40) 1 (41) Curb — (42)
1 Remove and Regrade
2 Install Wedge Modification

2 (40) 2 (41) Bridgerail — (42)
1 Rigid
2 Semi-rigid

(43)
1 Upgrade to Full Safety Standards
2 Move Laterally (Complete Box A)
3 Install Guardrail Along Bridgerail Face
4 Deck Over Gap Between Parallel Bridges and Install Single Bridgerail (Complete Box A)

2 (40) 3 (41) Guardrail — (42)
1 Remove Existing Guardrail
2 Upgrade to Full Safety Standards (Complete Box B if applicable)
3 Upgrade to Full Safety Standards and Close-up Gap (Complete Box B)
4 Close-up Gap Between Existing Guardrail (Complete Box B)
5 Anchor Existing Guardrail to Bridgerail
6 Safety Treat Guardrail Free-End Only

2 (40) 4 (41) Ditch — (42)
1 Reshape to Safe Cross Section
2 Replace with Storm Drain
3 Protect with Guardrail (Complete Box A)
(43)

BOX 4

SLOPE IMPROVEMENTS

3 (40) 1 (41) Install Guardrail to Protect Slope Not at Bridge — May Include Point Hazards on Slope (Complete Box A) — (42) (43)

3 (40) 2 (41) Install Approach or Departing Guardrail at Bridge — May Include Point Hazards on Slope (Complete Box A) — (42) (43)

3 (40) 3 (41) Install Continuous Guardrail Between Successive Bridges

3 (40) 4 (41) FLATTEN SLOPE

FRONT SLOPE
- Hinge Point Offset (H_p)(ft): Beginning (42 43) – End (44 45)
- Steepness: Beginning (46 47) :1; End (48 49) :1
- Distance "D_1" (ft): Beginning (50 51) – End (52 53)
- Slope Direction (54): 1 Positive, 2 Negative

2nd or BACK SLOPE
- Steepness: Beginning (55 56) :1; End (57 58) :1
- Distance "D_2" (ft): Beginning (59 60) – End (61 62)
- Slope Direction (63): 1 Positive, 2 Negative

Milepoint of Improved Slope (Complete if Different From Inventory): Beginning (64 65 66 67 68 69); End (70 71 72 73 74 75)

BOXES A & B

Box A (Install Guardrail)
- Right or Median Near Side or Approach Guardrail — Lateral Offset (ft): Beginning (44 45) – End (46 47)
- Median Far Side or Departing Guardrail — Lateral Offset (ft): Beginning (48 49) – End (50 51)

Box B (Changes to Existing Guardrail)
- Lengthen (ft): Beginning (43 44 45 46); End (47 48 49 50)
- Shorten (ft): Beginning (51 52 53 54); End (55 56 57 58)

BOX 5

4 (40) No Improvement Recommended

2 (77) Card Type

it provides the data for computation of the after condition hazard index for cost-effectiveness analysis. Box 1 and only one of boxes 2 through 5 are completed on each form.

COMPUTER ANALYSIS MODEL

The computerized evaluation analysis performs the cost-effectiveness mathematical computations and is structured so that all possible alternatives can be evaluated with a minimum of input information. Therefore, it was desirable to incorporate within the analysis model hazard severity, vehicle encroachment, and other such information. This reduced the input requirements to specific hazard information such as dimensions and location and specification of a particular improvement.

The computer analysis model, written in FORTRAN, uses 39 subroutines and a main program. In addition to simplifying the logic and model validation, subroutines provide the necessary flexibility for modifying or extending the analysis procedure to accommodate unique situations that may be encountered in the field.

Capabilities of Analysis Model

The model is capable of evaluating four improvement alternatives for a single hazard or a hazard grouping containing a maximum of 15 hazards with four improvement alternatives per hazard. Only in rare instances were more than two alternatives required.

Error and Flag Messages

Because operation of a computer program relies on precise data input, error messages were incorporated into the program to identify input errors. Because of the complexity of the program and extensive branching within subroutines from several data sources, data input errors will occur. To avoid program termination (which would normally occur for each data error), the program bypasses erroneous data, prints out an error message, and continues with the next data input.

Fifty-one error messages have been incorporated. The list of numbered messages is printed out for each computer run, and each error message is identified in the data output by reference number. Also printed out is the location within the program or subroutine in which the data error affected program execution. The message indicates the type of error and provides direction to remedy the data error. The program automatically terminates if 100 error messages are printed during any run.

Analysis Model Data Output

The computer output provides a listing of hazard data, improvement data including costs, and the cost-effectiveness value. Two case examples are presented to illustrate typical output.

Case 1: Point Hazard in Median

Figure 3 shows a typical point hazard—a set of three closely spaced bridge piers in a median. For analysis purposes, the three piers are considered as one point hazard with dimensions of the peripheral boundaries because a vehicle cannot pass between two adjacent piers. The four safety alternatives evaluated are (a) remove the piers (replace the bridge with a single-span structure), (b) install guardrail around the piers, (c) install a concrete median barrier integral with the piers, and (d) install an impact-attenuation system at the ends of the pier formation. Figure 4 shows the computer program out-

Figure 3. Hazard description, case 1.

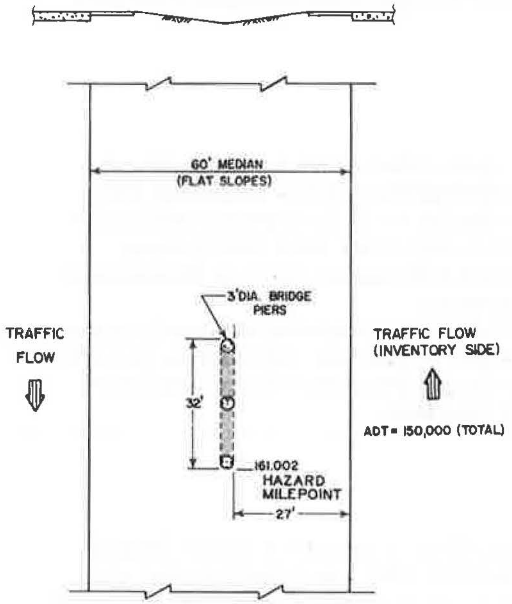

Figure 4. Cost-effectiveness program output, case 1.

TYPE HIGHWAY = INTERSTATE (CODE 08)
HIGHWAY CLASSIFICATION = CONTROLLED ACCESS -- INTERSTATE

HIGHWAY NO = 10
COUNTY NO = 230
DISTRICT NO = 19
CONTROL NO = 26
SECTION NO = 12

RECORDING DIRECTION = 1
ADT (1000) = 150
LIFE = 20(YRS)
INTEREST = 8.0(PERCENT)
DATE = 10-74

H A Z A R D										I M P R O V E M E N T						
HAZARD NO	IDENT CODE	DESC CODE	END TREATMENT BEG	END TREATMENT END	SEVERITY INDEX	OFFSET CODE	GROUP NO	MILE-POST BEG	MILE-POST END	IMPR ALT	IMPR CODE	SEVERITY INDEX	FIRST COST ($)	PRESENT WORTH ($)	ANNUAL COST ($/YR)	COST EFFECTIVE VALUE
100	11	1	0	0	82.5	2	0	161.002	161.008	1	1-1-1-0	0.0	225000	224999	22916	10114
100	11	1	0	0	82.5	2	0	161.002	161.008	2	1-2-0-0	*HAZARD IMPROVEMENT NOT COST-EFFECTIVE*				
100	11	1	0	0	82.5	2	0	161.002	161.008	3	1-3-0-0	2.6	1500	1990	202	96
100	11	1	0	0	82.5	2	0	161.002	161.008	4	1-4-0-0	1.0	10000	12181	1240	576

put for each of these alternatives.

Case 2: Group of Hazards in Median

Figure 5 shows the locations of five hazards in a grouping. Each cluster of trees is considered to be a point hazard within the group. The group also includes a guardrail, a critical slope, and a raised drop inlet. Each hazard within the group is inventoried individually. Although several alternatives exist, only two are discussed. The first alternative is upgrading the existing guardrail to full safety standards to protect the slope and leaving the other hazards as they exist. The second alternative is removing the guardrail, replacing the raised inlet with a flush inlet (removal of hazard), and removing the two clumps of trees. Figure 6 shows the analysis of these two alternatives.

Interpretation of Analysis Results

The program output basically is of two forms—individual hazards (point, longitudinal, or slope hazards) or a group of hazards containing several hazards of the same category or of mixed categories but for which a single improvement is recommended. Case 1 output is typical of the former; case 2 output illustrates the latter. For improvements to a group of hazards, the message "group" appears in the cost-effectiveness column adjacent to each individual hazard within the group except the last hazard. The cost-effectiveness value for the safety improvement of the complete group is shown adjacent to the last hazard in the group.

The output column headings generally are self-explanatory; however, the cost columns require some amplification. The first cost is the net cost to improve the existing hazard to the desired level. Hazard 101 in Figure 6 (guardrail) requires a first cost of $650 to upgrade it to full safety standards. The annual cost is the sum of the first cost, the cost of routine maintenance, and the repair cost per collision, all annualized over the life of the object. The present worth is the annual cost discounted to the present at an 8 percent interest rate. Object life and interest rate may be varied in the computer program.

Nature of the Cost-Effectiveness Value

Cost-effectiveness analysis relates the improvement cost of a hazard to the degree of hazard reduction achieved in comparison to the existing state. The conceptual model (1) that forms the analysis basis of the work is probabilistic rather than being based on accident experience. The general form of the model is

$$C/E = \frac{\text{cost (to the agency)}}{\text{relative hazard reduction}} \tag{1}$$

where

C/E = cost-effectiveness value (dollars per fatal or serious injury accident eliminated during the life of the improvement),
cost = annualized total cost (included normal annual maintenance cost and per-hit repair cost of the existing obstacle),
hazard reduction = difference in hazard index before and after improvement ($h_{before} - h_{after}$).

The cost elements, incurred at different points in time, must be converted to a common base. Annual costs over the life of the improvement are used in cost-effectiveness

Figure 5. Hazard description, case 2.

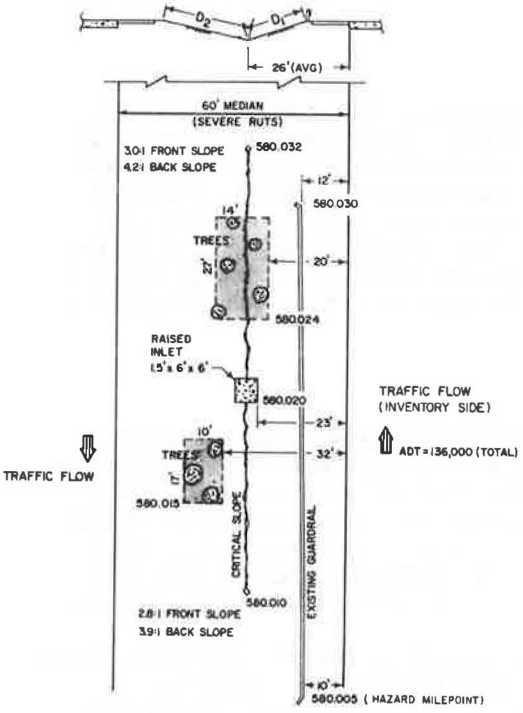

Figure 6. Cost-effectiveness program output, case 2.

TYPE HIGHWAY = INTERSTATE (CODE 08)
HIGHWAY CLASSIFICATION = CONTROLLED ACCESS -- INTERSTATE

HIGHWAY NO = 20
COUNTY NO = 163
DISTRICT NO = 15
CONTROL NO = 123
SECTION NO = 2

RECORDING DIRECTION = 1
ADT (1000) = 136
LIFE = 20(YRS)
INTEREST = 8.0(PERCENT)
DATE = 10-74

H A Z A R D										I M P R O V E M E N T						
HAZARD NO	IDENT CODE	DESC CODE	END TREATMENT BEG	END TREATMENT END	SEVERITY INDEX	OFFSET CODE	GROUP NO	MILE-POST BEG	MILE-POST END	IMPR ALT	IMPR CODE	SEVERITY INDEX	FIRST COST ($)	PRESENT WORTH ($)	ANNUAL COST ($/YR)	COST EFFECTIVE VALUE
101	6	2	2	2	17.3	2	333	580.005	580.030	1	2-3-2-0	3.7	650	157	15	GROUP
105	2	0	0	0	50.0	2	333	580.024	580.029	1	4-0-0-0	50.0	0	157	15	GROUP
104	10	1	0	0	82.5	2	333	580.020	580.021	1	4-0-0-0	82.5	0	157	15	GROUP
102	7	2	0	0	60.0	2	333	580.010	580.032	1	3-1-0-0	3.7	1600	2990	304	GROUP
103	2	0	0	0	50.0	2	333	580.015	580.018	1	4-0-0-0	50.0	0	2990	304	121
101	6	2	2	2	17.3	2	333	580.005	580.030	2	2-3-1-0	0.0	500	-1127	-114	GROUP
105	2	0	0	0	50.0	2	333	580.024	580.029	2	1-1-1-0	0.0	250	-1368	-139	GROUP
104	10	1	0	0	82.5	2	333	580.020	580.021	2	1-1-3-0	0.0	2000	631	64	GROUP
102	7	2	0	0	60.0	2	333	580.010	580.032	2	4-0-0-0	60.0	0	631	64	GROUP
103	2	0	0	0	50.0	2	333	580.015	580.018	2	1-1-1-0	0.0	175	315	32	8

analysis. A service life of 20 years and an interest rate of 8 percent have been assumed in the development of the cost-effectiveness computer program; however, other values may be substituted.

The numerator in equation 1 is composed of three major cost elements: annualized cost of improvement, difference in annualized routine maintenance cost before and after improvement, and difference in the annualized cost of repair following each expected collision with the existing object and after improvements. The denominator is the difference in the degree of hazard between the existing and the recommended improved states. The hazard index includes both the probability of the existing obstacle or the improvement being struck and the severity of the resulting collision. The difference in the hazard indexes before and after improvement is a measure of the effectiveness of the improvement.

As the cost of an improvement increases, the relative desirability of the improvement decreases; and as the change in hazard increases, the relative desirability of the improvement increases. Thus, the analysis model is internally consistent, and the smaller cost-effectiveness value represents the higher priority improvement.

The cost-effectiveness value is expressed as annualized dollars required to reduce one fatal or serious injury accident. The numerical value at which any given improvement alternative is considered to be cost effective is arbitrary. However, the cost-effectiveness analysis permits development of a priority listing of alternative improvements, and, therefore, improvements with large cost-effectiveness values are given lower priority.

Priority Rankings for Improvement Alternatives

Cases 1 and 2 represent only a sample of data obtained from a complete inventory. After the improvements throughout a particular section of roadway are evaluated, the various alternatives may be ranked in several ways: by cost-effectiveness value, by individual cost, by cumulative cost with respect to cost-effectiveness value, or in a variety of other ways depending on the desired use.

Safety improvement programs established from the cost-effectiveness analysis must be reviewed carefully to determine the practicality of the improvements. For example, assume that removing a system of trees is given the highest priority. With the current emphasis on beautification and preservation of natural beauty, it may not be politically feasible to remove the trees, particularly if these trees were planted as part of a recent beautification program. Sound engineering is a vital ingredient in evaluating the output and establishing a safety improvement program.

FIELD TESTING THE PROCEDURE

The validity of the procedure—hazard identification, hazard inventory, hazard improvements, and analysis—is highly dependent on the strengths and weaknesses of each of the facets. Each was subjected to rigorous field testing during the developmental stage.

One district in Texas was selected to validate the procedure and the analysis model under operational conditions. Several thousand roadside hazards were inventoried and analyzed during approximately 6 months. Separate data files were maintained for problem situations. After the data were collected, the problem areas were categorized. The hazard identification list was expanded where necessary to permit coding obstacles not previously included. The hazard inventory and improvement forms were modified to accommodate hazards and improvement alternatives not identified during initial field trials.

The entire analysis model was reworked and expanded to be responsive to the problems encountered in the full-scale implementation testing. All data collected were reanalyzed after the major program revision until the problems were alleviated. The procedure reported here represents the current status of the identification list, the inventory and improvements, and the analysis model as a result of all validation studies.

Since the latest procedural modifications were incorporated, the complete controlled-access roadway mileage in one district has been inventoried and analyzed; only very minor problems arose during procedure application.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

The results of this research provide a rational procedure for evaluating safety alternatives for roadside hazards and for establishing priorities to develop a safety improvement program. This procedure uses a safety evaluation team to conduct a comprehensive roadside inventory and recommend viable safety alternatives. The evaluative process and data forms developed provide an implementable method of obtaining the information necessary to use cost-effectiveness techniques in a consistent manner. The procedure can be applied throughout large regions, yet reflect cost differences that may exist within or between particular regions.

This research has extended current technology from a basic concept for evaluating freeways to a practical procedure that is readily applicable on both controlled- and non-controlled-access rural roadways. In addition, the concept and procedures developed in this research may be applied at the design stage to evaluate alternative designs; they are not limited to evaluation of existing hazards.

The process developed in this research provides a technique to put a basic concept to work in the area of roadside safety for all types of roadways—a technique that is readily adaptable to individual requirements and agency policies. Full success of the process as an administrative tool for the development of a priority safety improvement program is dependent on its flexibility for modification and expansion that may result from further field implementation and subsequent research.

Although the procedure can be implemented immediately, subsequent research will contribute to refinement and growth of the process. Specific recommendations for future research are as follows.

1. Vehicle encroachment characteristics for non-controlled-access highways, particularly those without medians, should be determined. The current analysis model incorporates encroachment data based on research findings concerning median encroachments.
2. Encroachment data applicable for horizontal curvature and bridges should be determined. These geometric features influence the encroachment characteristics and, hence, modify the encroachment data for tangent sections on which the analysis currently is based.
3. Additional field trials of the procedure on non-controlled-access highways will identify deficiencies that may exist in inventorying or improvement alternatives. After approximately 1 year, the process should be revised, as appropriate, to reflect the input from the results of the field trial. It is highly probable that the hazard inventory list will require extension to accommodate additional roadside obstacles.
4. Computerized file systems should be developed to summarize model output for administrative use in developing a safety priority program. Such file systems must be structured to meet the needs of the particular user.
5. As experience is gained through evaluation of analysis data from inventoried roadway mileage, it may become apparent that certain roadside obstacles currently being evaluated do not exhibit cost-effective improvements. The analysis output should be critically reviewed to identify those obstacles, and they should be omitted from subsequent inventorying or certain improvement recommendations that consistently produce non-cost-effective alternatives should be omitted.
6. Close liaison between design personnel and the safety evaluation team is encouraged. Only through cooperative effort can the results of the roadside safety evaluation be applied at the design stage where they can be most effectively applied to produce safer roadways.

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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.

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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):

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

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

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

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):

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

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

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

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

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.

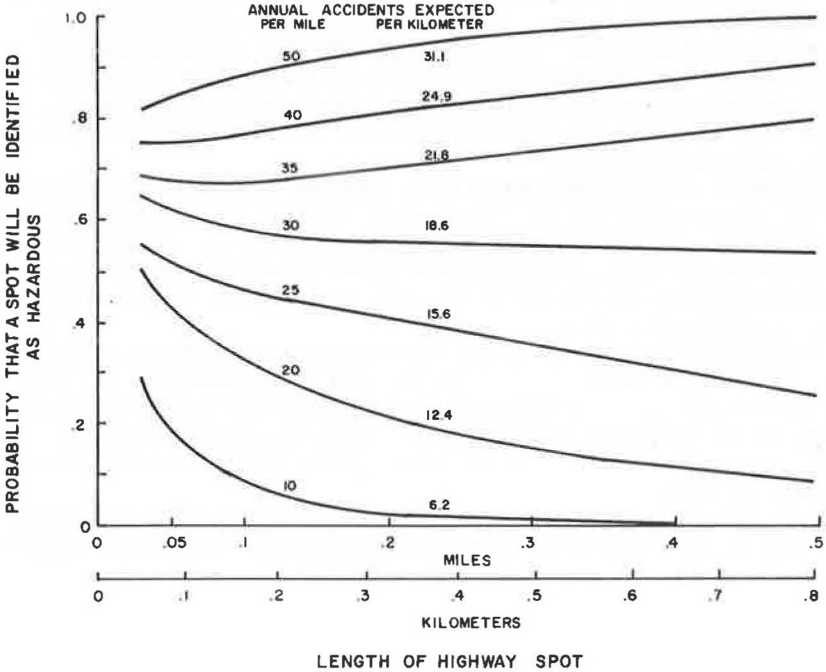
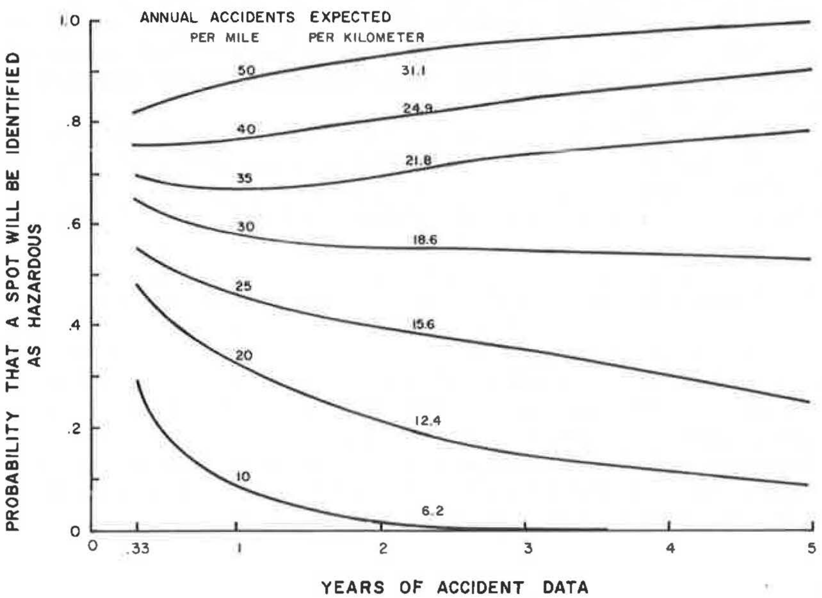


Figure 2. Effect of time periods on the probability of identifying a spot as hazardous.



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.

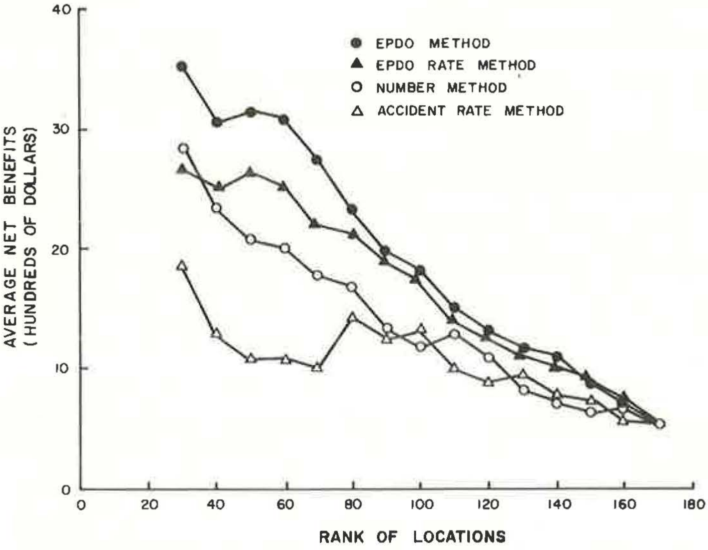
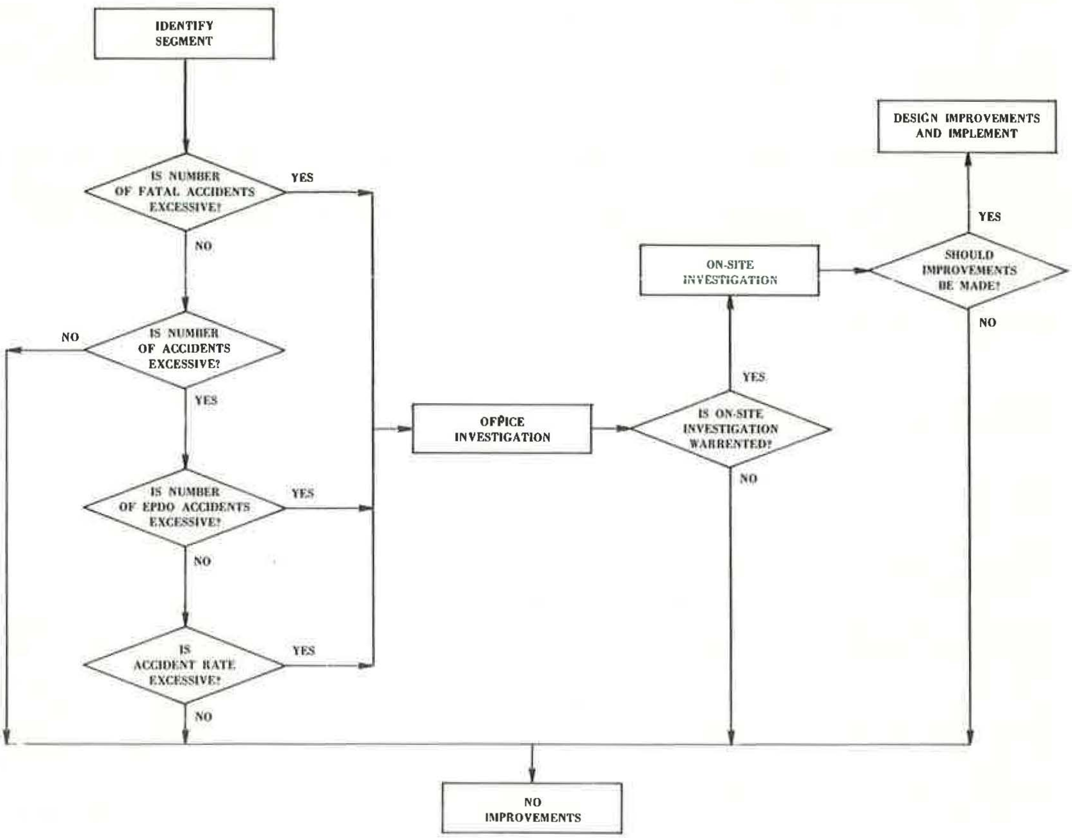


Figure 4. Recommended procedure for identifying and investigating hazardous highway segments.



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.

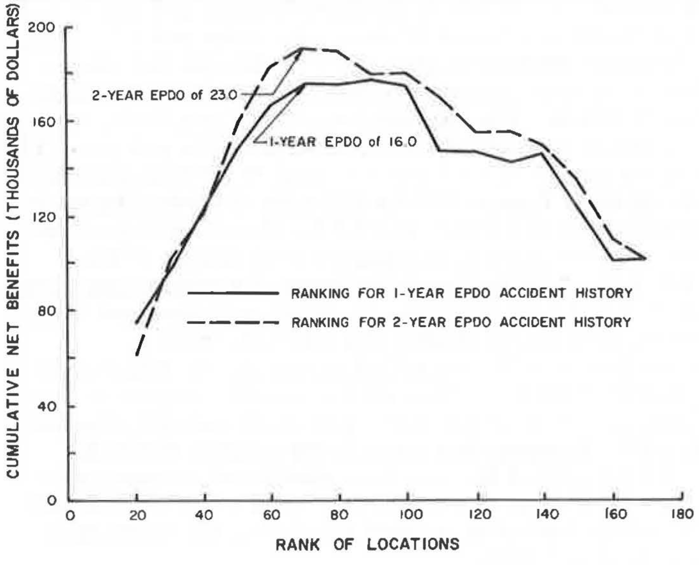
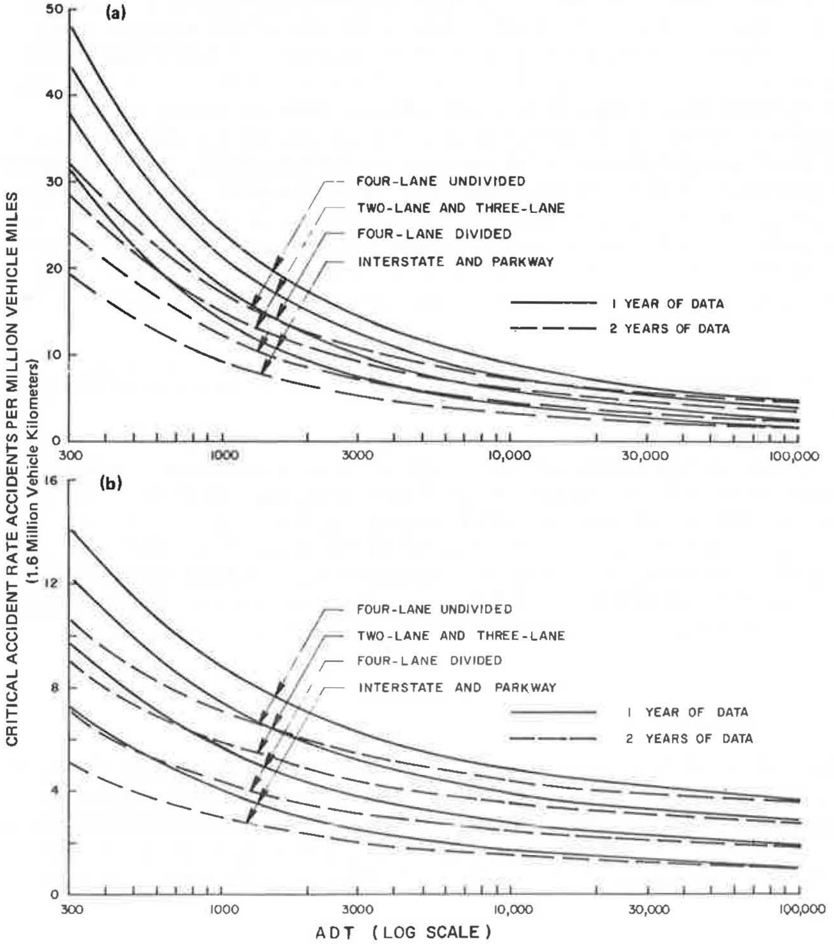


Figure 6. Critical accident rates for (a) 0.3-mile (0.48-km) nonintersection spots and (b) 3-mile (4.8-km) sections (p = 0.001).



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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USE OF A QUASI-COORDINATE LINK-NODE SYSTEM FOR LOCATING ACCIDENTS

Merrell E. Goolsby and Frank C. Yu, Wilbur Smith and Associates

The U.S. Public Land Survey method for land subdivision was used as the basis for development of a quasi-coordinate accident location system. The accident location and analysis system developed in Iowa is a link-node system that has been adapted to this quasi-coordinate method for recording accident location. This system is used to accurately identify accident locations for input to the computer system. This paper discusses the development of the system and the methodology for applying it to the complete network of urban and rural roadways in Iowa; sample maps developed for use by accident coders are included. The system is highly user oriented to provide a wide range of summaries and analyses for highway and traffic engineers and law enforcement agencies.

TRAFFIC ACCIDENT RECORDS are a basic element in any safety program to reduce the incidence or severity of highway collisions. Without a readily accessible information base containing accident history, trends, and relationships, the identification of deficiencies and decisions for improvement at specific locations are necessarily difficult and often subjective.

A usable traffic accident information system for accurately identifying the locations where accident losses have been significant would facilitate engineering or law enforcement countermeasures.

The U.S. Department of Transportation's Highway Safety Program Manual stipulates that "each state, in cooperation with county and other local governments, shall have a program for identifying accident locations and for maintaining surveillance of those locations having high accident rates or losses" (1).

This paper is based on a study conducted for the Iowa State Highway Commission to develop accident location and analysis concepts for a statewide computer-based accident records system that is responsive to local and state needs and conforms to the requirement of the U.S. Department of Transportation. The system developed has application to accidents occurring on all Iowa streets and highways. Iowa has one of the most intensely developed highway networks in the country: more than 112,000 miles (180 000 km) of streets and highways, of which 99,000 miles (159 000 km) are rural highways.

The objectives of the study were to develop a systematic procedure for accurately describing the location of accidents and to develop methods for analysis of interrelated accident, roadway, and traffic data to aid in determining appropriate remedial action.

This system will contain all accident reports for the entire state, including those on the state highway system, county road system, and local municipal streets. Because of the many accident reporting sources involved and the variety of methods used to report the locations of accidents, the coding of accident records for input to the state's computerized accident records system will be centralized.

It is axiomatic that any accident records system can be only as accurate as the information that comes from the field. Law enforcement agencies in Iowa will be

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requested to report accident locations to the desired degree of accuracy [generally 0.1 mile (0.16 km) in rural areas and 0.01 mile (0.016 km) in urban areas].

Although various methods of referencing accident locations in the field exist (2), all use a distance measurement from the point of incident to a known reference point and specify the direction of measurement. The characteristics of all data reduction from field recordings are essentially the same, whether the reduction is manual or computerized.

In order that accident information can be stored and retrieved systematically by location, accidents must be keyed internally in the computer.

A link-node concept was developed, based on a quasi-coordinate location system, that is applicable to the entire state of Iowa. Appropriate locational information is coded at the central processing facility for the state. This locational method and basic aspects of the function of the computer system are discussed later.

QUASI-COORDINATE NODAL SYSTEM FOR IOWA

In the link-node method, a unique node number is assigned to each intersection or other prominent feature of the roadway, such as railroad grade crossings and bridges. Thereby, a single node number identifies the location of a traffic accident occurring at that point. For an accident occurring between nodes, the link is identified by the nearest node in each direction and the distance from one of the nodes.

If node numbers are assigned arbitrarily without considering their spatial interrelationship, it may be difficult to assemble accident data on an areawide basis. It also is difficult to locate any given node on a map on the basis of its number alone. Even if nodes are initially numbered in a systematic manner, it may not be possible to relate new node numbers necessitated by land subdivision and new streets and highways to those numbers previously assigned. Therefore, a quasi-coordinate nodal system was developed (3). The system adopts the basic units of the U.S. Public Land Survey method and incorporates them in a nodal assignment system for identifying accident locations.

U.S. Public Land Survey Method

The public lands of many states, including Iowa, were originally subdivided into townships and sections under a rectangular system of land subdivision developed in 1785. These congressional townships are fixed land areas, each approximately 6 miles (9.6 km) square, bounded by meridional and latitudinal lines. (In contrast, civil townships are subdivisions established for purposes of political jurisdiction.) Congressional townships are divided into 36 secondary units called sections, each approximately 1 mile (1.6 km) square. A row of townships extending north and south is called a range, and a row extending east and west is called a tier (often referred to as township). The relationship of township, range, tier, and section is shown in Figure 1.

The Iowa State Highway Commission county and city maps contain no reference either to latitude and longitude lines or to any plane-coordinate system. Each map, however, does include a complete description of the system of congressional townships, ranges, and sections. County boundaries in Iowa include a number of complete congressional townships. This public land subdivision grid provided the basis on which the node-numbering scheme was developed. This readily available source of locational identification was a primary consideration in development of the quasi-coordinate system.

Selection of Nodes

The network of numbered nodes used in accident location coding includes all locations that an officer or motorist would ordinarily use as reference points to identify the

Figure 1. Relationship of township, range, tier, and section in the U.S. Public Land Survey method.

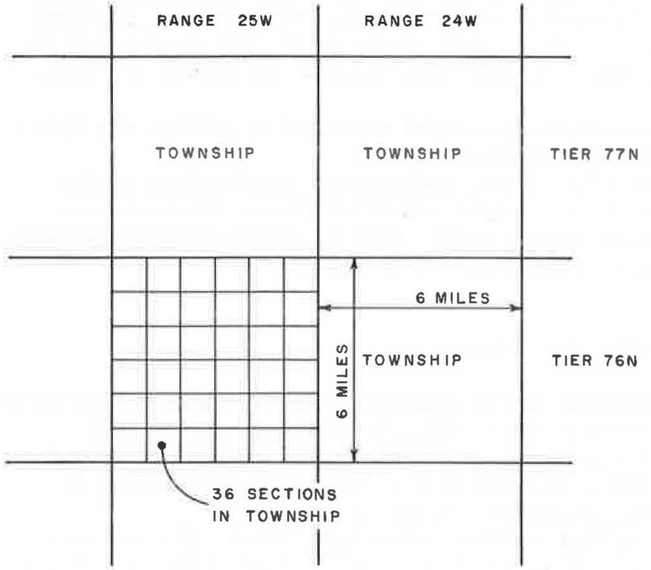
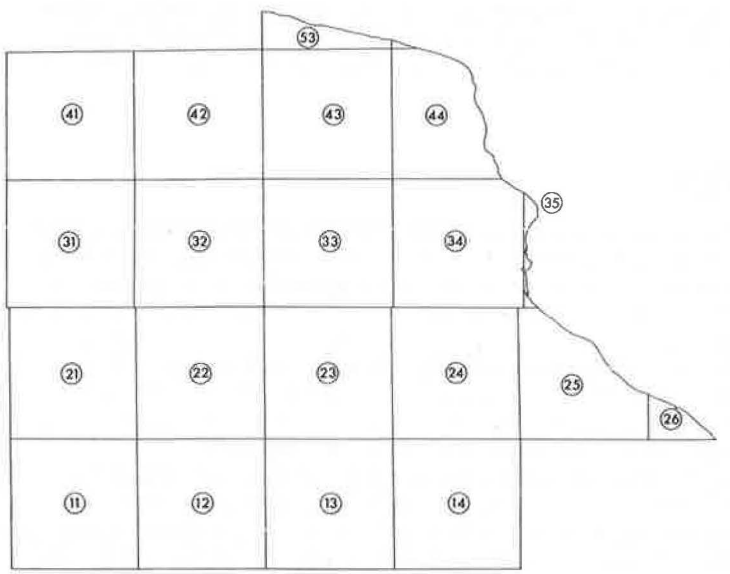


Figure 2. Example of township numbering scheme in a county.



location of an accident. Furthermore, to be usable in coding the accident location for the accident records system, all node locations must be identifiable on a county or city map.

Consequently, the following elements of the roadway network are assigned node numbers:

1. Intersections (except alleys),
2. Ramp terminals,
3. Railroad crossings,
4. Grade separation structures,
5. Bridges,
6. Road ends,
7. Ninety-deg turns, and
8. County boundaries.

The corporate limits of cities and towns are subject to change from year to year; therefore, they are not treated as nodes.

Numbering System

A special set of maps was developed for coverage of the complete state for use by office coders. County maps are used for indicating node numbers on rural highways, whereas larger scale maps are used for indicating nodes in cities and urbanized areas. These node maps were prepared by using specially developed scales to determine the appropriate node identification.

A six-digit number is assigned to each node. The first two digits represent the township in which the node is located. The first digit indicates the tier within a county, numbered sequentially from south to north, and the second digit indicates the range, numbered from west to east (Figure 2). This marking system gives county-level uniqueness only. For statewide uniqueness, a two-digit county number, which also appears in accident coding, is linked to this six-digit node number.

Each congressional township then is divided into 96 units in both the south-north and west-east directions. The third and fourth digits, therefore, indicate the south-north coordinate position, and the fifth and sixth digits indicate the west-east position within the township. A node is identified by the coordinate position that is closest to the scaled location of the node. The average spacing between available node numbers is approximately 330 ft (100 m) in each direction.

Some nodes, of course, are closer than the average spacing, whereas others are farther apart. It therefore is necessary to deviate somewhat from rigid coordinate positions in some instances in order to accommodate all nodes requiring numbers. Thus the system is not a true coordinate system; it is called a quasi-coordinate system because assignment of node numbers is based on approximate location in the grid. Generally nodes along a route are numbered in ascending order from south to north, or from west to east, within a county. For example, an intersection located in the second township at the center of the south edge of section 2 would be assigned the node number 2 1 81 73.

Dual node numbers are assigned to nodes on county borders (one for each county) on individual county maps, so that (a) both nodes on a single link that ends at the county boundary are assigned to the same county and (b) an accident occurring on the boundary may be assigned by county to the correct investigating agency (which varies from county to county).

Accidents at highway interchanges are assigned a node number to each ramp terminus. An example of interchange node numbering is shown in Figure 3. Sample node numbering on rural and urban maps is shown in Figures 4 and 5 respectively.

Figure 3. Example of freeway node coding.

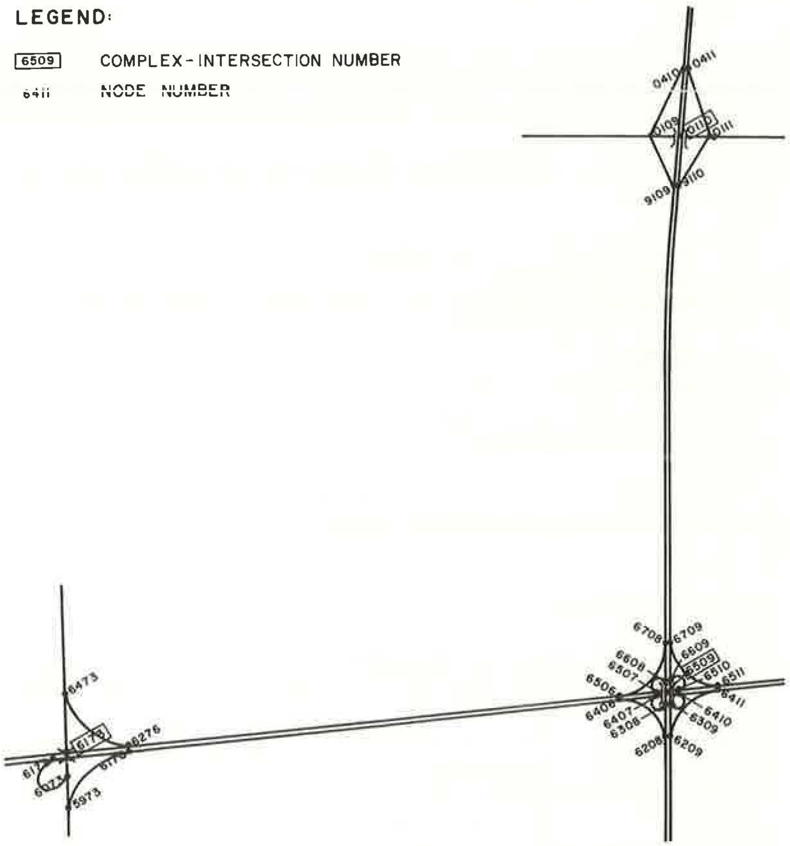


Figure 4. Example of rural node coding.

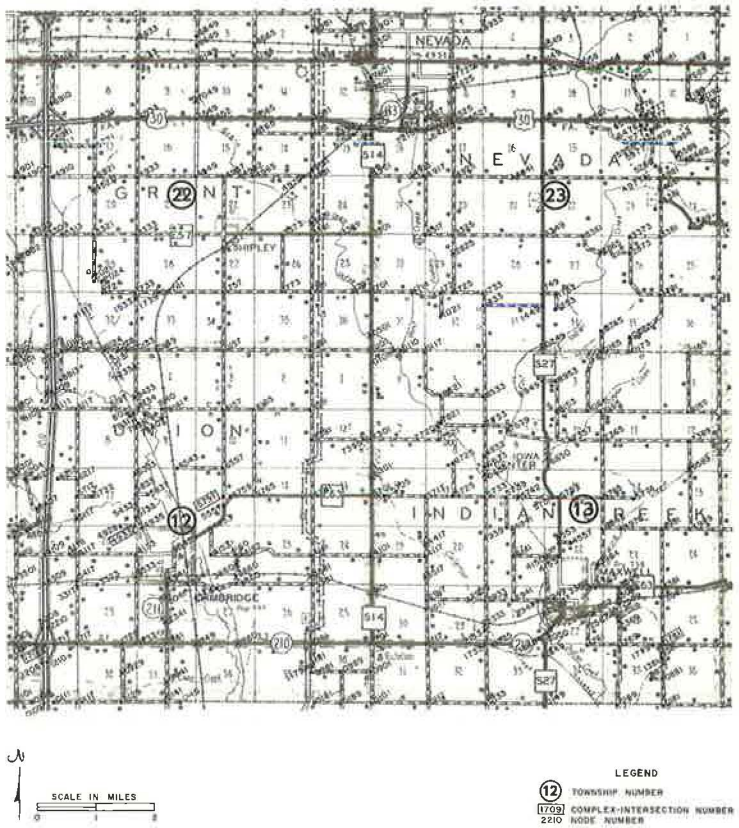
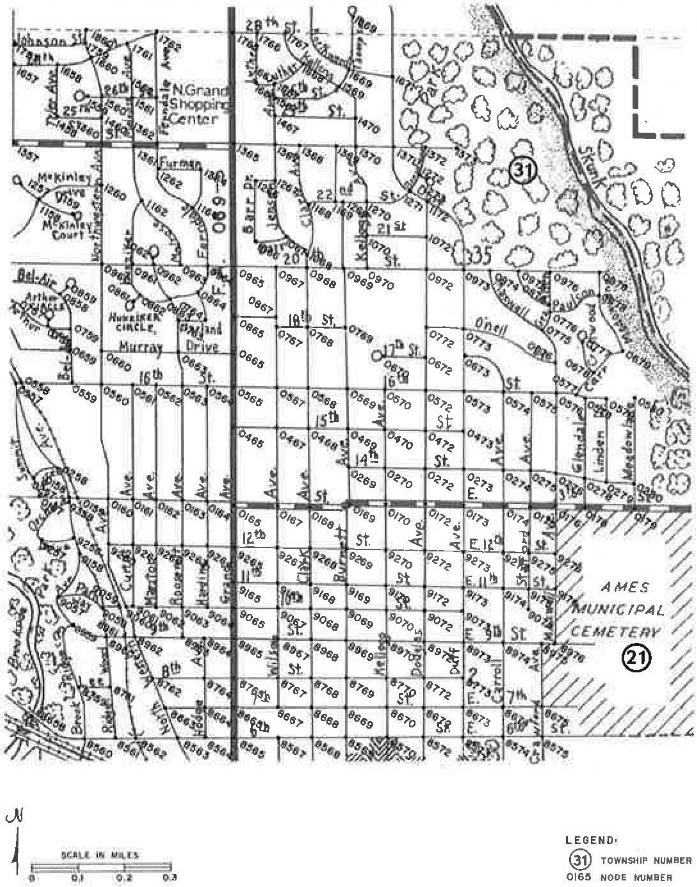


Figure 5. Example of urban street node coding.



Accident Location Coding

In the central office coding of accident reports, accidents occurring at intersections or other nodes are given a single-number location descriptor. Accidents occurring between nodes are coded by indicating (a) one of the two nodes defining the link on which the accident occurred, usually the nearer, (b) the distance from the first node in the direction of the second node, and (c) the second node.

For example, if an accident occurs 0.02 mile (0.03 km) west of an intersection bearing the node number 2 1 81 73, its location is coded as 218173/002/218172. No convention for deciding on the node to be referenced need be established. If the accident is 0.04 mile (0.06 km) west of node 218173, the location could also be coded as 218172/004/218173. The equivalency of these two location descriptions would be established by the computer accident system, which is interfaced with the roadway inventory system for roadway segment lengths.

Incomplete Locational Data

If an accident location cannot be determined from the information given on the accident report, zeros are coded in place of the unknown portions. For example, if the township alone is known, the location would be coded as 210000 (or 210000/0000/210000 for link accidents). Similarly, if the node numbers for a link accident are known but not the distance, the location of the accident would be coded as 281873/000/218172. By this method, accident information can be used to the extent possible in developing accident summaries.

Many location measurements on incoming accident reports are given in feet, particularly in urban areas. Coding personnel use conversion tables to convert from feet to miles.

Complex Intersections

A complex intersection or interchange containing several nodes, as shown in Figure 3, is identified by selecting one of the nodes as the intersection identifier and indicating it as such on the coding map. The intersection identifier is coded, in addition to the specific location identifiers discussed in the previous section. This field is left blank for all accidents not occurring within complex intersections.

Accident Location Accuracy

Investigating officers and drivers are required to cite reference points (nodes) on their respective reports only by their proper names, e.g., the intersection of two streets, a railroad grade crossing, and so on.

The location measurement given for an accident should be sufficiently accurate to pinpoint any roadway or environmental features that may have constituted a hazard. The Highway Safety Program Manual (1) recommends a minimum level of accuracy of 0.01 mile (0.016 km) for residential and commercial streets in urban areas, urban expressways and freeways, rural roads within the area of influence of an intersection, and all other locations where there is a convenient reference. In other cases, identification should be as accurate as possible under the circumstances.

Urban Areas

Accident locations in urban areas are generally referenced to the nearest intersection (node). If an accident does not occur at a node, a distance measurement is made by using tape or measuring wheel or possibly by visual estimation. An accuracy of 0.01 mile (0.016 km) is desired in all cases.

Rural Primary System

Accidents occurring on rural primary routes close to nodes may be referenced to the node by manual measurement, whereas other accidents generally are referenced to a milepost (which are placed only on the rural primary system) or highway feature by use of a standard automobile odometer. In this case, the accuracy obtainable would be approximately 0.1 mile (0.16 km).

Rural Secondary Roads

Many of the secondary roads in Iowa have not been assigned names or numbers. Thus description of these locations is often impossible. It was decided that the existing practice in Iowa of using reduced-scale county maps to pinpoint accident locations on these roads would be appropriate. These maps are supplied free of charge to all highway patrol districts, county sheriffs, and automobile insurance agencies.

Reports of accidents on the rural secondary system should be accompanied by a map with the accident location marked. Instructions to this effect are included in the accident report form. These maps are to be used by accident coders to associate an accident with the proper node or link. Marking a map will not replace an accurate distance measurement from the referenced node (for link accidents); this distance measurement should also be indicated on the report form.

ACCIDENT INFORMATION SYSTEM

A computerized accident location and analysis system (ALAS) that uses the location methods described previously was designed for the Iowa State Highway Commission. The first phase of development of this system became operational in early 1975 (4). ALAS has the capability of identifying locations of accidents and their characteristics and frequencies. The system has the flexibility to respond to information needs of the user and has numerous user-oriented options available. ALAS is being developed on a staged implementation basis and ultimately will be interfaced with the roadway inventory file as well as other data files to facilitate more detailed causative analyses and correlation.

The initial development of ALAS provides important new capabilities for identifying accident locations and permits special analyses to be made by the highway commission and other users of the system. ALAS can rank accident locations for the entire state or for individual counties and cities by any one of the following definitions of rank significance as specified by the user: total number of accidents, accident severity, and total value loss. Accident rankings can be obtained for intersections, nodes, or links. This permits the users of ALAS to identify locations that require special study, analysis, or on-site observation, with the objective of selecting design or control measures for reducing accident frequency or severity.

ALAS also can rapidly retrieve accident histories for specific locations or with particular attributes and can compile accident data for specific nodes, intersections, links, or node strings (sections of roadway). The system user can simply specify the location identification or attributes and the time interval of interest and obtain from the system a listing of accidents, and their characteristics, that took place at the specified location.

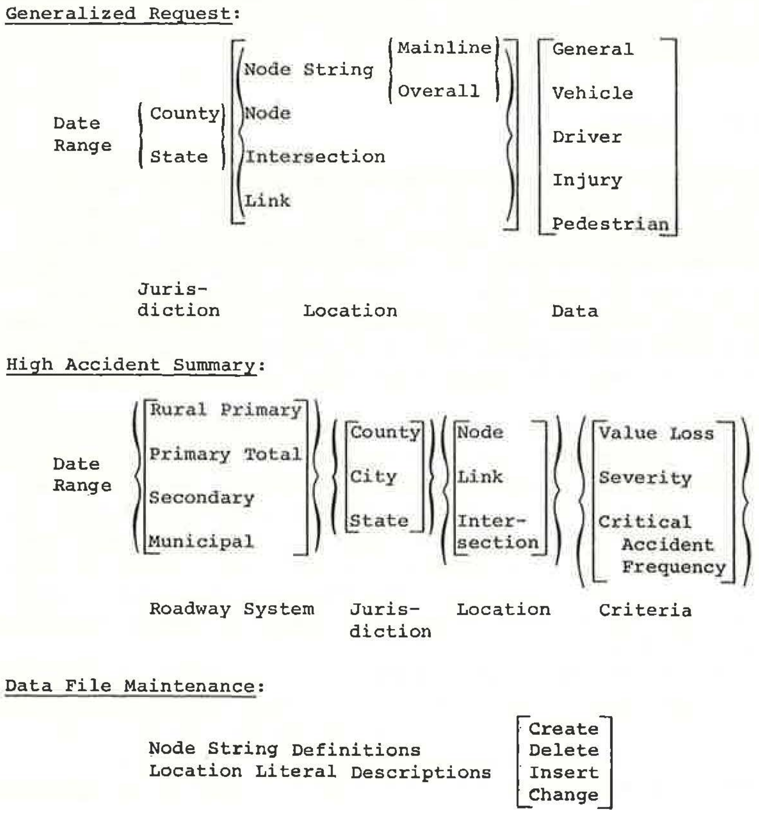
The capabilities of the initial development of ALAS are shown symbolically in Figure 6. Two types of data requests can be made: one for generalized accident information at specific locations or for particular attributes and the other for a high-accident summary. With either type of request, the range of dates to be covered in the accident records search must be specified. Following is an explanation of the symbols used in the figure:

1. Brackets represent alternatives that may be included or omitted, depending on requirements of the user;
2. Braces represent another choice of alternatives, one (and only one) of which must be chosen per request run;
3. Brackets within braces denote that one or more of the indicated options must be chosen, depending on the programming requirements; and
4. Braces within brackets denote that the information may be omitted if desired.

SUMMARY

The quasi-coordinate link-node system adopted in Iowa is based on the U.S. Public Land Survey method for land subdivision. This method of land subdivision is used by 30 states. The quasi-coordinate link-node system can be easily implemented for accident location when the township-range-section identifications are included on existing maps. It provides a permanent grid on which node numbers can be assigned, and additional node numbers can be added as new intersections (or other nodes) are created through realignment or as subdivision of land occurs. The coordinate properties of the node numbers offer some potential for schematic plotting, which would

Figure 6. Capabilities of ALAS.



be useful for accident analysis.

An accident information system using the quasi-coordinate link-node locational method was developed for Iowa. ALAS provides the capability to identify locations that have experienced a high accident record and to obtain accident records for selected locations or accidents possessing particular attributes.

ACKNOWLEDGMENTS

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The authors wish to express their appreciation to Harold C. Schiel, Dwight L. Stevens, and John P. Nervig of the Iowa State Highway Commission for their contributions to the development of concepts presented in this paper.

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UTILIZATION OF A MOTORCYCLE ACCIDENT TYPOLOGY

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This paper describes the creation of a motorcycle accident data base during the performance of a study for the Motorcycle Safety Foundation. The objective of the study was to determine the status of motorcycle accident data, to determine causal factors of accidents, to identify voids in the information, and to suggest a basis for future improved educational and public information programs. A motorcycle accident typology was devised to identify accident categories for which specific countermeasures could be designed. On the basis of the distribution of 1,191 motorcycle accidents in Maryland in 1973, 600 police accident reports were sampled in order to represent the six most prevalent accident types. Using this typology permitted the identification of accident culpability (who or what was at fault) and of primary and secondary causation factors for each of the accident types. A primary product of the study, which is described in detail in this paper, was the identification of statistically significant differences between accident types on each of the 54 accident variables coded.

•MOTORCYCLING is both a means of transportation and recreation. It is probably the form of powered transport that is the most exhilarating, economical, and, unfortunately, dangerous.

In 1945, there were 31 million registered motor vehicles in the United States. Of these, 198,000 were motorcycles. By 1973 there were 128 million registered motor vehicles, and slightly more than 4 million of these were motorcycles. Motorcycles used solely for off-road activities such as competition and trail riding and minibikes are not reflected in these statistics. Hare and Springer estimate that there were 5 million motorcycles in use nationwide at the end of 1972. This estimate includes the trail and competition cycles but excludes minibikes and motorized bicycles (2).

MOTORCYCLE ACCIDENT RESEARCH

Studies of motorcycle accidents in a number of states in the mid-1960s indicated that the growth of the motorcycle population was accompanied by a directly proportional growth in the number of motorcycle accidents. Researchers indicated that there is a high probability that a serious injury or fatality will result from a motorcycle accident (3-8).

A national study found that the fatality rate based on vehicle mileage (exposure) was five times greater for motorcycles than for passenger cars. The study indicated that the motorcycle rider has a greater probability of being killed than the user of any other conventional means of transportation (9).

In 1973, for the first time since 1970, there was a reduction in the number of highway accident fatalities. Only the motorcycle, perhaps as a result of increased use in response to the gasoline shortage, experienced a 20 percent annual rise in fatalities (Table 1).

Publication of this paper sponsored by Committee on Vehicle Characteristics and Committee on Traffic Records.

Scope

The challenge facing those responsible for motorcycle safety is one of devising programs to reduce the frequency and disproportionate severity of motorcycle accidents.

This paper summarizes some of the findings of a recent motorcycle accident study performed for the Motorcycle Safety Foundation. It describes the methodology used in developing a motorcycle accident data base and the findings obtained from a statistical comparison of accident types. The information presented can be used as a guide for the development of safety countermeasure approaches and local countermeasure programs.

Methodology and Rationale

The analysis of motorcycle accident data began with an examination of some 50,000 motorcycle accidents listed in the 1971 National Accident Summary File (NASF) of the National Highway Traffic Safety Administration. The NASF limitation of restricting the data gathered to 11 variables did not permit determinations of culpability or accident causation factors. To satisfactorily determine these factors, we needed access to a large number of police reports containing both narrative descriptions and accident diagrams. Analysis of the hard copies of police accident reports would serve the desired purpose.

A motorcycle accident typology was devised that partitioned the motorcycle accident data into eight exclusive accident types. The typology was based on three classification variables: single- versus multiple-vehicle, rural versus urban, and intersection versus nonintersection accidents. The typology permitted identification of causal factors for each specific accident type rather than for all accidents.

Design of accident remediation techniques requires identification of the makeup of each of the major accident types that compose the total motorcycle accident spectrum. Examination of the accident variables for each of the six major types is more important than identifying these variables for all motorcycle accidents. In this case, the parts are greater than the sum. This is because the use of the accident typology permits education and training material to be developed for each identified accident type. Comparison of variables for the multiple-vehicle, urban intersection accident (type 1) to the single-vehicle, rural nonintersection accident (type 6) will permit identification of differences and, therefore, unique remediation for each. Heretofore these differences could not be identified, and countermeasures were aimed at motorcycle accidents in general, primarily with the objective of ameliorating injuries through use of protective equipment.

In December 1973, the state of Maryland provided a breakdown of 1,191 statewide 1973 motorcycle accidents. Ninety-six percent of these accidents fell into six of the eight categories. Since it would be necessary to go back over 8 years to obtain 100 usable accidents in the latter category and 3 to 4 years in the former, these two categories were dropped.

Figure 1 shows the motorcycle accident typology used. One hundred accident reports per accident type were coded from the original police hard copy. Fifty-four variables were coded for each accident. The coders were trained. A number of accidents were coded, a reliability check was made, a revised definition of the variables was provided, a larger number of accidents were coded, and more than 90 percent intercoder agreement was obtained. All 600 accidents were screened before they were keypunched and input to the computer. The computer was given acceptable limits for each of the variables to screen out errors in keypunching. These were recoded, and 600 accurately coded motorcycle accidents were combined to form the motorcycle accident data base. The variables used, especially in the areas of culpability and primary and secondary causal factors, are definitions specified by BioTechnology and represent the evaluation of the trained coders, not that of the Maryland investigating officer. These factors represent motorcycle accident descriptors heretofore not available.

The typology used permitted a comparison of all the variables among each of the six accident types. It was thus possible to differentiate between statistical significance

Table 1. Highway fatalities.

Transportation Mode	1972	1973	Percentage Change
Pedestrian	10,700	10,600	-1
Pedalcycle	1,100	1,100	–
Motorcycle	2,700	3,300	+22
Total highway	56,600	55,600[a]	-2

[a]Includes 1,215 grade-crossing fatalities.

Figure 1. Motorcycle accident data base.

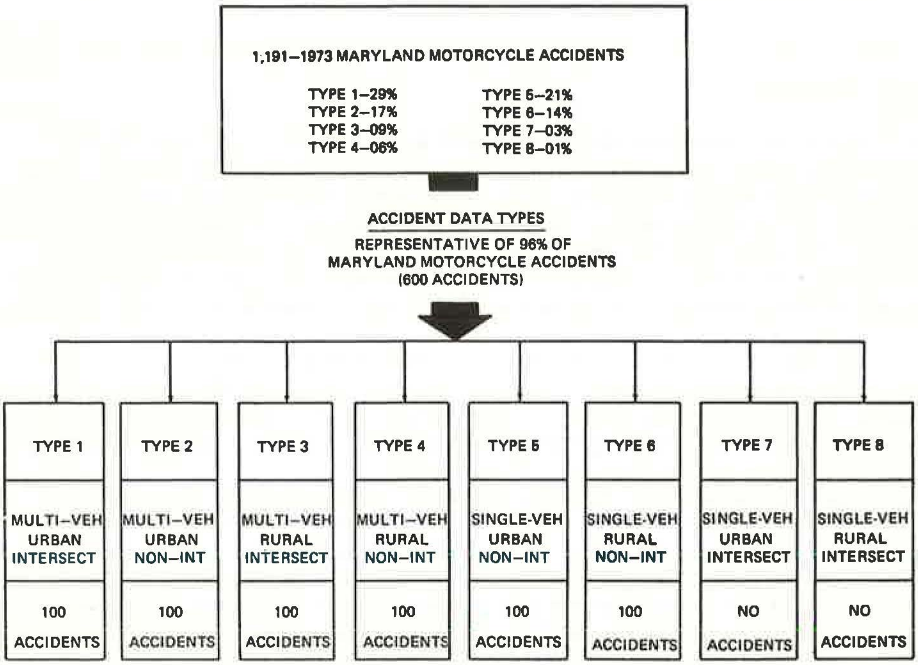
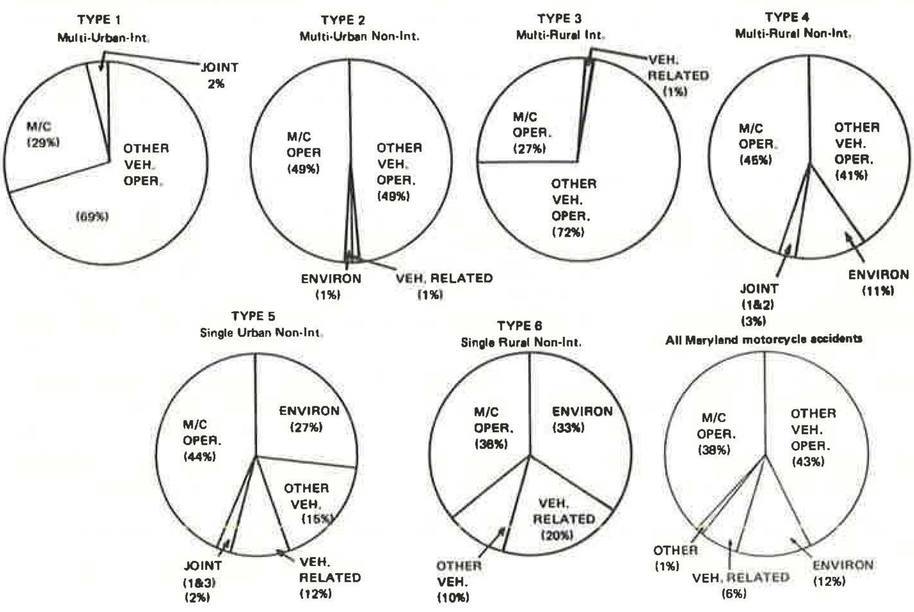


Figure 2. Accident culpability.



and random occurrence for each of the variables (motorcycle size, time of day, culpability, curvature of the road, etc.) by accident type. For example, a particular variable may be more prevalent in one type of accident (single-vehicle, rural nonintersection versus multiple-vehicle, urban nonintersection). This information can be used to determine data voids as well as to provide an input in the design of programs to reduce the number of accidents in each accident type.

Figure 2 shows the comparison of each accident type and all accident types for the variable culpability. The culpability for all accidents was obtained by

$$\text{Culp}_{(\text{all})} = \Sigma\ \text{culp}_{(\text{accident types 1-6})}\text{weighting factor}_{(\text{frequency of accident types 1-6})}$$

SIGNIFICANT DIFFERENCES AMONG ACCIDENT TYPES

Fifteen paired comparisons could be made of the six accident types [n(n - 1)/2]. We restricted the present analysis to the seven most meaningful comparisons. The intent of the comparisons was to isolate those accident characteristics that distinguished one accident type from another. [In most cases a Z-test of uncorrelated proportions was used to test differences. All differences reported here were significant beyond the 0.05 level (2 tail).] In particular, we were concerned with the characteristics that differentiated

1. Multiple- from single-vehicle accidents,
2. Urban from rural accidents, and
3. Intersection from nonintersection accidents.

The construction of the Maryland data base made it possible to determine the differences and to control for potential confounding factors. We were, for example, able to compare the characteristics of multiple- and single-vehicle accidents when both types of accidents occurred at urban nonintersections. Thus, we were able to control the situational context when exploring the differences between various accident types. Table 2 gives the comparisons used to identify the differences among the three classification variables listed above.

The results of the accident comparisons are discussed below. Tables are used to show the characteristics of each accident type; the characteristics were placed under the accident type that was found to have a higher proportion of that characteristic.

Multiple- Versus Single-Vehicle Accidents

The difference between multiple- and single-vehicle accidents was determined for both rural nonintersection and urban nonintersection contexts. Table 3 gives these comparisons.

Multiple-vehicle accidents were more frequently found to result in incapacitating injuries, and safety equipment was less often used. The riders were younger and drove smaller and newer motorcycles. The multiple-vehicle accidents were generally characterized by the failure of the motorcycle rider to obey traffic signals, yield right-of-way, and notice the other vehicle. Single-vehicle accidents, on the other hand, were more often associated with excessive speed, road and equipment defects, and avoiding another vehicle.

In the urban nonintersection context, the multiple-vehicle accident more often resulted in no injuires. The causal factors more frequently were the motorcyclist's failure to reduce speed and following too closely, and these accidents more often occur in clear weather. Single-vehicle accidents were more often caused by foreign objects on the roadway and negligent motorcycle riders.

Looking at both of the situations in which we have tested the multiple- and single-vehicle accidents, we find that, in addition to the previously discussed items, a series

Table 2. Structure for comparing the characteristics associated with the three classification variables.

Variable	Accident Types Compared	Situational Context
Multiple- versus single-vehicle	2 and 5	Urban nonintersection
	4 and 6	Rural nonintersection
Urban versus rural	1 and 3	Multiple-vehicle, intersection
	2 and 4	Multiple-vehicle, nonintersection
	5 and 6	Single-vehicle, nonintersection
Intersection versus nonintersection	1 and 2	Multiple-vehicle, urban
	3 and 4	Multiple-vehicle, rural

Table 3. Significant ($p \leqslant 0.05$) characteristics of multiple- and single-vehicle accidents.

Accident Type	Multiple-Vehicle	Single-Vehicle
Rural, nonintersection	1. Incapacitating injuries to motorcycle rider 2. No safety equipment worn 3. Motorcycle rider under 19; bike registered in parent's name 4. Newer motorcycle 5. Motorcycle failing to obey traffic signal 6. Motorcycle failing to yield right-of-way 7. Motorcycle failing to keep right of center 8. Motorcycle failing to notice other vehicle 9. Daylight 10. Other vehicle culpable	1. Older rider 2. Nonincapacitating injuries to rider 3. Larger engine size 4. Defective brakes 5. Punctures 6. Darkness; no lights 7. Speed too great for conditions 8. Blowouts 9. Road defects 10. Domestic animals in roadway 11. Motorcycle avoiding other vehicles 12. Environmental factors culpable 13. Vehicle defects culpable 14. 10 p.m. to 1 a.m.
Urban, nonintersection	1. 1 to 4 p.m. 2. Motorcycle stopped in traffic 3. No injury to motorcycle rider 4. Motorcycle rider is owner 5. Unspecified motorcycle defects 6. Clear weather 7. Three-lane roads 8. Motorcycle failing to reduce speed 9. Motorcycle following too closely 10. Daylight 11. Motorcycle failing to keep right of center 12. Other vehicle culpable 13. Surface streets	1. Nonincapacitating and incapacitating injuries to rider 2. Unspecified roadway surfaces 3. Negligent driving 4. Domestic animals in roadway 5. Foreign objects in roadway 6. Environmental factors culpable 7. Vehicle defects culpable 8. 10 p.m. to 1 a.m.

Table 4. Significant ($p \leqslant 0.05$) characteristics of urban and rural motorcycle accidents.

Accident Type	Urban	Rural
Multiple-vehicle, intersection	1. Monday 2. Sideswipes 3. Signalization 4. Possible injuries to motorcycle rider 5. Other vehicle failing to obey traffic signal 6. Other vehicle failing to notice motorcycle 7. Safety equipment worn 8. Surface streets	1. Saturday 2. Other vehicle slowing or stopping 3. Other vehicle starting from traffic lane 4. Stop sign 5. Divided roadway 6. Motorcycle rider properly licensed 7. Safety equipment worn 8. Other driver older 9. Excessive wear of tires of other vehicle 10. Darkness; street lights off
Multiple-vehicle, nonintersection	1. Other vehicle turning left 2. Other vehicle starting from parked position 3. No injury to motorcycle rider 4. Possible injury to motorcycle rider 5. Motorcycle rider is owner 6. Improper passing for motorcycle 7. Other vehicle failing to yield right-of-way 8. Improper entrance or exit into parking area for other vehicle 9. Surface streets	1. Other vehicle going straight ahead 2. Incapacitating injury to motorcycle rider 3. Motorcycle rider under 19; bike registered in parent's name 4. Condition of other driver apparently normal 5. Darkness; no lights 6. Four lanes in direction of travel of motorcycle 7. Expressways 8. Motorcycle speed too great for conditions 9. Other vehicle failing to yield right-of-way 10. Other vehicle speed too great for conditions 11. Foreign objects in roadway 12. Road curvature 13. Environmental factors involved in accident culpability
Single-vehicle, nonintersection	1. Thursday 2. Darkness; street lights on 3. Darkness; no lights 4. Other than dry road surface 5. Two-way, undivided traffic flow 6. Operator was owner 7. Surface streets	1. Ran-off-road collision 2. Motorcycle slowing or stopping 3. Motorcycle punctures or blowouts 4. Four lanes in direction of travel of motorcycle 5. Two-way, divided traffic flow 6. Expressways 7. Divided roadways 8. Motorcycle speed too great for conditions 9. Wildlife in roadway 10. Road curvature 11. Blowouts primary causes

of common factors emerges across situations. In particular, multiple-vehicle accidents more often occurred in daylight, and the motorcyclist was more frequently cited as failing to keep right of center. The other vehicle was more often judged culpable in multiple-vehicle accidents. In single-vehicle accidents, the environment, vehicle defects, domestic animals, and unknown causes were more frequently cited as contributory factors. Also, more single-vehicle accidents occurred between 10 p.m. and 1 a.m.

Urban Versus Rural Accidents

The differences between urban and rural accidents were determined in three situational contexts. Table 4 gives these comparisons.

Urban accidents in the multiple-vehicle, intersection context were more frequently found to consist of sideswipes and occurred more often at signalized intersections. The other vehicle was more often cited as failing to obey the traffic signal in the urban accidents and more frequently failed to notice the motorcycle.

Rural accidents in the multiple-vehicle, intersection context, on the other hand, were found to be involved in accidents with vehicles that were starting up, slowing down, or stopping. The intersection more often was controlled by a stop sign, and the roads were more often divided roadways. The motorcycle operator was generally older, was more often properly licensed, and used the appropriate safety equipment.

Urban accidents in the multiple-vehicle, nonintersection context more often involved a left turning vehicle. The other vehicle more frequently started from a parked position and did so improperly. The other vehicle more often failed to yield the right-of-way. On the other hand, the motorcycle operator was more often found to pass the other vehicle improperly. The urban motorcycle operator more often escaped without serious injury.

The rural multiple-vehicle, nonintersection accident is more often characterized by excessive speed on the parts of both the motorcycle and the other vehicle. Environmental factors, foreign objects on the roadway, and road curvature were more frequently cited in rural accidents. The other vehicle was more often going straight, and the motorcycle more frequently failed to yield the right-of-way.

Urban accidents in the single-vehicle, nonintersection context more often occurred on two-way, undivided roadways where the road surface was other than dry, and the operator more often owned the vehicle. Rural accidents in the same situational context more frequently involved slowing or stopping on the part of the motorcycle, blowouts, and domestic animals in the roadway. In addition, rural, single-vehicle, nonintersection accidents more often were associated with road curvature and excessive speed for conditions and occurred more frequently on divided roads or expressways.

The only factors that differentiated urban from rural accidents (for all three situations) are roadway characteristics. Urban accidents, not surprisingly, occurred more frequently on surface streets, whereas rural accidents more frequently occurred on divided and nondivided roadways.

Intersection Versus Nonintersection Accidents

The differences between intersection and nonintersection accidents were determined in the multiple-vehicle, urban and multiple-vehicle, rural contexts. Table 5 gives these differences.

The intersection accidents in the multiple-vehicle, urban context more often were characterized by the other vehicle's failure to obey the traffic signal and failure to notice the motorcycle. The motorcycle operator was more frequently cited for failure to yield the right-of-way. These intersection accidents more often occurred on surface streets and resulted in incapacitating injuries to the cyclist.

Nonintersection accidents in the same context were more frequently associated with the other vehicle making a U-turn, starting from a parked position and doing so im-

Table 5. Significant ($p \leqslant 0.05$) characteristics of intersection and nonintersection motorcycle accidents.

Accident Type	Intersection	Nonintersection
Multiple-vehicle, urban	1. Incapacitating injury to motorcycle rider 2. Surface streets 3. Motorcycle failing to yield right-of-way 4. Other vehicle failing to obey traffic signal 5. Other vehicle failing to notice motorcycle 6. Other vehicle culpable 7. Angle collision 8. Other vehicle turning both directions 9. Motorcycle turning left 10. Other vehicle failing to yield	1. Other vehicle making U-turn 2. Other vehicle starting from parked position 3. Other vehicle stopped in traffic lane 4. No injury to motorcycle rider 5. Motorcycle rider under 19; bike registered in parent's name 6. Motorcycle rider is owner 7. One-lane in direction of travel of motorcycle 8. Undivided highway 9. Motorcycle following too closely 10. Other vehicle stopped in roadway 11. Other vehicle entering or exiting parking position properly 12. Motorcycle speed too great 13. Motorcycle failing to keep right of center 14. Unexpected rapid deceleration 15. Motorcycle culpable 16. Other vehicle culpable 17. Other vehicle changing lanes 18. Motorcycle culpable 19. Head-on and rear collisions
Multiple-vehicle, rural	1. 4 to 7 p.m. 2. Safety equipment worn 3. Driver of other vehicle is female 4. Driver of other vehicle drinking 5. Darkness; street lights off 6. Divided roadways 7. Motorcycle passing improperly 8. Other vehicle failing to obey stop sign 9. Environmental visual obstructions 10. Motorcycle and environment culpable 11. Angle collision 12. Other vehicle turning both directions 13. Motorcycle turning left 14. Other vehicle failing to yield	1. Sideswipes 2. Motorcycle slowing or stopping 3. Other vehicle going straight ahead 4. Other vehicle starting from traffic lane 5. Other vehicle also motorcycle 6. Defective brakes on motorcycle 7. Condition of other driver apparently normal 8. Darkness; no lights 9. Four lanes in direction of travel of motorcycle 10. Expressways 11. Motorcycle speed too great for conditions 12. Other vehicle speed too great for conditions 13. Other vehicle failing to keep right of center 14. Foreign objects in roadway 15. Motorcycle failing to notice other vehicle 16. Environmental factors culpable 17. Other vehicle culpable 18. Head-on and rear-end collisions 19. Other vehicle changing lanes 20. Other vehicle decelerating rapidly 21. Motorcycle culpable

properly, or stopped in traffic or on the roadway. The motorcycle operator was more often the owner of the motorcycle and was more often following too closely.

In intersection accidents in the rural, multiple-vehicle context, the other driver's use of alcohol and his failure to obey stop signs were more often cited. A higher percentage of motorcyclists were found to be passing improperly. The cyclist did more often wear safety equipment. We also found that visual obstructions were more frequent in the intersection accidents.

The nonintersection accidents in the same context had a greater proportion of sideswipes. The motorcycle was more often slowing or stopping and was cited more frequently as having defective brakes. The motorcyclist more often did not notice the other vehicle in the nonintersection accidents. The other vehicle in the nonintersection accident was more often going straight ahead or starting from a traffic lane. The other vehicle was also more frequently cited for failure to keep right of center. Both vehicles were more often cited for excessive speed in these nonintersection accidents. Causal factors involving the environment were more often noted, including foreign objects on the roadway.

Analysis of both of the situations in which we tested intersection and nonintersection accidents revealed some common factors across situations. In particular, intersection accidents were more often angle collisions and involved another vehicle that was turning right or left and a motorcycle that was turning left. Failure of the other vehicle to yield the right-of-way was more frequently cited as a causal factor. On the other hand, nonintersection accidents were more often head-on and rear-end. The other vehicle was more often found to be slowing or stopping, changing lanes, or decelerating unexpectedly. The other vehicle was more often guilty of crowding the motorcycle. The motorcyclist more often was found to fail to reduce speed and keep right of center. The cyclist was also more frequently cited as culpable in nonintersection accidents.

CONCLUSIONS

We have seen that an accident typology can be created to define culpability information and causal factors for a series of accident types. It is suggested that this information be used in the design of future motorcycle education and training programs as well as in the development of accident research programs designed to reduce the frequency of these accidents.

It is further suggested that a representative sample of additional states be used to replicate the Maryland data base and serve as the basis for a national data base.

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