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16. Abstract

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

17. Key Words	18. Distribution Statement
Roadside Safety, Safety Priority Systems, Cost-Effectiveness, Safety Improvements	

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COST-EFFECTIVENESS ANALYSIS
A PRIORITY SYSTEM FOR
ROADSIDE SAFETY IMPROVEMENTS

by

Donald L. Woods

Research Report 11-4

Research Study No. 2-8-72-11

Cost-Effectiveness Priority Program
for Roadside Safety Improvements on Texas Freeways

Sponsored by

The Texas Highway Department
in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

August 1973

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS 77843

FOREWORD

This report entitled "Cost-Effectiveness--A Basis for Programming Roadside Safety Improvements" (Research Report 11-4) has been prepared to assist those individuals responsible for the development of roadside safety improvement programs in the interpretation and use of the cost-effectiveness analysis computer program. Details of the inventory procedure and computer program have not been included in this report for the sake of brevity. For detailed coverage of these items, the reader is referred to the following Texas Transportation Institute research reports:

Report 11-1 - "Procedures Manual for Roadside Hazard Inventory and Safety Improvement Alternatives"

Report 11-2 - "User's Manual for Remote-Terminal Computer Access"

Report 11-3 - "Documentation Manual for Cost-Effectiveness Computer Model"

DISCLAIMER

ABSTRACT

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

KEY WORDS: Roadside Safety, Safety Priority Systems, Cost-Effectiveness, Safety Improvements.

IMPLEMENTATION STATEMENT

The Cost-Effectiveness Analysis Procedure has been developed on an immediate implementation basis. The four reports prepared on the project have been designed to place the necessary information, and only that information, into the hands of individual users. This report provides the basis for administrative interpretation of the Cost-Effectiveness computer output. As such, immediate implementation of the materials in this report by the Districts is anticipated.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 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 work reported herein is presented in detail in reference 3, 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.

$$C/E = \frac{\text{Cost (to the Department)}}{\text{Relative Hazard Reduction}} \qquad \text{[Equation 1]}$$

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.

$$\text{Hazard Index} = P_H \, P_E \, S_H$$

where:

P_H = Probability of object being hit given a vehicle encroachment

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

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 high encroachment potential, 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 20 years and an interest rate of six 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 and after improvements. The denominator is the difference in the degree of hazard between 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.

1.2 Cost-Effectiveness as a Management Tool

The increasing emphasis on safety in recent years has brought about a host 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? This is the question which cost-effectiveness analysis has been designed to examine. It is a means of comparing and ranking two or more safety alternatives.

1.3 Advantages of Cost-Effectiveness Analysis

The primary application of cost-effectiveness analysis is 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 currently available.

The inventory phase of the cost-effectiveness analysis procedure requires District personnel to ask themselves what function each roadside element serves. These questions will identify deficiencies in the design process and possibly result in a more efficient process from both a design and maintenance standpoint.

Another potential application of the cost-effectiveness analysis procedure is in the evaluation of design alternatives. For example, should guardrail be used on a design cross-section which has a flat side slope for a distance of 20 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?

1.4 Engineering Judgment and Cost-Effectiveness Analysis

The most frequent question regarding the cost-effectiveness analysis concept is simple: "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. Even though an improvement may be cost-effective, it may not be practical. For example, it may be more economical to improve one type of hazard over an extended section of roadway rather than treating the first ten hazards on the cost-effectiveness priority list. These types of decisions are not meaningful when left to a computer program. 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 in order to make optimal use of the funds available.

2.0 INTERPRETATION OF THE COST-EFFECTIVENESS VALUE

2.1 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 increases, the relative desirability of the improvement increases. Thus, the model is internally consistent, and the smaller the cost-effectiveness (C/E) value, the higher the priority of the improvement.

Another characteristic of the C/E value is the unit involved. The C/E value is expressed as annualized dollars required to reduce one fatal and serious accident. The C/E Value at which any given improvement alternative is considered to be cost-effective is arbitrary. The C/E analysis procedure permits a priority listing of alternative improvements and, therefore, improvements which have a relatively large cost-effectiveness value would fall well down on the priority list.

2.2 Negative Cost-Effectiveness Value

The C/E value can be negative. This possibility carries with it the question "What does a negative cost-effectiveness mean?" A more detailed analysis of the model reveals that the C/E value can be negative as the result of either the numerator or denominator being negative. The proper interpretation of the C/E value requires a complete understanding of the model and program behavior.

Case 1 - Numerator of Equation 1 is negative

The numerator in equation 1 can be negative when the annualized cost of the improvement, including maintenance costs, is less than the cost of not treating the object. When this occurs, it is apparent that the improvement is cost-effective as 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 that returns the greatest value (i.e., the largest negative C/E value) should have the higher priority for improvement as the dollars saved by the Department would be greater.

Case 2 - Denominator of Equation 1 is Negative

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 occurs when a relatively small object of high severity is located a considerable distance from the edge of the traveled way and the safety treatment results in a much larger object of somewhat lower severity closer to the roadway. A good example of this is the use of 150 feet 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 hit than a 150-foot 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 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 printed by the computer program, it can only result from the situation described in Case 1 above, and the improvement alternative will result in increased safety for the motoring public.

3.0 DEVELOPMENT OF THE PRIORITY LIST

3.1 The Standard Computer Output

The computer output is a complete listing of hazard data, the improvement alternative data, and the cost-effectiveness analysis. A typical output sheet is presented in Figure 1. The hazard inventory codes are presented in Table 1, the improvement alternative codes in Table 2, and the error messages in Table 3. The output is in two basic forms: (1) the isolated hazard, as illustrated by hazards 20 or 124; and (2) grouped hazards as illustrated by hazards 112, 113, and 114 in which the cost-effectiveness is computed only for the entire group. In the latter case, each hazard in the group other than the last one has the message "GROUP" in the cost-effectiveness column to indicate that the item is a part of a group and that the cost-effectiveness for the last hazard in the group is the C/E value for all improvements included in that group. Each hazard within the group must have the same number of possible alternative treatments, and the first alternative investment for each hazard is analyzed as one group, the second alternative for each as another group, up to four alternatives.

The output column headings are generally self explanatory. The cost columns require some amplification in order to be effectively used. The "FIRST COST" is the cost to the Department to improve the situation to the desired level. Hazard Number 1 in Figure 1 requires a first cost of $10 to remove the curb now in place while in hazard number 7 the cost to remove the existing curb and regrade the area is estimated to be $100.

The "ANNUAL COST" is the sum of the "FIRST COST," 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 a 6% interest rate.

3.2 Possible Alternative Program Outputs

The results of the basic cost-effectiveness analysis will be stored at the Automation Division. By use of the MARK IV programming language, the District can call for a wide variety of output formats. Some of the possible listings are presented below.

1. List for one type of improvement (say all guardrails or sign supports).
2. List of improvements by cost-effectiveness priority.
3. List of all improvement alternatives having a first cost of a given amount or less.

Reading the computer listing shown in Figure 1 for hazard number 5, the following information is obtained:

DATA	MEANING
Code 2-0-0-0	Tree
Severity Index	50 on a scale of 100
Offset Code 2	Hazard located in the median
Group Number 0	Isolated hazard
Mile-Post 241.081 - 241.081	Milepost of hazard is 241.081
Improvement Alternative 1	First Alternative suggested
Improvement Code 1-1-0-0	Remove point hazard
Severity Index 0.0	Improvement severity index of zero
First Cost 10	Cost to remove tree is $10
Present Worth 9***	Total present worth including maintenance is $9
Annual Cost 0**	No annual cost associated with alternative
Cost-Effective Value* 8	Cost to reduce one fatal or injury accident is $8

*** Present worth can be less than first cost due to maintenance savings in future years.

** Annual cost of less than $1 is printed as 0 due to the truncation in printing process.

* When the hazard is a part of a group, the word "GROUP" may replace the value.

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

HIGHWAY NO = 35
COUNTY NO = 227
DISTRICT NO = 14
CONTROL NO = 15
SECTION NO = 13

RECORDING DIRECTION = 1
ADT (1000) = 20
LIFE = 20(YRS)
INTEREST = 6.0(PERCENT)
DATE = 8-73

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
1	2	0	0	0	50.0	2	0	241.015	241.015	1	1-1-0-0	0.0	10	9	0	5
2	10	2	0	0	3.1	1	0	241.021	241.021	1	1-2-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
3	10	2	0	0	3.1	2	0	241.021	241.021	1	1-2-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
4	2	0	0	0	50.0	2	0	241.061	241.061	1	1-1-0-0	0.0	10	9	0	8
5	2	0	0	0	50.0	2	0	241.081	241.081	1	1-1-0-0	0.0	10	9	0	8
6	2	0	0	0	50.0	2	0	241.105	241.105	1	1-1-0-0	0.0	10	9	0	8
7	5	2	0	0	4.7	1	0	241.400	241.438	1	2-1-1-0	0.0	100	99	8	192
8	5	2	0	0	4.7	1	0	241.438	241.438	1	1-1-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
9	5	2	0	0	4.7	1	0	241.438	241.442	1	2-1-1-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				

Figure 1 Typical Computer Output

14	12	3	0	0	3.3	1	1	241.670	241.715	1	4-0-0-0	3.3	0	0	0	GROUP
17	6	2	4	1	0.0	1	1	241.715	241.798	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.36				
10	6	2	1	4	8.9	1	1	241.469	241.670	1	4-0-0-0	8.9	0	0	0	GROUP
13	3	2	0	0	30.0	1	1	241.648	241.715	1	4-0-0-0	30.0	0	0	0	GROUP
11	7	2	0	0	3.6	1	1	241.481	241.670	1	4-0-0-0	3.6	0	0	0	END GROUP
15	12	3	0	0	3.3	2	2	241.670	241.715	1	4-0-0-0	3.3	0	0	0	GROUP
18	6	2	4	1	8.9	2	2	241.715	241.736	1	4-0-0-0	8.9	0	0	0	GROUP
12	6	2	1	4	8.9	2	2	241.630	241.670	1	4-0-0-0	8.9	0	0	0	GROUP
16	12	1	0	0	30.0	2	2	241.670	241.670	1	4-0-0-0	*****NO IMPROVEMENT HAZARD GROUPING*****				
19	5	2	0	0	4.7	1	0	241.849	241.868	1	2-1-1-0	0.0	100	-186	-16	-412
20	5	2	0	0	4.7	1	0	241.849	241.900	1	2-1-1-0	0.0	300	13	1	20
21	8	0	0	0	8.0	1	0	241.900	242.127	1	2-4-1-0	0.0	75	-211	-18	-63
100	6	1	1	1	3.7	2	20	251.017	251.068	1	4-0-0-0	3.7	0	0	0	GROUP
102	6	1	1	1	3.7	2	20	251.027	251.076	1	4-0-0-0	*****NO IMPROVEMENT HAZARD GROUPING*****				
100	6	1	1	1	3.7	2	20	251.017	251.068	2	2-3-1-0	0.0	250	249	21	GROUP
102	6	1	1	1	3.7	2	20	251.027	251.076	2	2-3-1-0	0.0	250	499	43	368
101	6	1	1	1	0.0	1	21	251.024	251.065	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
105	11	1	0	0	0.0	1	21	251.053	251.053	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
103	11	1	0	0	0.0	2	21	251.045	251.045	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
104	7	3	0	0	0.0	1	21	251.045	251.084	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
101	6	1	1	1	0.0	1	21	251.024	251.065	2	2-3-1-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
105	11	1	0	0	0.0	1	21	251.053	251.053	2	1-4-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
103	11	1	0	0	0.0	2	21	251.045	251.045	2	1-4-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
104	7	3	0	0	0.0	1	21	251.045	251.084	2	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
106	5	2	0	0	4.7	1	0	251.153	251.168	1	2-1-1-0	0.0	150	35	3	94
107	10	2	0	0	5.0	2	0	251.227	251.227	1	1-1-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
108	5	2	0	0	4.7	1	0	251.678	251.681	1	2-1-1-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				

Figure 1 (cont.)

109	6	2	1	4	0.0	1	23	251.743	251.994	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.36				
115	12	4	0	0	3.0	1	23	251.996	252.056	1	4-0-0-0	3.0	0	0	0	GROUP
111	3	2	0	0	30.0	1	23	251.952	251.952	1	4-0-0-0	30.0	0	0	0	GROUP
110	7	2	0	0	8.0	1	23	251.818	251.994	1	4-0-0-0	8.0	0	0	0	END GROUP
112	6	4	1	4	7.5	2	24	251.963	251.994	1	2-3-2-0	3.3	50	50	4	GROUP
113	12	4	0	0	3.0	2	24	251.994	252.054	1	4-0-0-0	3.0	0	50	4	GROUP
114	12	1	0	0	30.0	2	24	251.993	251.993	1	4-0-0-0	30.0	0	50	4	78
116	6	2	1	4	8.9	1	25	252.056	252.257	1	2-3-1-0	0.0	1000	325	28	GROUP
118	3	2	0	0	30.0	1	25	252.141	252.141	1	1-1-0-0	0.0	1000	1325	115	193
121	12	4	0	0	0.0	2	26	252.371	252.412	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
119	6	4	1	4	0.0	1	26	252.335	252.371	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
123	12	1	0	0	0.0	2	26	252.371	252.371	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
120	6	4	1	4	0.0	2	27	252.342	252.371	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
122	12	4	0	0	0.0	1	27	252.371	252.412	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
124	6	2	4	1	8.9	2	0	252.412	252.472	1	2-3-1-0	0.0	400	77	6	31
125	6	2	4	1	0.0	1	28	252.412	252.436	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
126	3	2	0	0	0.0	0	28	252.416	252.416	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
127	5	2	0	0	4.7	1	0	252.455	252.455	1	1-1-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
128	5	2	0	0	4.7	1	0	252.455	252.482	1	2-1-1-0	0.0	150	35	3	65
129	6	1	1	1	3.7	1	29	252.528	252.567	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.17				
132	11	1	0	0	82.5	1	29	252.555	252.555	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.17				
131	7	3	0	0	8.0	1	29	252.542	252.564	1	4-0-0-0	*****NO IMPROVEMENT HAZARD GROUPING*****				

Figure 1 (cont.)

140	5	2	0	0	0.0	1	30	252.753	252.838	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
139	12	4	0	0	0.0	1	30	252.753	252.838	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
130	6	1	1	1	0.0	2	30	252.535	252.584	1	2-1-1-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
133	11	1	0	0	0.0	2	30	252.561	252.561	1	1-4-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
142	5	2	0	0	0.0	2	31	252.753	252.838	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
141	12	4	0	0	0.0	2	31	252.753	252.838	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
136	6	4	1	4	0.0	1	31	852.717	252.753	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
138	3	2	0	0	0.0	1	31	252.735	252.735	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
135	5	2	0	0	0.0	1	31	252.673	252.753	1	2-1-1-0	*****ERROR***** SEE ERROR MESSAGE NO.31				
137	6	4	1	4	7.5	2	32	252.725	252.753	1	2-3-2-0	3.7	50	50	4	94
146	5	2	0	0	4.7	1	0	252.885	252.885	1	1-1-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
147	5	2	0	0	4.7	1	0	252.885	252.903	1	2-1-1-0	0.0	75	-39	-3	-91

Figure 1 (cont.)

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

HIGHWAY NO = 35
COUNTY NO = 227
DISTRICT NO = 14
CONTROL NO = 15
SECTION NO = 13

RECORDING DIRECTION = 2
ADT (1000) = 20
LIFE = 20(YRS)
INTEREST = 6.0(PERCENT)
DATE = 8-73

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
200	5	2	0	0	4.7	1	0	252.913	252.900	1	2-1-1-0	0.0	100	-14	-1	-42
206	5	2	0	0	4.7	1	50	252.851	252.767	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.26				
205	12	4	0	0	3.0	1	50	252.851	252.767	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.26				
203	3	2	0	0	30.0	1	50	252.870	252.870	1	4-0-0-0	*****ERROR***** SEE ERROR MESSAGE NO.26				
210	6	1	3	1	3.3	1	50	252.851	252.728	1	2-3-1-0	0.0	50	-6	0	GROUP
213	3	2	0	0	30.0	1	50	252.731	252.731	1	1-1-0-0	0.0	200	192	16	GROUP
201	6	4	1	3	0.0	1	50	252.895	252.851	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.36				
211	5	2	0	0	4.7	1	50	252.851	252.709	1	2-1-1-0	0.0	250	213	18	END GROUP
208	5	2	0	0	4.7	2	51	252.851	252.767	1	4-0-0-0	4.7	0	0	0	GROUP
212	6	1	3	1	3.3	2	51	252.851	252.756	1	4-0-0-0	3.3	0	0	0	GROUP
207	12	4	0	0	3.0	2	51	252.851	252.767	1	4-0-0-0	3.0	0	0	0	GROUP
209	12	1	0	0	30.0	2	51	252.851	252.851	1	4-0-0-0	30.0	0	0	0	GROUP
202	6	4	1	3	0.0	2	51	252.876	252.851	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.36				
204	3	2	0	0	30.0	2	51	252.855	252.855	1	4-0-0-0	30.0	0	0	0	END GROUP
214	5	2	0	0	4.7	1	0	252.690	252.655	1	2-1-1-0	0.0	150	35	3	47
215	9	1	0	0	47.5	1	0	252.645	252.645	1	1-1-0-0	0.0	500	499	43	868
216	6	1	1	1	3.7	1	52	252.608	252.568	1	4-0-0-0	3.7	0	0	0	GROUP
219	11	1	0	0	82.5	1	52	252.580	252.580	1	4-0-0-0	82.5	0	0	0	GROUP
218	7	3	0	0	8.0	1	52	252.601	252.571	1	4-0-0-0	*****NO IMPROVEMENT HAZARD GROUPING*****				
217	6	1	1	1	3.7	2	0	252.601	252.551	1	2-3-1-0	0.0	200	-57	-5	-72

Figure 1 (cont.)

223	12	4	0	0	3.0	2	53	252.418	252.379	1	4-0-0-0	3.0	0	0	0	GROUP
220	6	2	1	4	8.9	2	53	252.449	252.418	1	2-3-2-0	3.3	75	75	6	GROUP
222	12	1	0	0	30.0	2	53	252.420	252.420	1	4-0-0-0	30.0	0	75	6	GROUP
225	6	2	4	2	10.3	2	53	252.379	252.373	1	2-3-2-0	3.3	100	175	15	151
224	12	4	0	0	3.0	1	54	252.418	252.379	1	4-0-0-0	3.0	0	0	0	GROUP
226	6	2	4	1	8.9	1	54	252.379	252.356	1	2-3-2-0	3.3	100	100	8	GROUP
221	6	2	1	4	8.9	1	54	252.446	252.418	1	2-3-2-0	3.3	125	225	19	191
227	6	2	1	1	3.9	1	55	252.259	252.120	1	2-3-1-0	0.0	500	86	7	GROUP
228	3	2	0	0	30.0	1	55	252.144	252.144	1	1-1-0-0	0.0	1000	1080	94	525
229	6	2	2	4	0.0	1	56	252.120	252.054	1	2-3-2-0	*****ERROR***** SEE ERROR MESSAGE NO.36				
234	12	4	0	0	3.0	1	56	252.054	251.994	1	4-0-0-0	3.0	0	0	0	GROUP
236	6	1	4	1	7.5	1	56	251.994	251.744	1	2-3-2-0	3.3	800	800	69	GROUP
237	3	2	0	0	30.0	1	56	251.803	251.803	1	1-1-0-0	*****ERROR***** SEE ERROR MESSAGE NO.19				
238	3	2	0	0	30.0	1	56	251.749	251.749	1	1-1-0-0	*****ERROR***** SEE ERROR MESSAGE NO.19				
230	7	2	0	0	3.5	1	56	252.120	252.054	1	4-0-0-0	3.5	0	2192	191	END GROUP
233	12	4	0	0	3.0	2	57	252.054	251.994	1	4-0-0-0	3.0	0	0	0	GROUP
231	6	2	1	4	8.9	2	57	252.093	252.054	1	2-3-2-0	3.3	100	100	8	GROUP
232	12	1	0	0	30.0	2	57	252.054	252.054	1	4-0-0-0	30.0	0	100	8	GROUP
235	6	1	4	2	8.9	2	57	251.994	251.992	1	2-3-2-0	3.3	100	200	17	163
239	5	2	0	0	4.7	1	0	251.704	251.704	1	1-1-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
240	5	2	0	0	4.7	1	0	251.704	251.700	1	2-1-1-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
241	3	2	0	0	30.0	1	0	251.240	251.240	1	1-1-0-0	0.0	75	-39	-3	-36
242	5	2	0	0	4.7	1	0	251.240	251.223	1	2-1-1-0	0.0	100	-129	-11	-309
243	10	2	0	0	5.0	1	0	251.219	251.219	1	1-1-0-0	HAZARD IMPROVEMENT NOT COST-EFFECTIVE.				
244	6	1	1	1	3.7	1	58	251.074	251.034	1	4-0-0-0	3.7	0	0	0	GROUP

Figure 1 (cont.)

TABLE 1
INVENTORY CODES

IDENTIFICATION CODE		DESCRIPTOR CODE	ITEM
01		00	Utility Pole
02		00	Trees
03	Rigid Sign Support	01	Single pole mounted
		02	Double pole mounted
		03	Triple pole mounted
		04	Cantilever support
		05	Overhead sign bridge
04		00	Rigid base luminaire support
05	Curbs	01	Mountable design
		02	Non-mountable design less than 10" high
		03	Barrier design greater than 10" high
06	Guardrail or Median Barrier	01	W-section with standard post spacing
		02	W-section with other than standard post spacing
		03	Approach rail to bridge with reduced post spacing
		04	Approach rail to bridge without reduced post spacing
		05	Post and cable
		06	Median fence
		07	Median barrier (CMB or equivalent)

TABLE 1 Continued

IDENTIFICATION CODE	DESCRIPTOR CODE		ITEM
07	Sideslopes	01	Sod cut slope
		02	Sod fill slope
		03	Concrete faced cut slope
		04	Concrete faced fill slope
		05	Rubble rip-rap cut slope
		06	Rubble rip-rap fill slope
08		00	Washout ditches
09	Culverts	01	Headwall (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
12	Roadway Over Bridge Structure	01	Open gap between parallel bridges
		02	Closed gap between parallel bridges
		03	Rigid bridgerail--smooth continuous construction
		04	Semi-rigid bridgerail--smooth continuous construction

TABLE 1 Continued

	05	Other bridgerail-- penetration likely
	06	Elevated gore abutment
13	00	Retaining wall

TABLE 2

IMPROVEMENT CODES

POINT HAZARD CODES

1-1-(0)/(1)-0	Remove hazard
1-1-2-0	Make breakaway or relocate
1-1-3-0	Reconstruct inlet to safe design
1-1-4-0	Reconstruct cross drainage system
1-2-0-0	Protect with guardrail
1-3-0-0	Protect with concrete median barrier
1-4-0-0	Protect with energy attenuation system

LONGITUDINAL HAZARD CODES

2-1-1-0	Curbs	Remove curb and regrade
2-1-2-0	Curbs	Install wedge modification with curb
2-2-(1)/(2)-1	Bridgerail	Upgrade bridgerail to full safety standards
2-2-(1)/(2)-2	Bridgerail	Move bridgerail laterally
2-2-(1)/(2)-3	Bridgerail	Install guardrail along bridgerail face
2-2-(1)/(2)-4	Bridgerail	Deck over gap between parallel bridges
2-3-1-0	Guardrail	Remove existing guardrail
2-3-2-0	Guardrail	Upgrade to full safety standards
2-3-3-0	Guardrail	Upgrade to full safety standards and close up gaps
2-3-4-0	Guardrail	Close up gap in existing guardrail

TABLE 2 Continued

2-3-5-0	Guardrail	Install guardrail to protect slope
2-3-6-0	Guardrail	Anchor existing guardrail to bridgerail
2-3-7-0	Guardrail	Install guardrail at bridge approach
2-3-8-0	Guardrail	Install guardrail departing bridge
2-3-9-0	Guardrail	Safety treat guardrail--free end only
2-4-1-0	Ditch	Reshape to safe cross-section
2-4-2-0	Ditch	Replace with storm drain
2-4-3-0	Ditch	Protect using guardrail

SIDE SLOPE CODE

3-0-0-0	Reduce steepness of sideslope

NO IMPROVEMENT CODE

4-0-0-0	No improvement recommended

TABLE 3

LIST OF ERROR OR FLAG MESSAGES

Message Name	Description of Message
1	End milepost at hazard not specified
2	Unmatched point hazard and improvement codes
3	Non-existing improvement classification specified in Col. 42 of improvement form
4	Non-existing ditch improvement code classification
5	Guardrail installation not necessary--re-examine roadway group hazard
6	Non-existing hazard classification specified in Column 52 of inventory form
7	Non-existing point hazard improvement code (Column 40)
8	***** Available for later use *****
9	Distance between guardrail and obstacle less than 2.0 feet
10	***** Available for later use *****
11	Non-existing curb improvement class. Specified in Col. 43 of improvement form
12	Non-existing bridgerail imprvmnt class. Specified in Col. 43 of improvement form
13	Non-existing bridgerail imprvmnt class. Specified in Col. 44 of improvement form
14	Non-existing guardrail imprvmnt class. Specified in Col. 43 of improvement form
15	Guardrail end-treatment adjacent to bridge incorrectly specified
16	***** Available for later use *****
17	Non-existing slope direction class. Specified on inventory form
18	No slope recommendation specified on improvement form

TABLE 3 Continued

Message Name	Description of Message
19	Programming error--vehicle not permitted to penetrate guardrail
20	No improvement needed--flat slopes and/or lateral offset greater than 30 ft
21	Program error in subroutine zero--refer to flow charts
22	***** Available for later use *****
23	Stop computer program--100 error or flag messages
24	Unmatched hazard numbers on inventory and improvement form
25	Guardrail installation not necessary--re-examine roadway site
26	No improvement hazard exposed--re-examine roadway site
27	End of data and program
28	Unequal number of improvement alternatives per hazard in group
29	Program error in subroutine rail 1--refer to flow charts
30	Hazard improvement not cost-effective.
31	Hazards on right side and left side of roadway cannot be grouped together
32	Guardrail end treatment code not specified on inventory form
33	Guardrail end treatment code not defined--value greater than 4
34	Improvement costs not specified
35	Guardrail hazard maintenance costs not specified
36	Guardrail improvement maintenance costs not specified

3.3 Priority List

Based on the data presented in Figure 1, the priority list is as follows:

RANK	HAZARD NUMBER	FIRST COST	ACCUMULATED FIRST COST	C/E VALUE	ITEM
1	19	100	100	$-412	Remove Curb
2	242	100	200	-309	Remove Curb
3	147	75	275	- 91	Remove Curb
4	217	200	475	- 72	Remove Guardrail
5	21	75	550	- 63	Reslope Ditch
6	200	100	650	- 42	Remove Curb
7	241	75	725	- 36	Remove Sign
8	1	10	735	5	Remove Tree
9	4	10	745	8	Remove Tree
9	5	10	755	8	Remove Tree
9	6	10	765	8	Remove Tree
12	20	300	1235	20	Remove Curb
13	124	400	1635	31	Remove Guardrail
14	214	150	1785	47	Remove Curb
15	128	150	1935	65	Remove Curb
16	112 113 114	Group Improve-ment 50	1985	78	Upgrade guard-rail to full Safety Standards
17	106	150	2035	94	Remove Curb
17	137	50	2085	94	Upgrade guard-rail to full Safety Standards

Priority List continues until all improvements are included, eliminated due to errors in the data or shown not to be cost-effective.

The accumulative 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 items to be included in the program.

The program as determined by cost-effectiveness analyses must be carefully reviewed to determine if the improvements are practical. For example, in the priority list above, four of the top ten items are to remove trees. With the current emphasis on beautification and preservation of natural beauty, it may not be politically feasible to remove the trees. This is particularly true if these same trees were planted as part of a beautification program a few years ago. Good engineering judgment is the most important aspect in establishing the final safety project schedule.

4.0 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 Research Reports 11-1 and 11-2. It is important to again 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. The approach does not, and should not, replace existing spot safety improvement procedures, but rather should be used to complement them. 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.

5.0 REFERENCES

1. Burke, Dock. "Highway Accident Costs and Rates in Texas." Research Report 144-1F, Texas Transportation Institute, December, 1970.

2. Highway Safety Program Manual, Volume 13. "Traffic Engineering Services." U. S. Department of Transportation/Federal Highway Administration, April, 1973, p. 4.

3. Glennon, John C. "A Cost-Effectiveness Priority Approach for Roadside Safety Improvement Programs on Texas Freeways." Will be published by NCHRP in 1974, tentatively as NCHRP report no. 148.

6.0 APPENDIX

THE COST-EFFECTIVENESS MODEL

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

$$C/E = \frac{C_I + C_{MI} - C_{MO} + \dfrac{C_{CI}H_I}{S_I} - \dfrac{C_{CO}H_O}{S_O}}{H_O - H_I}$$

where:

C/E = Cost of reducing one fatal or injury accident ($ per accident reduced)

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's being struck. The hazard index H_I is the product of the probability of a vehicle encroachment, the probability of the encroaching vehicle's 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's or improvement's 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.