Methodology for Ranking Roadside Hazard Correction Programs

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This paper describes the development and use of a computerized system to facilitate the prioritizing of roadside fixed-object treatments. Developed for the Traffic Engineering Branch of the North Carolina Division of Highways, the system is designed to perform economic analyses of various fixed-object improvements on an areawide, or roadway segment, basis, for example, determining the effect of removing all trees within 9 m (30 ft) of the edge of pavement on rural, two-lane, secondary roads in the piedmont area of North Carolina. Developed inputs for the system include: (a) frequency and severity of the most affectable accidents for each given hazard-treatment combination, (b) expected reductions in fatal, injury, and property damage only accidents associated with implementation of the treatment, and (c) initial, maintenance, and repair costs over the service life of each treatment. System outputs include predicted accident savings, the net discounted present value and benefit-cost ratio for each candidate fixed-object treatment, and a priority ranking based on comparisons of net present value. Initial runs using the system indicated that the use of transition guardrail at hazardous bridge ends and tree removal in certain locations in North Carolina appear promising. System developmental efforts also reemphasized the continuing presence of a serious national problem—the lack of sound information concerning effectiveness levels for fixed-object countermeasures.

In recent years, more attention has been given to highway programs that are designed to make the roadside environment safer and, consequently, to lessen the severity of crashes associated with off-the-road hazards. Since funding for such programs is limited, developing cost-effective approaches to the problem is essential.

In an attempt to provide highway administrators and engineers with an economical tool to facilitate the prioritization of roadside fixed-object treatments, a computerized system was developed by the University of North Carolina Highway Safety Research Center (HSRC) for the Traffic Engineering Branch of the North Carolina Division of Highways (DOH). An accompanying user's manual was developed as an aid to engineers and computer programmers using the system.

An economic analysis of various roadside safety improvements on an areawide basis included a determination of the frequency and severity of the most affectable accidents for each treatment based on North Carolina accident data. In addition, the expected reductions in fatal, injury, and property damage only (PDO) accidents associated with the implementation of the treatment were analyzed. Benefits were developed based on accident savings by assigning dollar costs to fatal, injury, and PDO accidents. Improvement cost components included initial, maintenance, and repair costs over the service life of each treatment. The Net Discounted Present Value (NDPV) for each hazard-treatment combination was determined through economic analysis, and a priority ranking was developed based on comparisons of net present value. For alternatives with different service lives, the equivalent annual cash flow was calculated.

The system producing the priority ranking of roadside improvement programs was developed to analyze areawide improvements rather than spot improvements on which most existing fixed-object programs focus. Programs aimed at fixed-object spot locations are based on the assumption that a given hazard will be struck with a high enough frequency to be detected. Unfortunately, this is rarely the case. Rather than a specific hazard's (e.g., an identifiable tree) being struck numerous times, the roadside hazard problem evolves from the fact that a number of different hazards, perhaps of the same type, are struck numerous times. Any given hazard is struck with very low frequency, usually less than once per year. Hence, there is a need for a methodology to rank roadside fixed-object correction programs on an areawide basis.

The areawide approach attempts to identify hazards along an expanded spot that includes roadway segments on more than one route. What will be identified in this procedure is a given hazard with an appropriate treatment for a given type of roadway segment.

This methodology will allow the user to perform the economic analysis for a particular hazard-treatment combination for any expanded spot ranging from a statewide area to a much smaller area. The variables defining a specific area include the following:

1. Location (urban or rural);
2. Area in the state (coastal plain, piedmont, mountain);
3. Highway type (Interstate, U.S., state, secondary road, city street);
4. Number of lanes (two lanes, four or more lanes undivided, four or more lanes divided—for rural areas only);
5. Highway character (intersection, nonintersection);
6. Highway features (tangent section, curve section); and
7. Median width—0.3-3.6 m (1-12 ft), 3.9-9 m (13-30 ft), 9.3-18 m (31-60 ft), over 18.3 m (over 61 ft).

The first two columns of Table 1 list the roadside hazards and treatments examined for the analysis program that was developed. For example, the design methodology will allow one to analyze a combination such as a program aimed at removing all trees from the roadside on all curved, nonintersection segments of two-lane, North Carolina highways in the rural regions of the coastal plain. The benefits from this particular combination could then be compared to the benefits from any other hazard-treatment-segment combination that is defined.

METHODOLOGY

The basic research design used in this study is an extension of a system employed in an earlier one by Council and Hunter (1) and performed for the Motor Vehicle Manufacturers Association of the United States, Incorporated (MVMA). The present study, however, deals only with fixed-object accidents and related countermeasures rather than roadway safety countermeasures of all types. Figure 1 is a schematic representation of the basic tasks leading to the priority ranking of fixed-object improvement programs.

Determination of Accident Reduction Factors

Calculating the accident reduction factors was, perhaps, the most important input to the economic analysis phase. First, a literature review of fixed-object countermeasure evaluations was conducted. Many of the reports, unfortunately, had poor study designs, particularly before and after designs with no control groups. It was concluded from this literature search that more and better-conducted evaluative studies dealing with fixed-object improvement should be performed and published.

Another data source that provided limited information was the file of before and after studies compiled by the Traffic Engineering Branch of the North Carolina Division of Highways. It contained approximately 400 improvement studies on subjects such as delineation, channelization, and signal installation, but few pertaining to roadside fixed-object treatments.

Twelve state highway departments were contacted for

Table 1. Summary of hazard-treatment information.

Hazard	Treatment	% Reduction[a]			Cost ($)			Service Life (years)	Comment
		Fatal	Injury	PDO	Initial	Maintenance	Repair		
Utility poles	Breakaway	30	-1	0	36/pole	0	250/pole	10	Rural intersection, non-intersection
		30	-1	0	36/pole	0	550/pole	10	Urban intersection, non-intersection
		30	-1	0	36/pole	0	250/pole	10	Rural intersection
		30	-1	0	36/pole	0	550/pole	10	Urban intersection
	Relocate 9 m from edge of pavement	32	-1.7	0	375/pole	0	200/pole	20	Rural non-intersection
		32	-1.7	0	375/pole	0	500/pole	20	Urban non-intersection
		32	-1.7	0	375/pole	0	200/pole	20	Rural intersection
		32	-1.7	0	375/pole	0	500/pole	20	Urban intersection
	Remove	38	-1.5	0	930/pole	0	0	20	Rural non-intersection: cost/pole includes $11/m to bury cable at pole spacing of 75 m
		38	-1.5	0	1600/pole	0	0	20	Urban non-intersecting: cost/pole includes $20/m to bury cable at pole spacing of 75 m
		38	-1.5	0	435/pole	0	0	20	Rural intersection: cost/pole includes $11/m to bury cable for 90 m of cable required
		38	-1.5	0	850/pole	0	0	20	Urban intersection: cost/pole includes $20/m to bury cable for 150 m of cable required
Trees	Remove	50	25	-20	30/tree	0	0	10	Rural and urban (without removal of stump)
		50	25	-20	60/tree	0	0	10	Rural and urban (with removal of stump)
Exposed bridge rail ends	Transition guardrail	55	20	-50	1950/end	0	400/hit	15	Rural and urban, 2 lanes with 30 m total of approach or trail guardrail per end
		55	20	-50	5550/end	0	400/hit	15	Rural and urban, 4-lane (divided and undivided), 120 m of guardrail/ exposed bridge end
Substandard bridge rail	Improved rail (three beam)	15	5	-3	83/m	0	50/hit	20	Rural and urban
Underpasses (bridge piers)	Concrete median barrier with end treatment	60	40	-150	12 100/site	0	350/hit	20	Rural and urban, 4-lane divided, median piers
		60	40	-150	6000/site	0	350/hit	20	Rural and urban, 2-lane, 4-lane undivided, shoulder piers
	Attenuators:								
	Water-filled cushion	75	60	-300	24 000/site	0	500/hit	10	Rural and urban, 4-lane divided, median piers
		75	60	-300	24 000/site	0	500/hit	10	Rural and urban, 2-lane, shoulder piers
		75	60	-300	12 000/site	0	500/hit	10	Rural and urban, 4-lane undivided, shoulder piers
	Sand-filled cell	75	60	-300	10 000/site	0	800/hit	10	Rural and urban, 4-lane divided, median piers
		75	60	-300	10 000/site	0	800/hit	10	Rural and urban, 2-lane, shoulder piers
		75	60	-300	5000/site	0	800/hit	10	Rural and urban, 4-lane undivided, shoulder piers
	Steel barrels	75	60	-300	17 000/site	0	700/hit	10	Rural and urban, 4-lane divided, median piers
		75	60	-300	17 000/site	0	700/hit	10	Rural and urban, 2-lane, shoulder piers
		75	60	-300	8500/site	0	700/hit	10	Rural and urban, 4-lane, undivided, shoulder piers
Rigid signs or supports									
Small sign	Breakaway	70	25	-12	70/sign	0	100/sign	5	Rural and urban
Large metal support	Breakaway	60	20	-20	300/pole	0	150/sign	10	Rural and urban
Large metal support	Relocate behind guardrail	55	30	-5	125/sign	0	100/sign	10	Rural and urban (assumes no guardrail cost)
All supports combined	Breakaway	68	24	-14	100/sign	0	110/sign	5	Rural and urban
Guardrail ends	Breakaway cable terminal	55	25	-15	350/end	0	350/end	15	Rural and urban, median and shoulder
	Turned down Texas terminal	55	25	-15	300/end	0	300/end	15	Rural and urban, median and shoulder
Median-involved accidents									
Narrow median	Concrete median barrier	90	10	-10	66 000/km (67/m)	0	0	20	Rural and urban; median width, 0.3-3.6 m
		85	5	-25	66 000/km	0	0	20	Rural and urban; median width, 3.9-9 m
Wider median	Double-faced guardrail	75	2	-28	49 500/km	0	500/hit	15	Rural and urban; median width, 0.3-3.6 m
		85	5	-30	49 500/km	0	500/hit	15	Rural and urban; median width, 3.9-9 m
		85	5	-30	49 500/km	0	500/hit	15	Rural and urban; median width, 9.3-18 m

Note: 1 m = 3.3 ft; 1 km = 0.6 mile.

[a] Minus sign indicates an increase in the proportion of accidents.

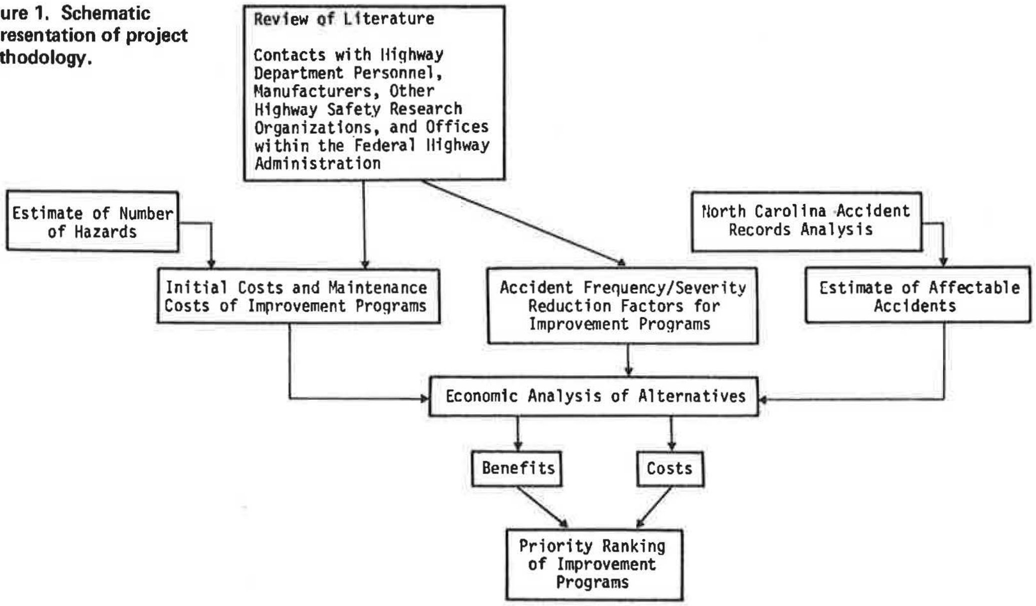

Figure 1. Schematic representation of project methodology.

any available information. Some states furnished reports in the form of aggregated before and after studies, and a few provided specific studies of fixed-object improvements. Several offices within the Federal Highway Administration (FHWA) were contacted, including the Office of Research, which provided useful information concerning both ongoing research and completed, but unpublished, research.

Based on these data sources, the final estimates of accident reduction factors were developed. Again, it was concluded that very little evaluation data exist for these roadside fixed-object programs. For treatment categories where a number of studies existed, the accident reduction factors were compared, and more weight was given to those with sound study designs. Most of the final composite reductions, or increases, were compared to a series of estimates developed by FHWA research engineers under a contract that seeks to prioritize targets for future research and development (2). The accident reduction figures, therefore, are the best current estimates of effect and should be systematically updated to reflect results of new research.

Determination of Initial and Maintenance Costs for Improvement Programs

Other necessary inputs to the economic analysis system are the initial treatment costs and maintenance costs. The literature review provided some cost data (3), but the major part of the cost data was supplied by state highway departments, research organizations, and manufacturers of safety equipment. Once this information was obtained, all cost figures were compared with current North Carolina costs. Follow-up meetings with field maintenance personnel provided data useful in developing average repair costs per crash for several hazard-treatment categories.

After compilation of all available accident reduction and cost data, a list of appropriate treatments and accompanying costs for each hazard was developed (see Table 1).

Estimation of Affectable Accidents

In analyzing any improvement program it is essential to determine the frequency of accidents that could be reasonably expected to be related to that improvement program. For example, if one is considering placing transition sections of guardrail around unprotected bridge ends, then the affectable accidents are those involvements where an untreated bridge end was struck.

For deriving estimates of affectable accidents, the most useful data source would be one in which accident data are merged with roadway geometric characteristics. Although such a data base is currently being developed in North Carolina, it did not exist for this project. Because of this, four different data files had to be merged to obtain estimates of annual proportions of affectable accidents for each roadside hazard.

The process followed in developing estimates of affectable accidents may be summarized as follows:

1. A composite estimate of the accident proportion for each hazard by highway segment (e.g., proportion of total statewide accidents involving utility poles on rural, U.S., two-lane tangent sections) was developed based on 3 years of accident data (1973-1975).
2. An estimated number of total North Carolina accidents for 1979, the base year used in all subsequent analyses, was developed from trends in past accident data (using a 6 percent incremental factor, a total of 164 889 accidents for 1979 was estimated).
3. The treatment-by-treatment composite proportions were multiplied by the 1979 totals to derive affectable frequencies of accidents for each hazard-treatment combination (these frequencies were used in all subsequent economic analyses).

In determining affectable accidents for this study, only single-vehicle accidents were considered. When a fixed object is struck in multivehicle collisions, there is no way of accurately determining when injury occurs, i.e., during the vehicle-to-vehicle crash or the subsequent vehicle-to-fixed-object collision. Thus, an injury or death occurring in a multivehicle collision may or may not be affected by treating a fixed object.

The restriction of affectable accidents to those involving only single vehicles, of course, will cause the final economic analysis outputs to be somewhat conservative. Thus, when interpreting the final results (and in subsequent use of the developed computerized system), the reader should be aware that programs shown to pay off would, in reality, pay off at a slightly higher rate, and those programs close to the breakeven point (i.e., a slightly negative NDPV) might be cost beneficial.

As indicated here, development of the composite estimates of these affectable accident proportions was a multistaged effort. First, the 1973-1975 North Carolina Accident Tapes were analyzed to develop tabulations of single-vehicle accident frequencies according to (a) fixed object struck, (b) geographical area, (c) rural or urban location, (d) highway type, and (e) accident severity. Second, because of the need for more specific information concerning point of impact in bridge-related crashes (i.e., bridge rail, bridge end) and in guardrail crashes (i.e., guardrail proper versus guardrail end), the accident sketches and narratives from the 1974 and 1975 accident report hard copies were manually examined. Third, because information concerning whether a fixed-object crash occurred on a curve or tangent section did not exist on the 1973-1975 data set, 1971-1972 data (where such a variable did exist) were used to form the same tabulations (e.g., area, urban/rural, highway types), but with the additional curve/tangent breakdown. This 1971-1972 information was then used to distribute the 1973-1975 accident data by curve versus tangent sections, assuming that the earlier curve/tangent accident proportions were applicable to the later years. This was done for all fixed-object categories except underpasses, bridges, and guardrails, where preliminary tabulations indicated that further expansion was impractical.

Finally, in order to partition the data by number of lanes, an additional tape containing data for North Carolina rural primary highways was developed and analyzed to further distribute the data into the categories of two lanes (2), four or more lanes undivided (4U), and four or more lanes divided (4D).

Thus, 3 years of single-vehicle accident data were distributed by roadway segment, the proportion of total accidents, and an accident severity distribution comprised of the proportions of fatal, injury, and property damage only (PDO) accidents for a particular fixed object. For example, the following table is based on data for fixed objects (trees) and roadway segment (rural, coastal plain area, Interstate, 4D, tangent):

Item	1973	1974	1975
Accident severity proportion:			
Fatal	0.000	0.068	0.127
Injury	0.434	0.308	0.404
PDO	0.566	0.625	0.469
Overall proportion	0.000 100 387	0.000 107 000	0.000 106 371

From these three estimates, the following composite estimate was formed:

Accident Severity	Overall Proportion
Fatal = 0.080 Injury = 0.325 PDO = 0.595	0.000 107 000

As noted earlier, 1979 was chosen as a base year since no additional fixed-object treatment programs could be implemented before then. Based on past accident trends, a total of 164 889 accidents were predicted for that year. Thus, to obtain the total number of affectable accidents for the hazard/roadway segment in the above example, the composite overall estimate is multiplied by 164 889. Then the total number of affectable accidents is multiplied by the composite accident severity proportions to provide the distribution of injuries for this hazard/roadway segment. In the computerized system, these overall accident and injury proportions are stored as internal data.

Estimate of Hazards

The final major component in this overall analysis methodology is the number of hazardous fixed objects beside the roadway. In order for the developed methodology to be implemented, frequency counts had to be developed for each of the ten categories of hazards shown in Table 1 and subdivided by location, area of the state, roadway type, number of lanes, roadway feature (e.g., curve, tangent), and roadway character (e.g., intersection, nonintersection).

Data concerning hazardous fixed objects were developed from two basic sources. First, where retrievable data existed, DOH computer files were analyzed to determine the necessary frequencies. Computerized information was available for hazardous bridge components (i.e., bridge ends, bridge rails, and bridge piers), and for hazardous medians on divided highways. Where such DOH data files did not exist, the basic source of information was a 1974 Traffic Engineering Branch report entitled Roadside Fixed Object Hazards Inventory (4). In this study, frequencies of eight classes of roadside fixed objects were developed from samples collected on different roadway segments in 17 North Carolina counties. In each sampling area, actual counts of hazardous obstacles were made in a windshield survey. Technicians conducting the inventory were instructed on what was to be considered hazardous in all cases. The data from these samples were expanded in the original study to provide estimates of the fixed-object frequencies for the entire state. In this study, data concerning guardrail ends, signs and luminaires, trees, and utility poles were extracted.

These estimates of hazards per kilometer (grouped by location, highway type, and number of lanes) were further examined in order to determine where obvious sample size-related inconsistencies appeared either between highway types, between number of lanes within highway types, or between rural and urban areas. These inconsistencies were then corrected based on two general assumptions concerning (a) the similarity of certain roadway types (e.g., 4D U.S. and 4D North Carolina routes are basically new sections of roadways), and (b) observation of trends within a given highway type when shifting from one roadway class to a higher order roadway class (i.e., the trend from U.S. 2-lane to 4U to 4D segments should be similar to the trend from North Carolina 2-lane to 4U to 4D). The estimates of hazards per kilometer were then converted to total frequencies per segment for each of the roadway segments by multiplying by the number of kilometers in each segment file.

It should be noted that estimated hazard frequencies for the three areas of the state were calculated by multiplying these average estimates of hazards per kilometer by the total kilometers for the different areas (coastal plain, piedmont, mountains). Thus, the underlying assumption was that the same number of hazards per kilometer would be found in all of the three areas across the state. This critical assumption had to be made because of the lack of other area-specific data.

The estimates of hazardous utility poles were further subcategorized into intersection and nonintersection sites based on the distribution of intersections within each location, area, highway type, and lane configuration and on assumptions concerning the average number of poles per intersection. The estimates of utility poles, trees, and signs were further subcategorized by whether the hazard was located on a tangent or curve section, based on independent DOH estimates of the percent of total roadway that are curves within each roadway segment type.

Information concerning the number of hazardous bridge rail ends, hazardous bridge rails, and hazardous bridge piers was developed using data from an existing bridge and structures file containing information about all structures on primary and secondary roadways. First, computer runs were made in order to determine the number of bridges and the number of sets of median and shoulder bridge piers categorized by the necessary roadway segment descriptors. Based on these bridge and pier frequencies, the number of possible hazardous bridge ends and piers and the number of meters of possible hazardous bridge rails were calculated.

Next, factors representing the proportions of these possible hazards that are truly hazardous bridge ends, rails, and piers were then estimated based on the percentage of roadway kilometers built to lower standards within each area, highway type, and number of lanes. These percentages were developed from construction and reconstruction dates, segment improvement dates, and inputs from DOH engineers. The proportions were then multiplied by the possible frequencies to generate the final frequencies of hazardous ends, piers, and railing lengths.

Finally, in the analysis of cross-median accidents where a median barrier might be an appropriate treatment, the required estimate of hazardous median sections was based on a count of the number of kilometers of median by roadway type, area, location, and number of lanes from an existing roadway characteristics file. This information was further subdivided by grouping medians into widths of 0.3-3.6 m (1-12 ft), 3.9-9 m (13-30 ft), 9.3-18 m (31-60 ft), and over 18.3 m (over 61 ft). Final estimates of unprotected (hazardous) median lengths in each of these categories were calculated by deleting those sections (especially Interstate segments) where barriers currently exist and by a slight modification to account for short sections now protected by barriers around bridge piers.

In summary, this methodology was used to estimate the number of hazards for each of the roadway segments to be analyzed. The validity of the estimates is dependent on both the adequacy of the sample used to develop the Roadside Fixed Object Hazards Inventory and the viability of the assumptions used.

ECONOMIC ANALYSIS METHODOLOGY FOR EVALUATING POTENTIAL IMPROVEMENTS

When considering the economic evaluation of various highway safety improvements, calculations involving costs, benefits, cost-effectiveness, or some combination of these are generally considered. In an attempt to provide administrators concerned with engineering improvements with a better tool for deciding how to allocate resources, the National Cooperative Highway Research Program (NCHRP) developed Methods for Evaluating Highway Safety Improvements (5). However, this report discusses several economic techniques without necessarily recommending one technique over others, although the benefit/cost ratio is recommended in the user's guide. It should also be noted that this NCHRP report has generated some comment concerning the ranking of alternatives (6).

Alternative Methods

One criticism is that it is basically unsound to rank competing alternatives on the basis of a calculated benefit/cost (B/C) ratio (6). The placement of certain costs, such as maintenance or repair costs, in either the numerator or denominator of the B/C ratio can affect the calculation in such a way as to alter any subsequent ranking based on B/C ratio (6, 7, 8). Indeed, it would appear that the numerator-denominator issue has spawned considerable debate, without a definite resolution of the issue.

Many references recommend the use of the net present worth or NDPV technique for ranking of alternatives. The NDPV method calculates the algebraic difference in the present worths of both outward cash flows (costs) and inward cash flows (benefits or incomes). The alternative with the greater NDPV is identified as the one with the greater economy. The NDPV technique was used to rank alternatives in this study, and the following specific rules were formulated:

1. For each investment in a particular safety measure, compute the service life of the project the NDPV of the measure, including capital and maintenance costs and accident benefits, using appropriate discount rates.
2. If the choice is between accepting or rejecting the investment, accept if the NDPV is greater than zero and reject if the NDPV is less than zero.
3. When comparing alternative investments, each having an NDPV greater than zero, where only one can be selected, accept the alternative for which the present value is greatest. If the time periods (service lives) encompassed by the alternative investments are not comparable, convert the two investments into average annual cash flows. Accept the alternative with the largest annual cash flow.

Due to its popularity, the B/C ratio was also developed for each alternative, with repair costs per crash subtracted from the calculated accident benefits in the numerator part of the ratio. This was done after discussions with North Carolina Division of Highways (DOH) Traffic Engineering Branch personnel indicated that, for most of the fixed-object crash-related repairs, the associated costs more closely represented a negative benefit. The denominator part of the ratio includes initial costs and periodic maintenance costs.

Other Considerations

In the performance of an economic analysis technique, numerous input data are involved. Some of the more important variables used are described here:

1. Discount rate. Based on long-term borrowing for roadway construction, a value of 6 percent was chosen.
2. Inflation rate. An inflation factor designed to reflect the increasing costs of accidents and treatments with time was included as a basic input variable. Since inflation seems to vary widely over time, average inflation rates have been estimated that correspond to three basic lives of 5, 10, and 20 years, as shown below:

Service Life (years)	Estimated Average Inflation Rate (%)	Inflation Factor
5	6.7	1.067
10	5.7	1.057
20	4.7	1.047

The appropriate inflation factor is applied to the maintenance costs, repair costs, and accidents costs in the economic analysis.

Recognizing the difficulty in predicting future inflation rates, the NCHRP report (5) recommends that no inflation factor be used in a highway economic study. However, after discussions with personnel in the Transportation Engineering Branch of the North Carolina DOH, it was decided that the above inflation factors would be used in developing the priority ranking, since they currently use similar inflation factors in other studies. Appropriate values may be input at any time the system is used in the future.

3. Service life. For the improvements used in this project, 20 years was the maximum value used (values for specific treatments are shown in Table 1).

4. Salvage values. It was felt that the use of salvage values would have a minimal effect on the outcome of the fixed-object improvements analyzed. Thus, zero salvage values were used in all cases.

5. Accident growth factor. An annual growth rate of 4 percent for untreated accidents was input into the analysis system. This growth rate was estimated by the North Carolina Division of Highways; it represents the approximate increase in yearly traffic volume. The internal computation algorithms assume that accidents are directly proportional to change in yearly traffic volume (or vehicle kilometers). This growth rate is also assumed to be constant over the service life of the project.

6. Starting year. Starting year is a basic input to the economic analysis and represents the year in which the treatment is implemented (i.e., the year preceding the initial benefit accumulation). The starting year (or year zero) for the development of the priority ranking presented in the Results section of this paper is 1979. Thus, accident benefits would first accrue in 1980.

7. Accident costs. In this analysis, benefits are derived from accident savings. Thus, costs must be associated with fatal, injury, and PDO accidents. To some, this notion of assigning costs to lives and injuries is totally unacceptable. To others, it is a necessary ingredient in the economic analysis of highway safety improvements. The concept has been used for many years by the Transportation Engineering Branch in its internal analyses.

Estimates of these accident costs vary widely, but the basis for the costs used in this study is a 1974 study by Barrett entitled Crashes and Costs: Societal Losses in North Carolina Motor Vehicle Accidents (9). Using a methodology similar to that employed by the National Safety Council, Barrett developed these costs in in 1973 dollars: fatality, $84 400; nonfatal injury, $5350; and PDO crash, $325. Expanding these numbers from an occupant to an accident base and applying the change in the consumer price index, these costs were updated from the end of 1973 in 1976 dollars with these results: fatal accident, $133 637; injury accident, $10 946; and PDO, $743.

These costs are internal inputs in the basic system. To inflate these 1976 costs to 1979 figures, an average annual inflation rate of 6.7 percent was used by the system. The computerized system expands 1976 costs to appropriate starting year dollars automatically, with the average inflation rate dependent on the length of time between 1976 and the starting year.

Computerized System

A major project goal was the development of a computerized system that would perform the economic analysis by combining all the inputs depicted in Figure 1, the schematic representation of the project methodology. Thus, the accident frequency/severity reduction factors, the estimate of affectable accidents, the estimate of hazard occurrence, the cost data, the linkage of the affectable accidents with the proper reduction factor, and the economic analysis of the alternatives are all computerized in the developed system.

The economic analysis component of the system may be activated for any hazard/treatment/roadway segment combination or combinations (i.e., any row or rows of an internal matrix) by submitting certain required user input cards. For example, one may be interested in determining the NDPV and the B/C ratio for the removal of trees within 9 m (30 ft) of the edge of pavement for the following roadway segment:

Area	Rural or Urban	Highway Type	No. of Lanes	Curve or Tangent
1	Rural	N.C.	2	Tangent

The information pertinent to the economic analysis (i.e., the accident, hazard, and treatment data) would be linked, the economic analysis portion of the system would be activated, and two output tables would be developed containing values for the predicted annual accident reductions, the NDPV, the B/C ratio, and the annual benefits.

In addition to the analysis of any number of individual hazard/treatment/segment combinations, the computerized system also contains an additional subroutine that was developed to allow users to collapse row combinations. The example presented here has been concerned with removal of hazardous trees on roadway segments defined as follows:

Area 1 Rural N.C. 2-lanes Tangent

This row collapse subroutine would allow the user to sum over certain roadway segment identifiers. For example,

Area (1 + 2) Rural (U.S. + N.C.) 2-lanes Tangent

could be studied in a subsequent economic analysis. In this example, areas 1 and 2 and U.S. and North Carolina highway types are combined for rural, 2-lane, tangent roadway sections. This feature provides the user with much flexibility.

RESULTS

Economic analyses for 942 basic hazard/treatment/segment combinations were performed. Less than one-third of this total, or 279 rows, had a positive NDPV.

The results of the ten top-ranked fixed-object improvement programs, based on NDPV, are presented in Table 2. As indicated earlier, the basic input variables included (a) a starting year of 1979, (b) 164 889 predicted accidents in 1979, (c) a discount rate of 6 percent, and (d) a traffic growth rate of 4 percent.

It is instructive to note that the top ten treatment programs in Table 2 are all concerned with either bridge ends, cross-median involvements, or trees. These top ten programs, however, have a combined total cost of approximately $61 million. The program shown to have the largest payoff was the use of transition guardrail at hazardous bridge ends for a rural, Interstate, 4-lane divided roadway in the piedmont section of North Carolina. The annual benefits for this program amount to $4.7 million, and the B/C rate is 80.54. The cost of

Table 2. Summary of 10 top-ranked, fixed-object improvement programs based on NDPV.

Rank	Hazard	Treatment	Rural or Urban	Area	Highway Type	Annual Benefit ($)	Benefit/ Cost Ratio	Treatment Cost ($)
1	Bridge ends	Transition guardrail	Rural	2	Interstate, 4-lane divided	4 717 396	80.84	599 400
2	Cross-median accidents	Concrete median barrier	Rural	2	Interstate, 4-lane divided	3 392 460	5.76	8 390 975
3	Bridge ends	Transition guardrail	Rural	2	N.C., 2-lane	3 296 543	15.32	2 326 350
4	Cross-median accidents	Double-faced guardrail	Rural	2	Interstate, 4-lane divided	2 493 450	5.00	6 293 231
5	Cross-median accidents	Double-faced guardrail	Rural	1	U.S., 4-lane divided	1 649 800	3.14	7 805 159
6	Cross-median accidents	Double-faced guardrail	Rural	1	N.C., 4-lane divided	1 495 312	8.50	2 014 055
7	Bridge ends	Transition guardrail	Rural	1	Interstate, 4-lane divided	1 138 157	61.95	188 700
8	Trees	Removal	Urban	2	City street	1 131 649	2.76	5 071 800
9	Trees	Removal	Rural	2	N.C., 2-lane	1 025 099	5.68	1 726 800
10	Trees	Removal	Rural	2	Secondary road, 2-lane	978 562	1.29	26 607 060

Note: N.C. = North Carolina route.

this treatment for this roadway segment is approximately $600 000.

Other interesting findings were gained from the examination of other row-by-row results for the specific treatment classes (many of which are not shown in Table 2). The transition guardrail for bridge ends pays off for practically all rural locations, but for only two Interstate locations in urban areas. Improved bridge rails, which could become a high priority item with FHWA in the near future, do not pay off on any roadway segment. This treatment, however, is relatively expensive.

The breakaway cable terminal (BCT) for shoulder guardrail ends appears to be most effective for rural locations in area 3, the mountainous area. The Texas twist end treatment, which was inserted for comparative purposes, exhibits similar characteristics. For median guardrail ends, both the BCT and Texas twist treatments pay off on almost all rural divided roadways.

The breakaway sign support treatment pays off on practically all rural roadway segments and quite a few of the urban segments. The same is true for the tree removal treatments, both with and without stump removed.

For unprotected shoulder bridge piers, the concrete median barrier (CMB) with guardrail treatment pays off better in coastal plain/rural locations and piedmont/urban locations than elsewhere. The three attenuator treatments for the shoulder bridge piers do not pay off nearly as well. For the unprotected median piers, both the CMB and attenuator treatments tend to pay off on rural U.S. and North Carolina roadways in both the coastal plain and the piedmont areas.

Breakaway utility poles pay off for many rural U.S. and North Carolina roadway segments in nonmountainous areas. Removing and relocating utility poles follow the same trend but do not pay off in nearly as many cases.

Finally, in terms of cross-median accidents, both the CMB and double-faced guardrail pay off for a number of rural/coastal plain and piedmont segments. The mountainous area does not show results as favorable because most of the Interstate system in area 3 already has the CMB in place.

Collapsing Results Within Treatments

Although the creation of a priority ranking such as the one discussed here is informative, it was felt that further comparisons of treatments would be helpful. Table 3 presents the results of implementing all treatments statewide (e.g., collapsing across areas, highway types, number of lanes) for rural locations. Similar information was developed for urban locations.

For rural locations, using transition guardrail at hazardous bridge ends is again the top-ranked program. Removing trees is the second-ranked program, while use of double-faced median barrier is third. Making rigid support posts break away appears to be quite effective also.

To try to further clarify these rural results, the benefits for each specific treatment within all highway types were examined. An example of the results is shown in Table 4. Transition guardrail for bridge ends pays off on all highway types except secondary roads, but is also very expensive (approximately $15.2 million for Interstate, U.S., and North Carolina routes). The Interstate routes have the highest payoff.

Tree removal (leaving ground-level stumps) pays off across all road types, but the costs are again extreme (almost $1 billion, including $79 million on secondary roads). The results indicate that U.S. and North Carolina routes should have priority. Double-faced median barrier is most effective on Interstate routes. Making rigid sign and luminaire supports break away also pays off across all highway types, with North Carolina routes appearing to have priority.

For the urban locations, only five treatments pay off. The two top programs are removal of trees with stumps and removal of trees without stumps. Transition guardrail for bridge ends, breakaway supports, and CMB for shoulder bridge piers follow in order. Tree removal (without stump) pays off on both Interstates and city

Table 3. Annual benefits, benefit/cost ratios, and costs for rural statewide treatment programs.

Rank	Hazard	Treatment	Annual Benefit ($)	Benefit/ Cost Ratio	Treatment Cost ($)
1	Bridge ends	Transition guardrail	10 041 539	3.14	47 507 249
2	Trees	Removal	8 417 187	1.67	99 113 460
3	Cross-median accidents	Double-faced guardrail	3 686 870	1.30	95 371 847
4	Cross-median accidents	Concrete median barrier	3 240 984	1.66	57 436 895
5	Signs and luminaires	Breakaway	1 715 087	8.49	1 125 900
6	Guardrail end-median	Texas twist treatment	389 293	12.02	357 000
7	Guardrail end-median	Breakaway cable terminal	381 764	10.26	416 500
8	Bridge piers-median	Concrete median barrier and guardrail	344 270	2.67	2 424 000
9	Bridge piers-shoulder	Concrete median barrier and guardrail	302 779	1.65	5 466 000
10	Guardrail end-shoulder	Texas twist treatment	179 777	1.63	2 892 000
11	Bridge piers-median	Sand-filled cells	153 597	1.60	2 020 000
12	Guardrail end-shoulder	Breakaway cable terminal	127 970	1.30	3 374 000

Table 4. Annual benefits, benefit/cost ratios, and costs for rural statewide treatment programs by highway type.

Hazard	Treatment	Highway Type	Annual Benefit ($)	Benefit/ Cost Ratio	Treatment Cost ($)
Bridge ends	Transition guardrail	Interstate	6 472 400	37.49	1 792 650
		U.S.	1 221 785	3.17	5 689 500
		N.C.	3 258 093	5.30	7 657 050
		S.R.	-910 738	0.72	32 368 050
Trees	Removal	Interstate	334 524	145.17	18 300
		U.S.	3 127 921	6.71	4 318 290
		N.C.	3 280 957	2.67	15 429 420
		S.R.	1 673 786	1.17	79 347 450
Cross-median accidents	Double-faced guardrail	Interstate	2 979 142	1.85	35 335 872
		U.S.	-344 510	0.94	54 218 736
		N.C.	1 052 239	2.83	5 817 240
		S.R.	-	-	-
Cross-median accidents	Concrete median barrier	Interstate	3 263 570	3.22	17 278 272
		U.S.	277 198	1.07	36 685 440
		N.C.	-249 783	0.15	3 473 184
		S.R.	-	-	-
Signs	Breakaway	Interstate	46 865	2.53	151 100
		U.S.	407 847	7.72	298 400
		N.C.	656 889	15.45	223 500
		S.R.	603 486	7.55	452 900

Note: U.S. = U.S. route; N.C. = North Carolina route; S.R. = Secondary Road.

streets. This reflects the large number of hazardous trees on city streets. Tree removal, including the stump, follows the same trend. The costs for these tree removal treatments, however, are enormous.

Bridge end transition guardrail pays off only on Interstate routes. No bridge end hazard estimates were available on city streets. Breakaway supports pay off on all highway types except on city streets, with the Interstate system receiving priority. Protecting shoulder bridge piers with CMB also pays off on all routes except city streets, with Interstate and U.S. routes having priority.

DISCUSSION AND RECOMMENDATIONS

This study was performed to respond to several specific needs in North Carolina, one of which is the development of a technique to deploy fixed-object improvement funds in a cost-effective manner. In the past, requisite data and system development have been lacking to formally tie the process together. The project thus represents the first effort at linking the necessary ingredients of such a system. As such, the system is not without flaws, and various improvements should be considered both in North Carolina and in other states developing a similar system. In addition, project efforts have pointed out a continuing need on the national level.

The most needed extension to the current system would be the incorporation of linear or dynamic programming algorithms for budget allocation purposes (10, 11). The development of a priority ranking provides the highway administrator with a rational tool for comparing alternatives; but when budget constraints are introduced, use of the ranking alone to formulate the budget package will not guarantee the global maximization of benefits. When constraints are such that programs become financially mutually exclusive, many combinations of budget packages may have to be examined—if the administrator is concerned with overall benefit maximization. Linear or dynamic programming packages have been developed to deal with such problems in other areas and a similar application should be considered here.

There is also a continuing need for examination of the effectiveness, cost, and injury factors that are the bases for the system, perhaps in some form of sensitivity analysis. The values used reflect the consensus of personnel of the DOH's Transportation Engineering Branch and of the HSRC as to the most rational current values for variables such as discount rate, rate of traffic growth, inflation rate, and accident and treatment costs. Changes in these input variables could obviously have a considerable effect on any ranking scheme.

In addition to the sensitivity analysis, some periodic consideration should be given to the possible addition of other costs into the system, such as the cost of time, vehicle operating costs, and pollution effects. Some of these variables, as related to the system output, could become more significant in the future.

Although cost factors may well continue to vary, the fact that such a sensitivity analysis is needed for the effectiveness factors—the fact that the estimates of effectiveness are not more specifically defined—is a major roadway safety issue. There is a continuing and very serious need for more well-designed effectiveness evaluations of fixed-object treatments. As can be seen from the literature review, there is a scarcity of good evaluations concerning fixed-object improvement programs. Where such evaluations exist, they generally are the before and after type with no control group; thus, they are subject to accident fluctuations, regression to the mean, and other artifacts. As projects concerned with fixed-object improvements become implemented across the nation, the Traffic Engineering Branch—perhaps in conjunction with the roadway design branch of each state—should evaluate the effects of the programs as thoroughly as possible and incorporate sound results into the developed system.

The only solution to such problems is to try to carefully build the evaluation process into the project—a planning sequence that can ensure proper evaluation designs (often including control groups or locations) and the proper statistical tests.

When an evaluation is completed, it is very important that the knowledge gained be transmitted to others in the highway safety field, including other state highway departments, research organizations, and federal organizations. It is apparent that the publication of technical information is a rather low priority item in most highway departments, but there is an urgent need for dissemination of the results of evaluative efforts by these agencies.

Thus, a system has been developed to aid engineers in making decisions about fixed-object correction programs. As with most other tools needed by states, the system is dependent on both in-state and national input variables. Solutions to the problems, which have been reemphasized here, should be of top priority for both the engineers and the researchers who work on roadside safety.

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Evaluation of Highway Safety Projects Using Quality-Control Technique

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Highway improvement projects are generally aimed at alleviating highway deficiencies related to traffic flow, congestion, and safety. Although significant effort is expended in developing and implementing the most appropriate countermeasures for specific deficiencies, not enough work is undertaken by highway agencies to evaluate the impact of such improvements. The evaluation of implemented projects is critical in determining future courses of action for the agencies regarding specific countermeasures related to individual problems. Although statistical methods of analysis using Poisson and chi-square distributions have been in existence, they are neither suitable for locations with very low accident frequency nor responsive to local conditions or standards. This paper offers an alternative procedure—quality-control technique—that overcomes the shortcomings of the other methods and offers the advantages of performing parametric comparisons by facility type or improvement type utilizing various measures of effectiveness. This procedure can also be adapted for identification of safety deficient locations. Parametric control charts required for this procedure can be readily prepared by computer or manual methods from existing data for various facility types.

Increased highway travel during the past decade has resulted in increasing numbers of accidents and fatalities. However, due to higher traffic volumes on the highways, the accident rate is not increasing (1). Recent emphasis on various highway safety programs is believed to have contributed to decreasing the rate of highway accidents and fatalities. Decisions on whether to continue, delete, or improve various highway safety programs depend on the ability to measure their individual effectiveness. While overall program evaluations are done at the state and federal levels, the evaluation of specific projects and treatments at the local level is often neglected. Hence, program evaluation is often subjective and based on limited data.

A comprehensive traffic engineering project was initiated in Oakland County, Michigan, to assess the current status of traffic engineering activities and to develop and implement appropriate projects for the promotion and improvement of traffic engineering activities to reduce the safety deficiencies. As a part of the project, a need was established indicating that a simplified and practical methodology for the evaluation of highway safety projects is necessary. Furthermore, this methodology must be in a suitable format to encourage in-