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HIGHWAY
DEPARTMENT

COOPERATIVE
RESEARCH

COST-EFFECTIVENESS PROGRAM FOR ROADSIDE SAFETY IMPROVEMENTS ON TEXAS HIGHWAYS--VOLUME THREE, COST-EFFECTIVENESS ANALYSIS MANUAL

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 15-1
STUDY 2-10-74-15
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16. Abstract

This report presents the general concept of the Cost-Effectiveness analysis procedure for roadside safety improvement alternatives, and the necessary information for interpretation and effective utilization of the Cost-Effectiveness computer program output. Typical outputs from the program are included to illustrate the development of the Cost-Effectiveness Priority List.

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COST-EFFECTIVENESS PROGRAM FOR ROADSIDE SAFETY IMPROVEMENTS ON TEXAS HIGHWAYS

VOLUME 3: COST-EFFECTIVENESS ANALYSIS MANUAL

by

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and

Graeme D. Weaver

Research Report 15-1

Research Studies 2-8-72-11 and 2-10-74-15

Sponsored by
The Texas Highway Department
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IMPLEMENTATION STATEMENT

The Cost-Effectiveness Analysis Manual has been developed on an immediate implementation basis. This report provides the basis for administrative interpretation of the Cost-Effectiveness analysis model output for the roadside safety improvement evaluation program currently being implemented within the State of Texas.

The complete research study is documented in three volumes, each being oriented toward the informational needs of particular readers.

The implementation procedure includes distribution of the appropriate research manuals and the conduct of an instruction orientation session by D-18-S personnel to each Texas Highway Department District. The orientation sessions include formal instruction for inventory procedures, computer input, and interpretation of computer output in addition to practical field application to illustrate the procedure under operational conditions.

DISCLAIMER

ABSTRACT

This report presents the general concept of the Cost-Effectiveness analysis procedure for roadside safety improvement alternatives, and the necessary information for interpretation and effective utilization of the Cost-Effectiveness computer program output. Typical outputs from the program are included to illustrate the development of the Cost-Effectiveness Priority List.

FOREWORD

This report represents the revised final report (Volume 3 of 3) of Research Study 2-10-74-15, entitled, "Cost-Effectiveness Priority Program for Roadside Safety Improvements on Non-Controlled Access Roadways," a follow-on to Research Study 2-8-72-11, "Cost-Effectiveness Priority Program for Roadside Safety Improvements on Texas Freeways."

The complete research study has been reported in three volumes, each being oriented toward the informational needs of particular readers. Volume 1 presents detailed procedures to conduct the roadside inventory, and is prepared for the field personnel conducting this aspect of the cost-effectiveness evaluation program. Volume 2 presents details of the computer analysis model including complete flow charts for operational understanding, and was prepared specifically for use by the computer personnel. Volume 3, prepared specifically for administrative interpretation of analysis output, presents methodology for ranking improvement alternatives and abbreviated descriptions of the cost-effectiveness values.

All three volumes are necessary to document the three individual phases of the complete operational procedure. For detailed coverage of the complete research study, the reader is referred to the following:

Cost-Effectiveness Program for Roadside
Safety Improvements on Texas Highways

Volume 1: Procedures Manual

Volume 2: Computer Program Documentation Manual

Volume 3: Cost-Effectiveness Analysis Manual

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1. INTRODUCTION

COST-EFFECTIVENESS ANALYSIS

Cost-Effectiveness (C/E) analysis relates the improvement cost of a hazard to the degree of hazard reduction achieved in comparison to the existing state.

The conceptual model which forms the basis of the analysis used in the research reported herein is presented in detail in reference 1, and the significant portions of that report are presented in the appendix. The model is probabilistic rather than being based on accident experience. The general form of the model is presented in Equation 1.

$$C/E = \frac{\text{Cost (to the Department)}}{\text{Relative Hazard Reduction}} \quad \ldots\ldots \quad \text{(Eqn. 1)}$$

where:

C/E = Cost-Effectiveness Value (Dollars per fatal or serious injury accident eliminated during the life of the improvement)

Cost = Annualized Total Cost, including normal annual maintenance cost and maintenance per hit cost of the existing situation.

Degree of Hazard Reduction = Difference of hazard index before and after improvement.

$$\text{Hazard Index} = P_H \, P_E \, S_H \quad \ldots\ldots\ldots \quad \text{(Eqn. 2)}$$

where:

P_H = Probability of object being struck given a vehicle encroachment

P_E = Probability of an encroachment occurring for a given traffic volume

S_H = Accident severity due to a collision with the object

P_H is primarily a function of distance from the edge of the roadway and the size of the object. P_E is determined primarily by the traffic volume at that point on the roadway, and the severity is determined by vehicle speed and the rigidity of the object. Probabilities of vehicle encroachments are based on data obtained for vehicles exiting from a tangent section. The severity indices used in the programming of the model are average values determined from a survey of Texas Highway Department and other personnel.

The exposure in gore areas at exit ramps is much greater than will be indicated by the computer program. Encroachment data for gore areas to establish an expected encroachment probability are not available. It should be recognized that gore areas are areas of potentially high encroachment, and every effort should be made to keep these areas clear of objects or to protect the motorist from objects located there.

The cost elements are incurred at different points in time and it is necessary to convert the cost to a common base. Annual costs over the life of the improvement are used in cost-effectiveness analysis. A service life of twenty years and an interest rate of eight percent have been assumed in the development of the cost-effectiveness computer program.

The numerator of Equation 1 is composed of three major cost elements: (1) annualized cost of improvement; (2) difference in annualized routine maintenance cost before and after improvement; and (3) difference in the annualized cost of repair following each expected collision with the object before and after improvements. The denominator is the difference in the degree of hazard between the existing and recommended improved state. The hazard index includes both the probability of the existing object or improvement being struck and the severity of the resulting collision. The difference in the hazard indices before and after improvement is a measure of the effectiveness of the improvement.

COST-EFFECTIVENESS AS A MANAGEMENT TOOL

The increasing emphasis on safety in recent years has produced a variety of safety-related highway improvement efforts (for example, breakaway supports, bridge widening, etc.). A question often arises regarding the scope of safety improvement activities. Specifically, would one or two major improvements be more beneficial than a larger number of relatively small improvements or a lesser number of moderate cost improvements? Cost-effectiveness analysis has been designed to examine this question. It provides a means to compare and rank two or more safety alternatives.

ADVANTAGES OF COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is applicable primarily in scheduling roadside safety improvements to obtain the greatest return for the safety dollar invested. There are a number of other areas of application. In long range programming, the need for safety improvements could be computed directly and utilized as a safety benefit of any new construction or reconstruction. Such data generally are not available currently.

The inventory phase of the cost-effectiveness analysis procedure requires District personnel to critically identify and evaluate the function that each roadside element serves. Hence, deficiencies in the design process may be identified, thus possibly resulting in a more efficient process from both a design and maintenance standpoint.

The cost-effectiveness analysis procedure also exhibits potential application in the evaluation of design alternatives. For example, should guardrail be specified on a cross-section design having a flat side slope for a distance of twenty feet from the edge of the traveled way and a very steep slope beyond that point? Is it cost-effective to eliminate bridge piers close to the traveled way by designing single span structures on roadways with medians less than some defined width?

ENGINEERING JUDGMENT AND COST-EFFECTIVENESS ANALYSIS

The most frequently asked question regarding the cost-effectiveness analysis concept is: "Will it force me to do this or that?" The answer is definitely "No." Cost-effectiveness is one tool to assist in the effective use of available safety funds. Although an improvement may be cost-effective, it may not be practical. For example, it may be more economical to improve one type of hazard throughout an extended section of roadway rather than treating the first ten hazards on the cost-effectiveness priority list. To determine this, the system of improvements would require re-analysis using the reduced costs resulting from economic scale. Cost-effectiveness permits direct comparison of projects of grossly differing scope and monetary investment. It permits the development of a priority listing of safety improvements which, in the absence of other information, could serve as the basic program. Consideration of budgetary, scheduling, personnel, and other constraints will be necessary to make optimal use of the funds available.

2. INTERPRETATION OF THE COST-EFFECTIVENESS VALUE

NATURE OF THE COST-EFFECTIVENESS VALUE

As the cost of the improvement increases, the relative desirability of the improvement decreases, and as the change in hazard becomes larger, the desirability of improvement increases. Thus, the model is internally consistent and the smaller cost-effectiveness (C/E) value represents the higher priority improvement.

Another characteristic of the C/E value is the unit involved. The C/E value is expressed in annualized dollars required to eliminate one fatal or serious injury accident. The numerical C/E value at which any given improvement is considered to be cost-effective is arbitrarily selected. The C/E analysis procedure permits a priority listing of alternative improvements and, therefore, improvements having relatively large cost-effectiveness values will be located well down on the priority list.

NEGATIVE COST-EFFECTIVENESS VALUE

The C/E value can be negative as the result of either the numerator or demoninator being negative. The proper interpretation of the C/E value requires a complete understanding of the model and program behavior. Two example cases are used to illustrate the meaning of a negative C/E value.

Case 1: Negative Numerator

The numerator in equation 1 can be negative when the annualized costs of the improvement, including maintenance costs, are less than the costs associated with not treating the object in its existing state. When this occurs, it is apparent that the improvement is cost-effective because the annual cost to the Department is less with the improvement than to take no action at all. Further, the magnitude of the negative value is of significance. The improvement which returns the greater value (i.e., the larger negative C/E value) should have the higher priority for improvement because the dollars saved by the Department would be greater.

Case 2: Negative Denominator

When the Hazard Index after the improvement is greater than the Hazard Index prior to treatment, the denominator, and thus the cost-effectiveness value, will be negative. This situation may occur when a relatively small object of high severity is located a considerable distance from the edge of the traveled way and the recommended safety treatment involves placement of a much larger object of somewhat lower severity close to the roadway. An example of this involves the installation of a 150-ft length of guardrail to protect the end of a small pipe culvert. The original hazard is three or four feet wide and considerably less likely to be struck than a 150-ft section of guardrail. Since the objective of this study is safety improvement, it has been assumed in the programming of the cost-effectiveness model that negative hazard improvement resulting from a negative denominator is not cost-effective and a message "HAZARD IMPROVEMENT NOT COST-EFFECTIVE" is printed in lieu of a cost-effectiveness value.

When a negative cost-effectiveness is displayed in the computer output data, it can result only from the situation described in Case 1 above, and the improvement alternative will result in increased safety for the motoring public.

3. ANALYSIS MODEL DATA OUTPUT

EXAMPLES OF 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 1 illustrates a typical point hazard--a set of three closely spaced bridge piers in a median. For analysis purposes here, the three individual piers are considered to act 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 (1) remove the piers (replace the bridge with a single span structure), (2) install guardrail around the piers, (3) install a concrete median barrier integral with the piers, or (4) install an impact attenuator system at the end(s) of the pier formation. Figure 2 illustrates the computer program output for each of these four alternatives. Alternative 3, installation of a concrete median barrier integral with the piers, is the preferred alternative in this analysis.

Case 2: Group of Hazards in Median. Figure 3 illustrates 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 here for illustrative purposes. The first alternative

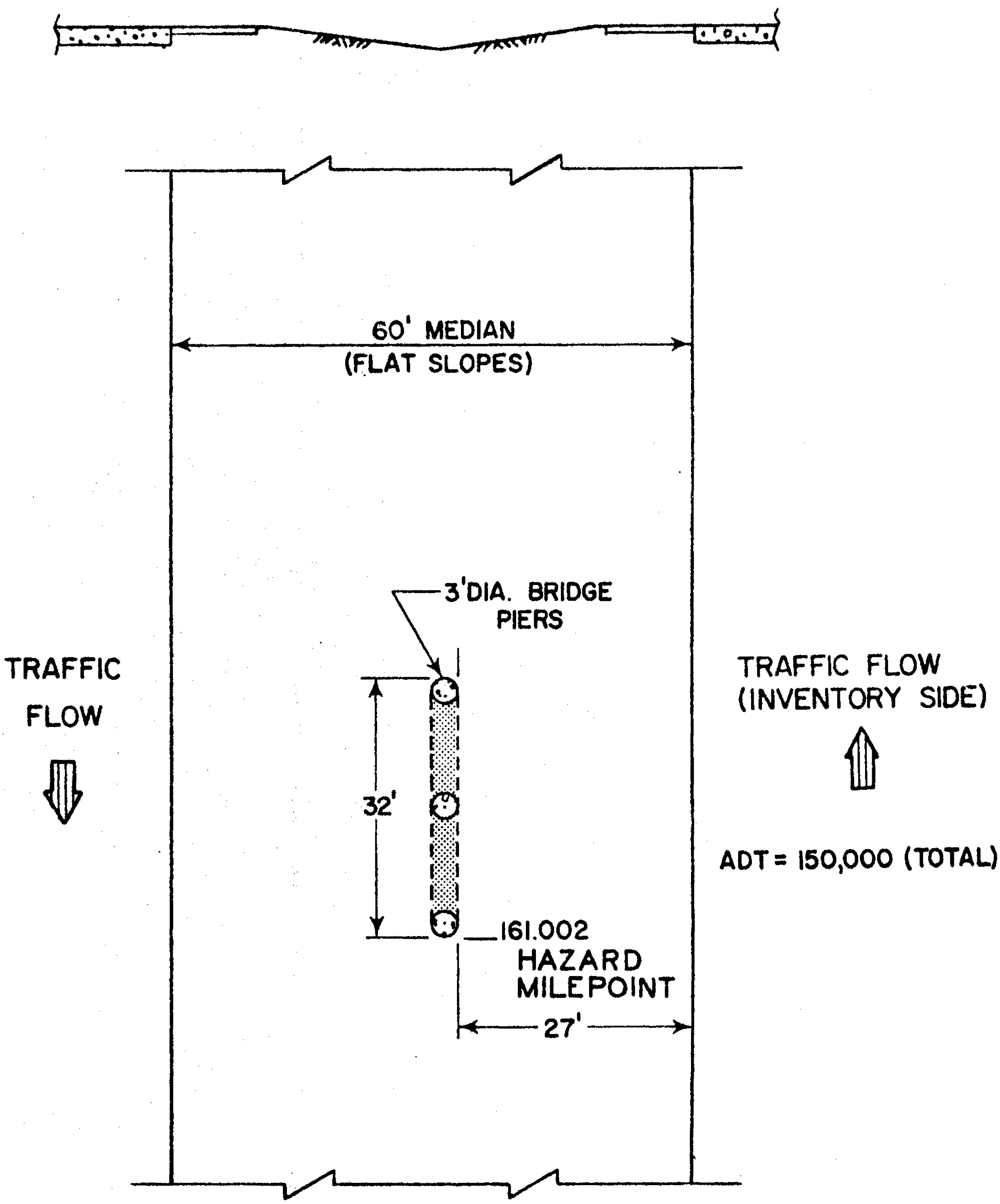

Figure 1. Hazard description and location -- Case 1.

C O S T   E F F E C T I V E N E S S   P R O G R A M

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

Figure 2. Analysis model data output -- Case 1.

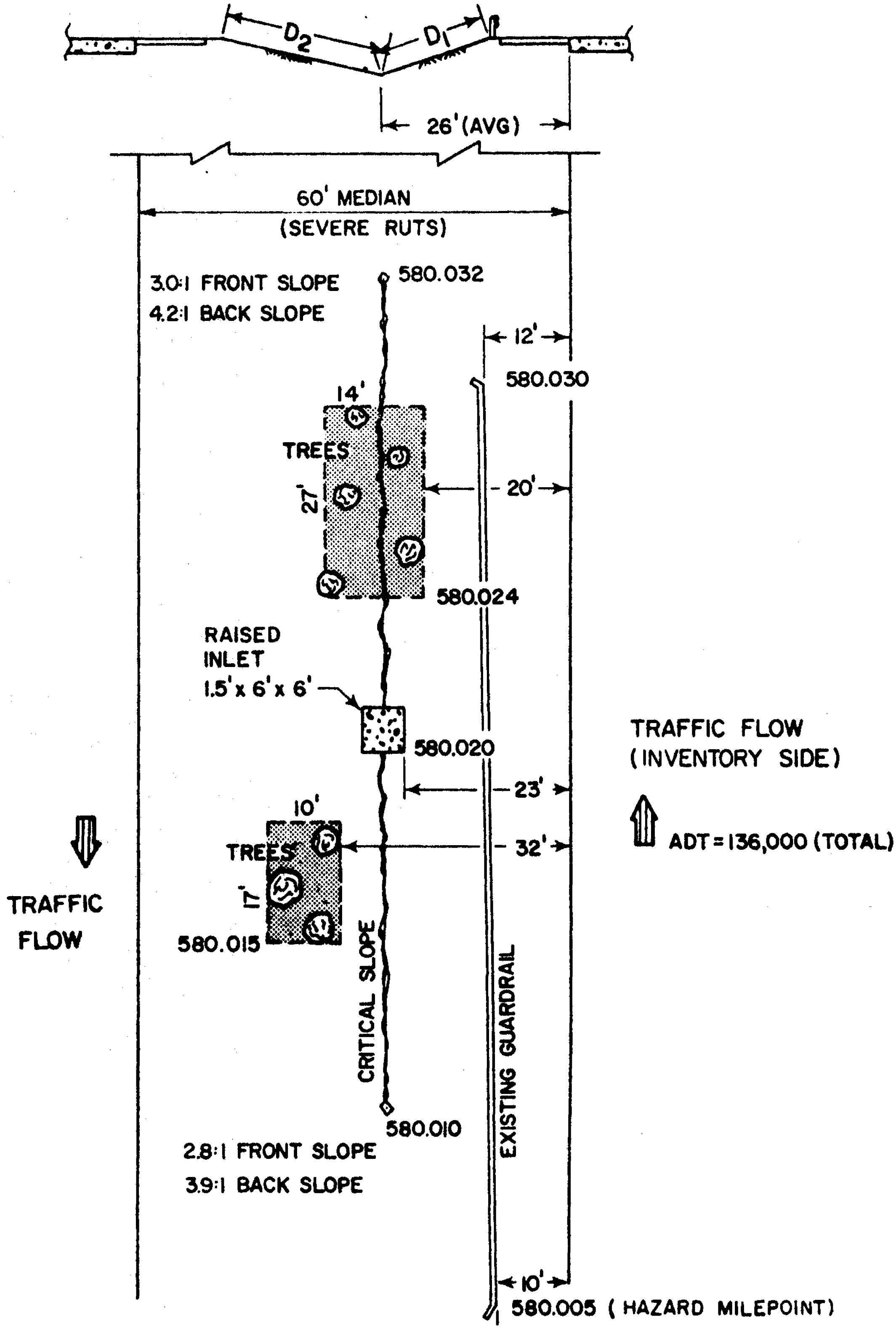

Figure 3. Hazard description and location -- Case 2.

includes upgrading the existing guardrail to full safety standards to protect the slope and leaving the other hazards as they currently exist. The second alternative includes guardrail removal, replacing the raised inlet with a flush inlet (removal of hazard) and removal of the two clumps of trees. Figure 4 presents the analysis of these two alternatives. From Figure 4, it is apparent that the second alternative is by far the more cost-effective.

INTERPRETATION OF DATA OUTPUT

The program output basically is of two forms--individual hazards (point hazards, longitudinal hazards or slope hazards) or a group of hazards containing several hazards of the same category or of mixed categories, but to which a single improvement is recommended for all hazards within that group. 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 complete group safety improvement 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 No. 101 in Figure 4 (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

C O S T   E F F E C T I V E N E S S   P R O G R A M

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

Figure 4. Analysis model data output -- Case 2.

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.

ERROR MESSAGES

Since computer program execution is highly dependent on precise data input both in type and location, error messages have been incorporated into the program to identify input errors. Due to the complexity of the program and extensive branching within subroutines from several data sources, it is expected that data input errors will occur. To avoid program termination (which would normally occur for each data error), the program has been developed to bypass the erroneous data, print out an error message, and continue with the next data input.

The fifty-one error messages shown in Table 1 have been incorporated. The list of numbered messages is printed out for each computer run, and each error message occurring 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 the program execution. The message indicates the type of error and provides direction to remedy the data error. The program will automatically terminate if 100 error messages are printed during any run.

The message, "Hazard Improvement Not Cost-Effective," as discussed previously, may appear in the data output. This is not an error message, and is not included in the 100-maximum count for automatic program termination. It indicates that the recommended improvement produces, for all intents and purposes, no safety benefit over the hazard currently existing. Under certain circumstances, it indicates that the recommended improvement in fact produces a more hazardous situation than the existing one. The message may be obtained under two circumstances as shown below.

The simplified cost-effectiveness ratio is determined by:

$$\text{Cost-Effectiveness} = \frac{\text{Cost}}{H_B - H_A} \quad . \; . \; . \; . \; . \; . \; . \; . \quad \text{(Eqn. 3)}$$

where

H_A = Hazard index after improvement

H_B = Hazard index before improvement (existing)

If H_A is greater than H_B, the denominator becomes negative. This means that the recommended alternative is more hazardous than the existing situation. Obviously, it is impractical to incur costs to produce a more critical situation than currently exists; therefore, the flag message "Hazard Improvement Not Cost-Effective" is printed out when this occurs and the cost-effectiveness ratio is not computed.

When H_A is only slightly less than H_B, the denominator becomes very small numerically, hence the cost-effectiveness ratio becomes very large. Based on statistical logic, a lower cut-off level has been incorporated into the model such that when the numerical value of $H_B - H_A$ is less than 0.02, the flag message is printed out and the cost-effectiveness ratio is not computed. The 0.02 level indicates a 55-percent probability of no hazard reduction.

TABLE 1

LIST OF ERROR OR FLAG MESSAGES

Message Number	Subroutine Calling Message	Description of Message
1	HAZARD	End milepoint at hazard not specified
2	PTHAZ	Unmatched point hazard and improvement codes
3	PTHAZ	Non-existing improvement classification specified in column 41 of improvement form
4	DITCH	Non-existing ditch improvement code classification
5	RAILNG	Guardrail installation not necessary--reexamine roadway group hazard
6	HAZARD	Non-existing hazard classification specified in column 51 of inventory form
7	PTHAZ	Non-existing point hazard improvement code (column 40)
8	PTHAZ	No improvement needed, flat slopes and/or offset greater than 30 ft (right side or median near side)
9	PTRAIL	Distance between guardrail and obstacle less than 3.0 ft
10	LGHAZ	No improvement needed, flat slopes and/or offset to longitudinal hazard > 30 ft (full median)
11	CURB	Non-existing curb improvement classification specified in column 42 of improvement form
12	BRIDGE	Non-existing bridgerail improvement classification specified in column 42 of improvement form
13	BRIDGE	Non-existing bridgerail improvement classification specified in column 43 of improvement form

TABLE 1, CONTINUED

Message Number	Subroutine Calling Message	Description of Message
14	RAIL	Non-existing guardrail improvement classification specified in column 42 of improvement form
15	RAIL6	Guardrail end-treatment adjacent to bridge incorrectly specified
16	LGHAZ	Longitudinal hazard offset on non-critical slopes greater than 30 ft (right or median near side)
17	SLOPE1	Non-existing slope direction classification specified on inventory form
18	LGHAZ	Curb improvement valid only for curb hazard
19	ZERO, DITCH	Logic breakdown--vehicle not permitted to penetrate guardrail
20	PTHAZ	No improvement needed, flat slopes and/or offset greater than 30 ft (median inventoried across)
21	ZERO	Logic breakdown in subroutine ZERO--refer to flow charts
22	PTHAZ	Point hazard offset greater than 30 ft on right or median near side (critical slopes)
23	MAIN PROGRAM	Stop computer program -- 100 or more errors
24	HAZARD	Unmatched identification information
25	LGHAZ	Bridgerail improvement valid only for bridgerail hazard
26	LGHAZ	Guardrail improvement valid only for guardrail hazard
27	INVTRY	End of data and program

TABLE 1, CONTINUED

Message Number	Subroutine Calling Message	Description of Message
28	HAZARD	Unequal number of improvement alternatives per hazard in group
29	RAIL1	Not permitted to remove 1 guardrail on median side if other group on same side is not removed
30	MAIN PROGRAM	*Hazard improvement not cost-effective*
31	HAZARD	Hazards on right side and left side of roadway cannot be grouped together
32	HAZARD	Guardrail end treatment code not specified on inventory form
33	HAZARD	Guardrail end treatment code not defined--value greater than 4.
34	HAZARD	Improvement costs not specified
35	HAZARD	Guardrail hazard repair and/or maintenance costs not specified
36	HAZARD	Guardrail improvement repair and/or maintenance costs not specified
37	LGHAZ	Longitudinal hazard offset greater than 30 ft (critical slopes) on right or median near side
38	ZERO	Logic breakdown in group consisting of point hazards and group on both sides of median
39	ZERO	Improvement not needed for existing point hazard behind existing guardrail
40	----	Reserved for future use
41	BRIDGE	Median inventoried across width allowed only for improvement codes 2 or 4 in column 43

TABLE 1, CONTINUED

Message Number	Subroutine Calling Message	Description of Message
42	DITCH	Ditch improvement not needed behind existing guardrail
43	LGHAZ	Ditch improvement valid only for ditch hazard
44	BRGR	Approach and departing guardrail offsets not specified in columns 44 through 51
45	LGHAZ	Non-existing improvement classification specified in column 41 of improvement form
46	DTRAIL	Median inventoried across full width but no guardrail specified to protect far side
47	SLHAZ	Slope improvement not specified in columns 40 or 41 on improvement form
48	SLRAIL	Inventory median full width only if guardrail also needed on far side to protect slope
49	LGHAZ	Non-existing longitudinal hazard improvement code (column 40)
50	BRGR1	Logic breakdown in placing guardrail between successive bridges
51	BRGR	Bridge approach or departing guardrail lateral offset in wrong location in Box A

The message, "No Improvements Recommended" merely indicates that for that particular hazard, the recommended safety improvement was "No Improvement Recommended" (code 4, column 40, improvement form). It is not counted as an error message for program termination.

If data errors occur within a grouping, a group cost-effectiveness cannot be determined. Therefore, an error message will be printed out and the message, "End Group" will also appear where the grouping cost-effectiveness value would normally appear. The message "Group" denotes that the cost-effectiveness value represents a total group value.

DATA OUTPUT CODES

Hazard and improvement information are printed in the data output as coded information. Hazard inventory codes are presented in Table 2; improvement alternative codes are listed in Table 3.

TABLE 2

HAZARD INVENTORY CODES

Note: Circled Codes denote Point Hazard

Identification Code	Descriptor Codes
01. Utility Poles	(00)
02. Trees	(00)
03. Rigid Signpost	(01) single-pole-mounted (02) double-pole-mounted (03) triple-pole-mounted (04) cantilever support (05) overhead sign bridge
04. Rigid Base Luminaire Support	(00)
05. Curbs	(01) mountable design (02) non-mountable design less than 10 inches high (03) barrier design greater than 10 inches high
06. Guardrail or Median Barrier	(01) w-section with standard post spacing (6 ft-3 in.) (02) w-section with other than standard post spacing (03) approach guardrail to bridge--decreased post spacing (3 ft--1 in.) adjacent to bridge (04) approach guardrail to bridge--post spacing not decreased adjacent to bridge (05) post and cable (06) metal beam guardrail fence (barrier) (in median) (07) median barrier (CMB design or equivalent)
07. Roadside Slope	(01) sod slope (positive) (02) sod slope (negative) (03) concrete-faced slope (positive) (04) concrete-faced slope (negative) (05) rubble rip-rap slope (positive) (06) rubble rip-rap slope (negative)

TABLE 2, CONTINUED

Identification Code	Descriptor Codes
08. Ditch (includes erosion, rip-rap runoff ditches, etc. --does not include ditches formed by front and back slopes)	(00)
09. Culverts	(01) headwall (or exposed end of pipe culvert)
	(02) gap between culverts on parallel roadways
	(03) sloped culvert with grate
	(04) sloped culvert without grate
10. Inlets	(01) raised drop inlet (tabletop)
	(02) depressed drop inlet
	(03) sloped inlet
11. Roadway under Bridge Structure	(01) bridge piers
	(02) bridge abutment, vertical face
	(03) bridge abutment, sloped face
12. Roadway over Bridge Structure	01 open gap between parallel bridges
	02 closed gap between parallel bridges
	(03) rigid bridgerail--smooth and continuous construction
	(04) semi-rigid bridgerail--smooth and continuous construction
	(05) other bridgerail--probable penetration, severe snagging and/or pocketing, or vaulting
	(06) elevated gore abutment
13. Retaining Wall	(01) retaining wall (face)
	02 retaining wall (exposed end)

TABLE 3

HAZARD IMPROVEMENT ALTERNATIVE CODES

Point Hazard Improvement Codes (Primary Code, 1)

Code	Identification	Descriptor
1-1-1-0	Alleviate Hazard	- remove
-2-0		- make breakaway and/or relocate
-3-0		- reconstruct inlet to safe desig
-4-0		- reconstruct cross-drainage syst (remove headwalls, extend cul- vert, grade, etc.)
1-2-0-0	Protect hazard with Guardrail (Hazard not on critical slope)	
1-3-0-0	Protect hazard with concrete median barrier (CMB)	
1-4-0-0	Protect hazard with energy at- tenuation system	

Longitudinal Hazard Improvement Codes (Primary Code, 2)

Code	Identification	Descriptor
2-1-1-0	Curb	- remove
-2-0		- install wedge modification
(1)	Rigid Bridgerail	- upgrade to full safety standards
2-1- -1		
(2)	Semi-rigid Bridgerail	- upgrade to full safety standards
-2		- move laterally
-3		- install guardrail along bridge- rail face
-4		- deck over gap between parallel bridges and install single bridgerail

TABLE 3, CONTINUED

Longitudinal Hazard Improvement Codes (Primary Code, 2), Continued

Code	Identification	Descriptor
2-3-1-0	Guardrail	- remove existing guardrail
-2-0		- upgrade to full safety standards
-3-0		- upgrade to full safety standards and close up gap
-4-0		- close up gap between existing guardrail
-5-0		- anchor existing guardrail to bridgerail
-6-0		- safety treat guardrail free-end only
2-4-1-0	Ditch	- reshape to safe cross-section
-2-0		- replace with storm drain
-3-0		- protect with guardrail

Slope Improvement Codes (Primary Code, 3)

Code	Identification
3-1-0-0	Install guardrail to protect slope not at bridge (May include point hazards on slope)
3-2-0-0	Install approach or departing guardrail at bridge (May include point hazards on slope)
3-3-0-0	Install continuous guardrail between successive bridges
3-4-0-0	Flatten slope

No Improvement Code (Primary Code, 4)

Code	Identification
4-0-0-0	No improvement recommended.

4. DEVELOPMENT OF THE PRIORITY LIST

PRIORITY RANKINGS FOR IMPROVEMENT ALTERNATIVES

After the improvements throughout a particular section of roadway are evaluated, the various alternatives may be ranked in several ways. They may be ranked 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. Some possible listings are presented below:

1. List of a particular type of improvement analysis (ex. all guardrail upgrading, or sign support protection).
2. List of improvements by cost-effectiveness priority.
3. List of all improvement alternatives having a first cost of a given amount or less.

It is anticipated that future computer programs will be developed to permit users to generate the above and similar listings. Figure 5 presents typical output data from an actual inventory and analysis, and is used to illustrate the development of a priority ranking based on cost-effectiveness value.

Table 4 presents a list of improvements from the data in Figure 5 ranked according to increasing cost-effectiveness value. The accumulated first-cost column reflects the initial cost of improving all hazards down to that point on the priority list. Available funds will determine the number of improvement items to be included in the program.

The safety improvement program established from the cost-effectiveness analysis <u>must</u> be carefully reviewed to determine if the

COST EFFECTIVENESS PROGRAM

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

HIGHWAY NO = 820
COUNTY NO = 220
DISTRICT NO = 2
CONTROL NO = 9
SECTION NO = 13

RECORDING DIRECTION = 2
ADT (1000) = 29
LIFE = 20(YRS)
INTEREST = 8.0(PERCENT)
DATE = 9-74

HAZARD										IMPROVEMENT						
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
2	6	4	2	4	15.9	1	1	30.033	29.890	1	2-3-2-0	3.3	3050	3050	310	GROUP
3	12	3	0	0	3.3	1	1	29.890	29.828	1	4-0-0-0	3.3	0	3050	310	GROUP
5	6	2	4	2	10.3	1	1	29.828	29.710	1	2-3-2-0	3.3	2725	5775	588	GROUP
4	7	2	0	0	50.0	1	1	29.828	29.710	1	4-0-0-0	50.0	0	5775	588	GROUP
1	7	2	0	0	50.0	1	1	30.010	29.890	1	4-0-0-0	50.0	0	5775	588	30
6	5	2	0	0	4.7	1	0	29.710	29.695	1	2-1-1-0	0.0	500	499	50	824
7	7	1	0	0	50.0	1	0	29.620	29.476	1	3-4-0-0	30.0	1875	1874	190	67
8	6	2	2	2	17.3	1	2	29.475	29.461	1	2-3-2-0	3.7	1650	2257	229	GROUP
11	10	1	0	0	15.9	1	2	29.207	29.206	1	1-1-3-0	*****ERROR***** SEE ERROR MESSAGE NO.39				
10	7	1	0	0	9.6	1	2	29.461	29.000	1	3-4-0-0	30.0	3500	6157	627	GROUP
9	3	5	0	0	52.5	1	2	29.463	29.461	1	4-0-0-0	52.5	0	6157	627	END GROUP
12	5	2	0	0	4.7	1	0	28.791	28.767	1	2-1-1-0	0.0	800	799	81	611
15	6	4	2	4	15.9	1	3	28.761	28.680	1	2-3-2-0	3.3	2725	3115	317	GROUP
17	12	3	0	0	3.3	1	3	28.670	28.652	1	4-0-0-0	3.3	0	3115	317	GROUP
19	6	2	4	2	10.3	1	3	28.652	28.515	1	2-3-2-0	3.3	3025	6141	625	GROUP
21	9	0	0	0	50.0	1	3	28.542	28.513	1	4-0-0-0	50.0	0	6141	625	GROUP
13	9	0	0	0	2.2	1	3	28.775	28.700	1	4-0-0-0	2.2	0	6141	625	GROUP
20	10	1	0	0	15.9	1	3	28.542	28.541	1	4-0-0-0	15.9	0	6141	625	GROUP
16	10	1	0	0	15.9	1	3	28.700	28.699	1	4-0-0-0	15.9	0	6141	625	GROUP
18	7	2	0	0	50.0	1	3	28.652	28.515	1	4-0-0-0	50.0	0	6141	625	GROUP
14	7	2	0	0	50.0	1	3	28.761	28.680	1	4-0-0-0	50.0	0	6141	625	4459

Figure 5. Typical analysis model data output (1 of 4).

22	5	2	0	0	4.7	1	0	28.513	28.493	1	2-1-1-0	0.0	400	399	40	345
23	7	1	0	0	50.0	1	0	28.455	28.388	1	3-4-0-0	30.0	3500	3499	356	202
24	6	4	2	4	15.9	1	4	28.210	28.200	1	2-3-2-0	3.3	1950	2464	250	GROUP
26	12	3	0	0	3.3	1	4	28.200	28.174	1	4-0-0-0	3.3	0	2464	250	GROUP
27	6	2	4	2	10.3	1	4	28.174	28.151	1	2-3-2-0	3.3	1225	3689	375	GROUP
25	12	1	0	0	30.0	1	4	28.200	28.175	1	4-0-0-0	30.0	0	3689	375	42
28	8	0	0	0	50.0	1	0	28.130	28.082	1	2-4-1-0	0.0	750	749	76	55
29	7	2	0	0	50.0	1	0	28.047	27.886	1	3-1-0-0	3.7	7300	11510	1172	386
30	9	1	0	0	47.5	1	0	27.850	27.849	1	1-1-4-0	0.0	1000	999	101	489
31	6	2	0	0	*****	1	5	27.820	27.818	1	2-3-1-0	*****ERROR***** SEE ERROR MESSAGE NO.32				
32	3	5	0	0	52.5	1	5	27.819	27.817	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO. 8				
33	5	2	0	0	4.7	1	0	27.806	27.785	1	2-1-1-0	0.0	400	399	40	378
39	11	1	0	0	82.5	1	6	27.614	27.597	1	4-0-0-0	82.5	0	0	0	GROUP
40	10	1	0	0	15.9	1	6	27.534	27.532	1	4-0-0-0	15.9	0	0	0	GROUP
42	12	3	0	0	3.3	1	6	27.374	27.325	1	4-0-0-0	3.3	0	0	0	GROUP
41	6	4	2	4	15.9	1	6	27.530	27.374	1	2-3-2-0	3.3	7325	10411	1060	GROUP
43	12	2	0	0	14.5	1	6	27.374	27.325	1	4-0-0-0	14.5	0	10411	1060	GROUP
34	8	0	0	0	50.0	1	6	27.785	27.664	1	2-4-1-0	*****ERROR***** SEE ERROR MESSAGE NO.42				
36	6	2	2	2	17.3	1	6	27.664	27.659	1	2-3-1-0	0.0	60	12861	1309	GROUP
35	9	1	0	0	47.5	1	6	27.666	27.666	1	4-0-0-0	47.5	0	12861	1309	GROUP
38	7	3	0	0	50.0	1	6	27.654	27.530	1	4-0-0-0	50.0	0	12861	1309	GROUP
37	3	5	0	0	52.5	1	6	27.661	27.659	1	4-0-0-0	52.5	0	12861	1309	END GROUP
39	11	1	0	0	82.5	1	6	27.614	27.597	2	1-2-0-0	3.7	3450	5488	558	GROUP
40	10	1	0	0	15.9	1	6	27.534	27.532	2	4-0-0-0	15.9	0	5488	558	GROUP
42	12	3	0	0	3.3	1	6	27.374	27.325	2	4-0-0-0	3.3	0	5488	558	GROUP
41	6	4	2	4	15.9	1	6	27.530	27.374	2	2-3-2-0	3.3	2575	8063	821	GROUP
43	12	2	0	0	14.5	1	6	27.374	27.325	2	4-0-0-0	14.5	0	8063	821	GROUP
34	8	0	0	0	50.0	1	6	27.785	27.664	2	2-4-1-0	*****ERROR***** SEE ERROR MESSAGE NO.42				
36	6	2	2	2	17.3	1	6	27.664	27.659	2	2-3-1-0	0.0	60	10513	1070	GROUP
35	9	1	0	0	47.5	1	6	27.666	27.666	2	1-2-0-0	0.0	1850	10513	1070	GROUP
38	7	3	0	0	50.0	1	6	27.654	27.530	2	4-0-0-0	50.0	0	10513	1070	GROUP
37	3	5	0	0	52.5	1	6	27.661	27.659	2	4-0-0-0	52.5	0	10513	1070	END GROUP

Figure 5. Typical analysis model data output (Continued, 2 of 4).

47	12	3	0	0	3.3	1	7	27.295	27.247	1	4-0-0-0	3.3	0	0	0	GROUP
46	12	1	0	0	30.0	1	7	27.295	27.267	1	4-0-0-0	30.0	0	0	0	GROUP
45	6	4	2	4	15.9	1	7	27.300	27.295	1	2-3-2-0	3.3	2480	3381	344	GROUP
48	6	2	4	2	10.3	1	7	27.247	27.200	1	2-3-2-0	3.3	3400	7691	783	GROUP
44	7	1	0	0	50.0	1	7	27.325	27.295	1	4-0-0-0	50.0	0	7691	783	53
49	6	2	1	2	5.4	1	8	27.200	27.015	1	2-3-2-0	3.7	3175	2678	272	GROUP
50	7	2	0	0	3.6	1	8	27.200	27.070	1	4-0-0-0	3.6	0	2678	272	2980
52	6	2	2	2	17.3	1	9	26.828	26.801	1	2-3-2-0	3.7	2500	3558	362	GROUP
53	11	1	0	0	82.5	1	9	26.825	26.806	1	4-0-0-0	82.5	0	3558	362	GROUP
51	7	3	0	0	50.0	1	9	26.838	26.792	1	4-0-0-0	50.0	0	3558	362	2402
52	6	2	2	2	17.3	1	9	26.828	26.801	2	2-3-1-0	0.0	300	-460	-46	GROUP
53	11	1	0	0	82.5	1	9	26.825	26.806	2	1-4-0-0	1.0	3380	3080	313	GROUP
51	7	3	0	0	50.0	1	9	26.838	26.792	2	4-0-0-0	50.0	0	3080	313	1192
54	5	2	0	0	4.7	1	0	26.624	26.604	1	2-1-1-0	0.0	400	399	40	576
60	12	4	0	0	3.0	1	10	25.775	25.647	1	4-0-0-0	3.0	0	0	0	GROUP
59	6	4	4	4	11.0	1	10	25.910	25.775	1	2-3-2-0	3.3	3450	3450	351	GROUP
57	12	3	0	0	3.3	1	10	25.990	25.910	1	4-0-0-0	3.3	0	3450	351	GROUP
56	6	4	2	4	15.9	1	10	26.567	25.990	1	2-3-2-0	3.3	7725	11679	1189	GROUP
61	6	2	4	1	8.9	1	10	25.647	25.591	1	4-0-0-0	8.9	0	11679	1189	GROUP
55	7	2	0	0	3.6	1	10	26.605	25.990	1	4-0-0-0	3.6	0	11679	1189	GROUP
62	7	2	0	0	3.6	1	10	25.647	25.591	1	4-0-0-0	3.6	0	11679	1189	GROUP
58	7	2	0	0	3.6	1	10	25.910	25.775	1	4-0-0-0	*HAZARD IMPROVEMENT NOT COST-EFFECTIVE*				
63	5	1	0	0	2.4	1	0	25.591	25.577	1	4-0-0-0	*****NO IMPROVEMENTS RECOMMENDED*****				
64	10	1	0	0	15.9	1	11	25.575	25.573	1	1-1-3-0	0.0	600	599	61	GROUP
68	10	1	0	0	15.9	1	11	25.471	25.469	1	1-1-3-0	0.0	600	1199	122	GROUP
65	11	1	0	0	82.5	1	11	25.481	25.477	1	1-2-0-0	3.7	3300	6255	637	GROUP
67	7	1	0	0	50.0	1	11	25.474	25.426	1	4-0-0-0	50.0	0	6255	637	GROUP
69	7	3	0	0	50.0	1	11	25.426	25.330	1	4-0-0-0	50.0	0	6255	637	GROUP
66	7	3	0	0	50.0	1	11	25.483	25.474	1	4-0-0-0	50.0	0	6255	637	143
64	10	1	0	0	15.9	1	11	25.575	25.573	2	4-0-0-0	15.9	0	0	0	GROUP
68	10	1	0	0	15.9	1	11	25.471	25.469	2	4-0-0-0	15.9	0	0	0	GROUP
65	11	1	0	0	82.5	1	11	25.481	25.477	2	1-2-0-0	3.7	6700	10664	1086	GROUP
67	7	1	0	0	50.0	1	11	25.474	25.426	2	4-0-0-0	50.0	0	10664	1086	GROUP
69	7	3	0	0	50.0	1	11	25.426	25.330	2	4-0-0-0	50.0	0	10664	1086	GROUP
66	7	3	0	0	50.0	1	11	25.483	25.474	2	4-0-0-0	50.0	0	10664	1086	252
70	5	2	0	0	4.7	1	0	25.367	25.325	1	4-0-0-0	*****NO IMPROVEMENTS RECOMMENDED*****				

Figure 5. Typical analysis model data output (Continued, 3 of 4).

72	9	1	0	0	47.5	1	12	25.285	25.284	1	4-0-0-0	47.5	0	0	0	GROUP
73	7	2	0	0	50.0	1	12	25.284	25.038	1	4-0-0-0	50.0	0	0	0	GROUP
71	8	0	0	0	50.0	1	12	25.284	25.038	1	4-0-0-0	*****NO IMPROVEMENTS RECOMMENDED*****				
72	9	1	0	0	47.5	1	12	25.285	25.284	2	4-0-0-0	47.5	0	0	0	GROUP
73	7	2	0	0	50.0	1	12	25.284	25.038	2	3-1-0-0	3.7	11900	18505	1884	GROUP
71	8	0	0	0	50.0	1	12	25.284	25.038	2	4-0-0-0	50.0	0	18505	1884	177
74	9	1	0	0	47.5	1	0	24.835	24.834	1	1-1-4-0	0.0	5480	5479	558	5297
74	9	1	0	0	47.5	1	0	24.835	24.834	2	1-2-0-0	3.7	3300	5042	513	11137
75	5	2	0	0	4.7	1	0	24.805	24.790	1	2-1-1-0	0.0	400	399	40	686
76	10	1	0	0	15.9	1	0	24.783	24.781	1	1-1-3-0	0.0	600	599	61	812
78	10	1	0	0	15.9	1	13	24.732	24.730	1	4-0-0-0	15.9	0	0	0	GROUP
79	10	1	0	0	15.9	1	13	24.673	24.671	1	4-0-0-0	15.9	0	0	0	GROUP
83	10	1	0	0	15.9	1	13	24.615	24.613	1	4-0-0-0	15.9	0	0	0	GROUP
84	10	1	0	0	15.9	1	13	24.545	24.543	1	1-1-3-0	0.0	600	599	61	GROUP
81	11	1	0	0	82.5	1	13	24.636	24.632	1	1-2-0-0	3.7	8400	8999	916	GROUP
80	7	3	0	0	50.0	1	13	24.639	24.630	1	4-0-0-0	50.0	0	8999	916	GROUP
77	7	1	0	0	50.0	1	13	24.783	24.639	1	4-0-0-0	50.0	0	8999	916	GROUP
82	7	1	0	0	50.0	1	13	24.630	24.600	1	4-0-0-0	50.0	0	8999	916	211
78	10	1	0	0	15.9	1	13	24.732	24.730	2	1-1-3-0	0.0	600	599	61	GROUP
79	10	1	0	0	15.9	1	13	24.673	24.671	2	1-1-3-0	0.0	600	1199	122	GROUP
83	10	1	0	0	15.9	1	13	24.615	24.613	2	4-0-0-0	15.9	0	1199	122	GROUP
84	10	1	0	0	15.9	1	13	24.545	24.543	2	1-1-3-0	0.0	600	1799	183	GROUP
81	11	1	0	0	82.5	1	13	24.636	24.632	2	1-2-0-0	3.7	4200	7262	739	GROUP
80	7	3	0	0	50.0	1	13	24.639	24.630	2	4-0-0-0	50.0	0	7262	739	GROUP
77	7	1	0	0	50.0	1	13	24.783	24.639	2	4-0-0-0	50.0	0	7262	739	GROUP
82	7	1	0	0	50.0	1	13	24.630	24.600	2	4-0-0-0	50.0	0	7262	739	164
86	10	1	0	0	15.9	1	14	24.480	24.478	1	4-0-0-0	15.9	0	0	0	GROUP
87	10	1	0	0	15.9	1	14	24.402	24.400	1	4-0-0-0	15.9	0	0	0	GROUP
88	10	1	0	0	15.9	1	14	24.295	24.293	1	4-0-0-0	15.9	0	0	0	GROUP
89	10	1	0	0	15.9	1	14	24.226	24.224	1	4-0-0-0	15.9	0	0	0	GROUP
90	11	1	0	0	82.5	1	14	24.190	24.166	1	4-0-0-0	82.5	0	0	0	GROUP
85	7	3	0	0	50.0	1	14	24.543	24.150	1	3-1-0-0	3.7	17300	27941	2845	325
86	10	1	0	0	15.9	1	14	24.480	24.478	2	1-1-3-0	0.0	600	599	61	GROUP
87	10	1	0	0	15.9	1	14	24.402	24.400	2	1-1-3-0	0.0	600	1199	122	GROUP
88	10	1	0	0	15.9	1	14	24.295	24.293	2	1-1-3-0	0.0	600	1799	183	GROUP
89	10	1	0	0	15.9	1	14	24.226	24.224	2	1-1-3-0	0.0	600	2399	244	GROUP
90	11	1	0	0	82.5	1	14	24.190	24.166	2	1-2-0-0	3.7	3100	7140	727	GROUP
85	7	3	0	0	50.0	1	14	24.543	24.150	2	4-0-0-0	50.0	0	7140	727	77
92	10	1	0	0	15.9	1	15	24.083	24.081	1	1-1-3-0	0.0	600	599	61	GROUP
93	10	1	0	0	15.9	1	15	24.029	24.027	1	1-1-3-0	0.0	600	1199	122	GROUP
91	7	1	0	0	50.0	1	15	24.120	23.995	1	4-0-0-0	50.0	0	1199	122	60

Figure 5. Typical analysis model data output (Continued, 4 of 4).

TABLE 4

IMPROVEMENT PRIORITY LIST

Rank	Hazard Number(s)	First Cost	Accumulated First Cost	Cost-Effectiveness Value	Item
1	1-5	5775	5775	30	Group Improvement
2	24-27	3175	8950	42	Group Improvement
3	44-48	5880	14830	53	Group Improvement
4	28	750	15580	55	Reshape Ditch
5	91-93	1200	16780	60	Group Improvement
6	7	1875	18655	67	Flatten Slope
7	85-90	5500	24155	77	Group Improvement
8	64-69	4500	28655	143	Group Improvement
9	77-84	6000	34655	164	Group Improvement
10	71-73	11900	46555	177	Group Improvement
11	23	3500	50055	202	Flatten Slope
12	77-84	9000	59055	211	Group Improvement
13	64-69	6700	65755	252	Group Improvement
14	85-90	17300	83055	325	Group Improvement
15	22	400	83455	345	Remove & Regrade Curb
16	33	400	83855	378	Remove & Regrade Curb
17	29	7300	91155	386	Install Guardrail to Protect Slope
18	30	1000	92155	489	Reconstruct Culvert Headwall
19	54	400	92555	576	Remove & Regrade Curb
20	12	800	93355	611	Remove & Regrade Curb
21	75	400	93755	686	Remove & Regrade Curb

TABLE 4, CONTINUED

Rank	Hazard Number(s)	First Cost	Accumulated First Cost	Cost-Effectiveness Value	Item
22	76	600	94355	812	Reconstruct Inlet
23	6	500	94855	824	Remove & Regrade Curb
24	51-53	3680	98535	1192	Group Improvement
25	51-53	2500	101035	2402	Group Improvement
26	49-50	3175	104210	2980	Group Improvement
27	13-21	5750	109960	4459	Group Improvement
28	74	5480	115440	5297	Reconstruct Culvert Headwall
29	74	3300	118740	11137	Protect Culvert with Guardrail

improvements are practical. For example, assume that the priority list reflected removal of a system of trees as being the highest priority improvement. With the current emphasis on beautification and preservation of natural beauty, it may not be politically feasible to remove the trees, particularly if these same trees were planted as part of a recent beautification program. Sound engineering is a vital ingredient in evaluating the output and establishing the final safety program.

5. CONCLUDING STATEMENT

This report attempts to present the information necessary for interpretation of the cost-effectiveness analysis computer program output. For a more detailed description of the procedures used and the computer program logic, the reader is referred to the research reports listed in the Foreword of this report. It is important to stress that cost-effectiveness analysis does not necessarily in itself constitute a safety priority program, but is considered as one tool to assist in the development of a safety program.

It often is assumed that cost-effectiveness analysis replaces spot improvement programs and other similar safety activities. This is not the case. Certainly, at high frequency accident locations, immediate remedial treatment is essential. On the other hand, cost-effectiveness techniques expand available safety analysis procedures to include those hazards that have a low probability of any given one being struck but which, due to their numbers, constitute a substantial safety problem. It, therefore, complements a spot improvement program.

Cost-effectiveness analysis cannot take into account all possible variables that can interact to produce a high accident location. It provides only one method to evaluate, on a common basis, alternative safety treatments for identifiable roadside hazards.

REFERENCES

1. Glennon, John C. "A Cost-Effectiveness Priority Approach for Roadside Safety Improvement Programs on Texas Freeways." NCHRP Project 20-7, Task Order 1/1 Final Report. Texas Transportation Institute Report 625-2F. February 1972 (Also published as NCHRP Report No. 148).

APPENDIX A

THE COST-EFFECTIVENESS MODEL

The form of the model used in this program is presented below.

$$C/E = \frac{C_I + C_{MI} - C_{MO} + \frac{C_{CI}H_I}{S_I} - \frac{C_{CO}H_O}{S_O}}{H_O - H_I} \quad \ldots \text{(Eqn. 4)}$$

where

C/E = Cost of eliminating one fatal or serious injury accident ($ per accident eliminated)

C_I = Annualized cost of the improvement

C_{MI} = Annualized cost of routine maintenance of improvement

C_{MO} = Annualized cost of routine maintenance of hazard before improvement

C_{CI} = Annualized cost of maintenance per collision with improvement

C_{CO} = Annualized cost of maintenance per collision with object

H_I = Hazard index of improvement

H_O = Hazard index of object

S_I = Severity index of improvement

S_O = Severity index of object

The elements of the model are self-explanatory except for the repair costs for each collision. The annualized cost of maintenance per collision must be multiplied by the probability of the improvement being struck. The hazard index H_I is the product of the probability of a vehicle encroachment, the probability of the encroaching vehicle reaching the object, and the severity of the resulting collision. Therefore, the ratio of H_I to S_I is the probability of the improvement being struck. The object repair cost per collision is computed in the same manner.

The denominator is the difference in the hazard index in the unimproved and improved states. The hazard index includes both the probability of the object or improvement being struck and the severity of the resulting collision. The difference in the hazard indices "before" and "after" improvement is a measure of the effectiveness of the improvement.

APPENDIX B

INVENTORY AND IMPROVEMENT FORMS

ROADSIDE HAZARD INVENTORY FORM

The extremely large number of hazards that must be inventoried along a section of roadway necessitates use of a systematic coding process for eventual analysis by computer. The roadside hazard inventory form shown in Figure B-1 has been designed to accomplish this. The form is applicable for all controlled access highways and rural non-controlled access highways, the analysis procedures being accommodated internally within the computer program depending on the highway type and classification code entered on the form. Table 2 (pg. 22) presents a list of hazard inventory codes.

The inventory form was developed cooperatively by personnel of the Texas Highway Department, Federal Highway Administration, and the Texas Transportation Institute and represents the culmination of repeated field trials and modifications after field implementation on controlled access Interstate highways in several Districts. The format is particularly responsive to the thorough field implementation experience gained in the Fort Worth District.

Volume 1, Procedures Manual, presents detailed discussion for proper completion of the hazard inventory form.

ROADSIDE HAZARD IMPROVEMENT FORM

The manner in which improvement alternative information is input to the program is equally as important as the inventory data input.

The roadside hazard improvement form (Figure B-2) was designed to provide a system whereby feasible safety improvements for each category of hazard can be coded and evaluated in the cost-effectiveness model. Also included are cost data associated with the improvement selected. The format of the form is similar to that of the hazard inventory form. The hazard improvement alternative codes shown in Table 3 (pg. 24) are taken from the hazard improvement form alternative codes. The improvement form is applicable for all controlled access highways and rural non-controlled access highways and has undergone extensive field trial on Interstate highways, particularly in the Fort Worth District.

Form 1378-1
Rev. 10-10-74

ROADSIDE HAZARD INVENTORY

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

SLOPES

BOX 5

FRONT SLOPE

- 3 — 51
- Hinge Point Offset, D_0, (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

/ Card Type — 77

Recommendations:________

Figure B-1. Roadside Hazard Inventory Form.

Form 1379
Rev. 10-10-74

ROADSIDE HAZARD IMPROVEMENTS

BOX 1

1 2 3 4 Hazard Number | 5 6 7 8 Highway Number | 9 10 11 County 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 (D_0)(ft): 42 43 Beginning – 44 45 End — Steepness: 46 47 Beginning :1 — 48 49 End :1 — 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 Beginning :1 — 57 58 End :1 — 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

Figure B-2. Roadside Hazard Improvement Form.