COST-EFFECTIVENESS ANALYSIS OF ROADSIDE SAFETY IMPROVEMENTS

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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 noncontrolled-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

- 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

- 51 [2]
- 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

- 51 [3]
- Hinge Point Offset, O_H (ft): 52 53 Beginning; 54 55 End
- Steepness: 56 57 Beginning __:1; 58 59 End __:1
- 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 Beginning __:1; 68 69 End __:1
- 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

✓

[/] Card Type

77

Recommendations: ____________________

Figure 2. Roadside hazard improvement form.

BOX 1

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

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

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

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

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) — 42 43 Lateral Offset (ft) Right or Median Near Side — 44 45 Lateral Offset (ft) Median Far Side

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

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

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): 42 43 Beginning, 44 45 End — Steepness: 46 47 :1 Beginning, 48 49 :1 End — Distance "D_1" (ft): 50 51 Beginning, 52 53 End — 54 Slope Direction: 1 Positive, 2 Negative

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

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

BOXES A & B

Box A (Install Guardrail)

Right or Median Near Side or Approach Guardrail — Lateral Offset (ft): 44 45 Beginning, 46 47 End

Median Far Side or Departing Guardrail — Lateral Offset (ft): 48 49 Beginning, 50 51 End

Box B (Changes to Existing Guardrail)

Lengthen (ft): 43 44 45 46 Beginning, 47 48 49 50 End

Shorten (ft): 51 52 53 54 Beginning, 55 56 57 58 End

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.

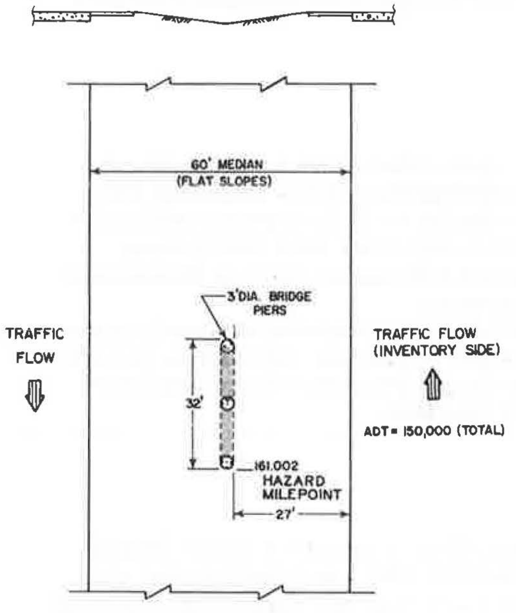

Figure 4. Cost-effectiveness program output, case 1.

```
          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
```

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
H A Z A R D										I M P R O V E M E N T						
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	1,990	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.

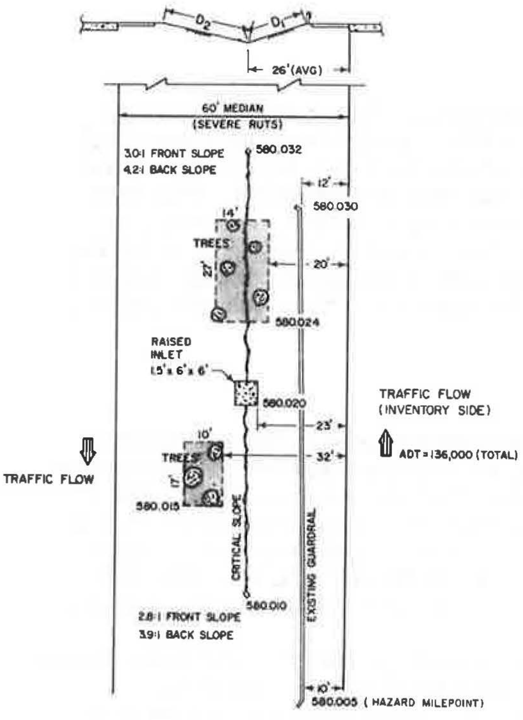

Figure 6. Cost-effectiveness program output, case 2.

```
                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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