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Procedure for the Evaluation of Completed Highway-Safety Projects

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The highway-safety engineer must constantly make crucial decisions involving the selection and implementation of safety-improvement countermeasures. To facilitate decisions regarding the continuation, addition to, or deletion of various types of highway-safety programs, valid effectiveness evaluations of completed safety projects should be conducted and made available to other engineers. Critical to the decision-making process are quantitative answers as to whether or not the project is accomplishing its intended purposes, how the purposes are being accomplished, and whether the project is producing unexpected or contrary results. Without the evaluation of individual projects, the effectiveness of highway-safety programs cannot be determined and limited safety funds cannot be allocated to those programs that are most effective in saving lives and reducing injuries and property damage. Too often, effectiveness-evaluation efforts are deemphasized because of monetary and staff constraints and the absence of a single, comprehensive procedure, designed specifically for the evaluation of deployed highway-safety countermeasures. In this study, the literature and current practices relative to effectiveness evaluations were examined to determine whether or not existing techniques and methods are appropriate for use in a single methodology for the evaluation of various roadway- or roadside-improvement projects. It was concluded that existing techniques are appropriate but that they should be organized into a structured procedure that would be practical for use by engineers and highway-safety personnel. This paper describes the procedure developed from state-of-the-art techniques for performing effectiveness evaluations of various types of completed highway-safety projects.

National highway-accident statistics (1) indicate that the annual number and rate of traffic-accident deaths have declined to their lowest levels since the early 1960s. This, together with the fact that annual vehicle kilometers of travel have generally increased throughout the same period, indicates that positive gains are being achieved from recent highway-safety efforts. In general, programs aimed at improving highway conditions, vehicle designs and driver awareness are responsible for the improvement in highway safety.

Transportation programs administered by the Federal Highway Administration (FHWA) are directed toward reducing traffic-accident fatalities, injuries, and property damages attributable to highway-system failures (as opposed to vehicle or driver failures). To create a hazard-free highway system, FHWA has developed a collection of highway-safety programs that consists of a full range of projects and types of improvements. These projects include improvements at railroad-highway crossings, installation of pavement markings, improvements at high-hazard locations, and elimination of roadside obstacles. On an aggregate basis, these projects have definitely affected the number and severity of traffic accidents. However, the extent to which individual projects and types of improvements have affected the accident experience at specific locations is not fully known. Thus, the effectiveness of individual projects and improvements needs to be determined. This could be accomplished by conducting effectiveness evaluations of existing highway-safety treatments.

The need to conduct effectiveness evaluations is generally recognized by the highway-safety profession. In fact, evaluation data on project effectiveness is required for all federal-aid safety projects. All too often, however, effectiveness-evaluation efforts are deemphasized because of monetary and staff constraints and the absence of a single, comprehensive procedure capable of evaluating the full range of possible highway-safety treatments.

This paper describes a procedure that was developed specifically for evaluating highway-safety projects. It is based on existing state-of-the-art techniques and procedures and is intended for use by practicing state and local highway-safety engineers for conducting intensive effectiveness-evaluation studies of completed highway-safety projects. The development of the procedure included the development of a guide (2) and a 3-day training session and workshop for practicing highway-safety engineers.

EVALUATION PROCEDURE

A highway-safety project, in the context of the evaluation procedure, is defined as a roadway- or roadside-safety improvement that has been implemented to affect the frequency, rate, or severity (or a combination thereof) of traffic accidents. For a project to be considered a safety improvement, traffic-accident reduction must be its primary raison d'être, although the improvement of traffic operations is allowable as a secondary effect. A project can be composed of one or more countermeasures, implemented at an intersection or on an extended roadway section. A project can also consist of several locations, each of which are treated by a similar countermeasure or set of countermeasures.

The initial step in the development of the procedure consisted of a literature review and a current-practices survey. Existing valid evaluation methodologies were identified, and deficiencies in current and past evaluation procedures were defined. It was found that the evaluation studies conducted thus far often suffer from deficiencies in traffic-accident-recording systems, inappropriate experimental plans, lack of statistical testing procedures, misinterpretation of evaluation results, or the absence of proper documentation and dissemination of results. It was, however, concluded from the literature review that the current state of the art has the sophistication to allow the development of an evaluation methodology that can overcome the deficiencies of past evaluation efforts.

The evaluation procedure was designed to provide a logical structure for assessing the effectiveness of a highway-safety project. It consists of six functions, each formulated into a series of systematic steps that guide an evaluator through the activities and decision-making processes of a properly designed evaluation study. Worksheets and data forms were developed to aid the evaluator in organizing the data. The functions are

Function	Description
A	Develop evaluation plan
B	Collect and reduce data
C	Compare measures of effectiveness
D	Perform tests of significance
E	Perform economic analysis
F	Prepare evaluation documentation

Function A: Develop Evaluation Plan

Function A addresses fundamental planning activities that should be considered before the evaluation study is performed. The project purposes, evaluation objectives, measures of effectiveness (MOEs), experimental plans, and data-collection schemes are examined in this function. This function is designed as a guide for the establishment of future evaluation activities for programmed projects as well as for the organization of a plan for evaluating completed projects.

The project purposes are based on the identified safety deficiency at the project site and the types of accidents that the countermeasures are expected to reduce. They may include the reduction of total accidents, of accidents of a specific type, or of specific accident-severity categories, or combinations thereof.

The project purposes serve as the basis for the selection of the evaluation objectives and the MOEs. Evaluation objectives are statements that reflect the specific type of accident or category of severity to be evaluated in the study. An objective can correspond to a project purpose or any other accident-severity or traffic-performance measure. However, as a minimum, the evaluation objectives should include the effects of the project on total, fatal, injury-producing, and property-damage accidents. The evaluation of these fundamental objectives allows for the determination of the effect of the project on the overall accident picture. MOEs are expressed as the percentage change in rate of occurrence of each evaluation objective. For example, objectives for a project in which a traffic signal was installed might be to test the effect of the new signal installation on total, angular, rear-end, fatal, and injury-producing accidents by using MOEs that relate to the percentage change in accident rates for each of the accident categories cited.

Four experimental plans were selected for inclusion in the procedure. These plans provide the evaluator with an analytical framework for the evaluation. The experimental plans are

1. A before-and-after study that includes control sites (B-A and C),
2. A before-and-after study (B-A),
3. A comparative parallel study (CP), and
4. A before-, during-, and-after study (B-D-A).

The B-A and C plan can be used when there are available several unimproved sites (control sites) that are similar to the improved site before the project was implemented. This plan allows the evaluator to control for such factors as weather, road conditions, and enforcement. The B-A plan can be used when control sites are not available. When the quality of accident data is suspect, the CP plan can be used. In this plan, before accident data are not required; however, control sites must be available. The B-D-A plan can be used for temporary or experimental improvements that will be removed or discontinued. To aid the evaluator in the selection of an appropriate experimental plan, the function includes a general set of criteria based on control-site availability, accident-data quality, and staff resources. In addition, it includes a discussion of pro-and-con aspects and the assumptions and applicability of each plan.

Finally, the function describes the data-collection scheme including identification of required data variables, sample sizes, and data-collection techniques needed.

Function B: Collect and Reduce Data

Function B provides guidance in collecting and reducing the data according to the data-collection scheme developed in function A. The use of three years of accident data, both before and after project implementation, is recommended. Guidance in identifying and selecting control sites is also provided in this function.

Function C: Compare Measures of Effectiveness

Function C presents the analytical techniques for determining the changes in the MOEs of the study. These techniques vary, depending on the experimental plan selected for the evaluation. Components of the MOE comparison process that are determined in this function are (a) the expected MOE values if the project had not been implemented, (b) the percentage change in each MOE, and (c) the expected accident frequency if the improvement had not been made. The latter two components are used directly in the statistical procedure for testing the significance of the changes in the accident-related MOEs.

Function D: Perform Tests of Significance

Function D provides four statistical procedures for testing the significance of the changes observed in the MOEs. The Poisson test was selected for testing changes in accident-related MOEs. This technique requires the percentage changes and expected accident frequencies for the do-nothing alternative determined in function C. A set of criteria based on project cost and the cost of a type 1 error versus that of a type 2 error is provided to assist in the selection of an appropriate level of statistical confidence. Three additional statistical techniques are provided for testing MOEs related to traffic-performance variables. These include tests for assessing changes in (a) discrete-variable MOEs such as the change in the proportion of vehicles exceeding the speed limit—i. e., a test of proportions, (b) continuous-variable MOEs such as the change in average intersection delay—i. e., a t-test, and (c) variance-related MOEs such as the change in speed variance—i. e., an F-test.

Function E: Perform Economic Analysis

In function E, two economic-analysis techniques are provided: the benefit-cost ratio and the cost-effectiveness. The procedure recommends that one of them be applied to all MOEs found to be significantly changed at the level of confidence selected for the evaluation. The use of these techniques enables the evaluator to perform a fiscal evaluation of project effectiveness. A set of criteria based on the types of projects and the evaluation objectives to be considered is provided to assist in the selection of an economic-analysis technique. Each technique is then described by a step-by-step procedure. Current accident-cost figures developed by the National Safety Council and the National Highway Traffic Safety Administration are provided for use in the procedure. However, agencies that have adopted a specific set of cost figures are encouraged to use them. Also, recommendations on service lives, interest rates, salvage values, and other economic components are provided.

Function F: Prepare Evaluation Documentation

Because the full benefit of conducting evaluation studies depends on disseminating the results to other safety engineers, function F is included in the procedure to provide guidance in interpreting results and documenting both successful and unsuccessful highway-safety projects. Guidance is also provided for the development of data bases of effectiveness results of various types of projects, stratified by surrounding land use, type of roadway, type of location, and ranges of traffic volumes and other variables that may relate to the project site and its environs.

CASE STUDY

As part of the project in which the procedure was developed, five case studies were prepared to illustrate the use of the evaluation methodology and to serve as instructional aids in the training session and workshop. One abbreviated case study, based on a skid-resistance treatment to a section of an Interstate freeway, is discussed here to demonstrate the evaluation procedure.

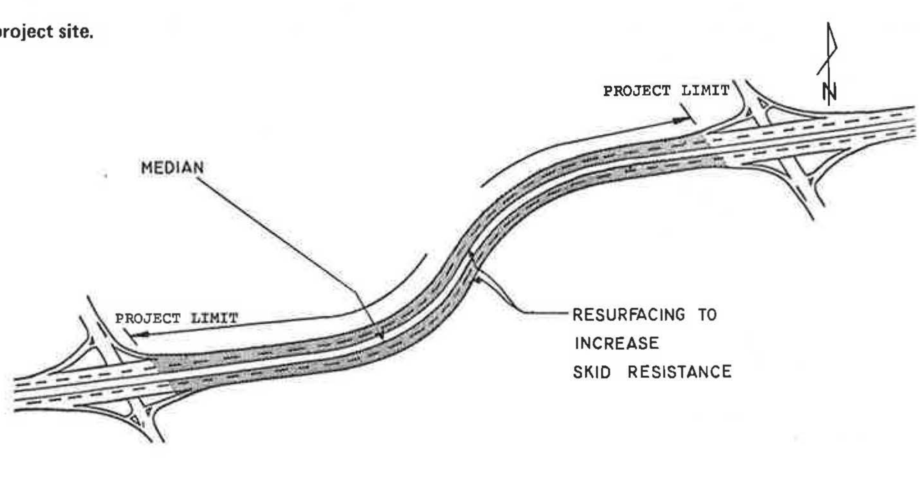
The project site consisted of a 1.4-km (0.9-mile) section of a four-lane, divided, rural Interstate highway that was resurfaced to increase its skid resistance and reduce the high number of total and wet-surface accidents. The project consisted of applying a 2.54-cm (1-in) open-graded asphalt-friction-course overlay to the existing pavement surface. The project site (see Figure 1) was treated in June 1973 at a cost of \$80 000. The cost of maintaining the section after project implementation averaged \$200/year for the first 3 years. Accident records were obtained for an analysis period that included 3 years before and 3 years after project implementation.

Function A: Develop Evaluation Plan

A review of the traffic-accident summaries for the 3-year before-project period indicated that 59 of the 123 accidents (48 percent) that had occurred were wet-surface accidents. This percentage was high in comparison with other sections of the Interstate system in the area, which averaged only 10 percent. Also, the percentage of the total of wet-surface accidents at the study site that involved injuries or fatalities was 56 and the area average was 30. Based on these findings and the nature of the implemented project, the purposes of the project were determined by the evaluator to be

1. To reduce total accidents,
2. To reduce wet-surface accidents, and
3. To reduce wet-surface accidents that involved injuries or fatalities.

Figure 1. Case-study project site.



The project purposes were recorded on a project-purpose listing form, and the objectives and MOEs of the evaluation were identified. The objectives included the determination of the effect of the skid-treatment project on

1. Total accidents,
2. Fatal accidents,
3. Injury-producing accidents,
4. Property-damage accidents,
5. Wet-surface accidents that involved injuries and fatalities, and
6. Wet-surface accidents.

(Objectives 1-4 are selected for all evaluation studies. Additional objectives can be based on project purposes or other accident types of interest to the evaluator.)

Rate-related MOEs were chosen because average annual daily traffic volumes were available for 3 years before and 3 years after project implementation. Because the project site is an extended roadway section, the exposure factor selected was vehicle travel for both directions of travel combined. The MOEs for each listed objective include the percentage changes in

1. Total accidents per unit of vehicle travel,
2. Fatal accidents per unit of vehicle travel,
3. Injury-producing accidents per unit of vehicle travel,
4. Property-damage accidents per unit of vehicle travel,
5. Wet-surface accidents that involved injuries and fatalities per unit of vehicle travel, and
6. Wet surface accidents per unit of vehicle travel.

The evaluation objectives and the corresponding MOEs were recorded in an objective-and-MOE listing form for future reference.

In selecting the experimental plan, it was recognized that there might be differences in the number of inclement days occurring during the before and the after periods and that this factor would affect the wet-surface accident experience at the project site, regardless of the skid treatment. Thus, a B-A-and-C plan was selected to compensate for climatic variations. The use of this type of study was considered feasible in terms of the available time and staff of the evaluating agency and the availability of similar sites.

Data needs were next established to facilitate the data-collection process. Accident data at the project and control sites (to be selected in function B) for each MOE were specified for the analysis periods of 3 years before (July 1970 to June 1973) and 3 years after (July 1974 to June 1977) project implementation. A construction and adjustment period of 1 year (July 1973 to June 1974) was used. Annual traffic-volume data were also specified for the two 3-year analysis periods, along with environmental and highway-features data for the project and control sites. All data to be used in the evaluation were recorded in a data-requirements form.

Function B: Collect and Reduce Data

Control sites were selected that were similar to the project site in terms of the following key variables:

1. Percentage of wet-surface accidents,
2. Type of pavement surface,
3. Number of lanes,
4. Posted speed limit,
5. Horizontal alignment,
6. Grade, and
7. Skid number.

Volume data for all sites were obtained from state traffic-volume data files and tabulated on traffic-volume summary tables.

Wet-surface-accident data for the control sites were checked for completeness and accuracy and tabulated on accident-summary tables.

An investigation was made for each project and control site to determine whether environmental or highway-feature changes had taken place during the analysis periods. It was recognized that the 88.5-km/h (55-mph) speed limit was imposed in October 1973, but this was considered to be of no consequence because this variable was common to both test and control sites. No other major changes at the sites were identified that would affect accident experience.

Function C: Compare Measures of Effectiveness

An MOE data-summary form was prepared for the experimental plan of the evaluation to show the MOE data to be evaluated. Based on the data contained in the MOE data-summary table, expected rate-related MOEs and percentage changes were calculated for all MOE variables and recorded in the MOE data-summary form. The following equation was used to determine the expected rate-related MOEs.

$$E_R = B_{PR}(A_{CR}/B_{CR}) \tag{1}$$

where

E_R = expected MOE rate at the project site if the improvement had not been made,
B_{PR} = MOE rate at project site during before-project period,
A_{CR} = MOE rate at control sites during after-project period, and
B_{CR} = MOE rate at control sites during before-project period.

For illustration purposes, the expected MOE rate for total accidents is calculated below. The MOE rate at the project site for the before-project period was 3.05 accidents/million vehicle-km (4.88 accidents/million vehicle miles) and the before-project and after-project rates at the control sites were 2.63 and 2.54 accidents/million vehicle-km (4.20 and 4.06 accidents/million vehicle miles), respectively.

E_R = 3.05(2.54/2.63) = 2.95 total accidents/million vehicle-km (4.72 total accidents/million vehicle miles).

The percentage changes were determined by using the following equation:

$$\text{Percentage change} = [(E_R - A_{PR})/E_R] \times 100 \tag{2}$$

where A_{PR} = MOE rate at project site during after-project period.

The percentage change in the total-accident MOE rate was determined by using the expected MOE rate found above and an after-project-period total-accident rate of 2.25 accidents/million vehicle-km (3.60 accidents/million vehicle miles) at the project site as shown below:

Percentage change = [(2.95 - 2.25)/2.95] × 100 = 23.7.

Percentage reductions were calculated for the remaining MOEs and tabulated in an MOE comparison table.

Next, the expected before-project-period accident frequencies were determined for statistical testing purposes. The following equation was used to transform the expected rate-related MOE to the expected before-project-period accident frequency.

$$E_F = E_R \text{ (after-project-period average daily traffic } \times 365 \times T_A \times L_p)/10^6 \quad (3)$$

where

E_F = expected before-project-period accident frequency,
T_A = length of time of after-project period, and
L_p = section length for the project site.

The expected 3-year accident frequency for total accidents was then calculated as illustrated below. In this case, the 3-year average daily traffic was 14 230 vehicles for the 2.9-km (1.8-mile) project site.

E_F = 2.95(14 230 × 365 × 3 × 2.9)/10^6 = 133.3 total accidents for 3 years.

Expected before-project-period accident frequencies were calculated for each MOE.

Function D: Perform Tests of Significance

The implementation cost of the skid-resistant-overlay project was $80 000; this was a moderately cost-intensive project in relation to other highway-safety projects. Therefore, neither an extremely high nor an extremely low level of confidence is required. It was decided that the 90 percent level of confidence was appropriate for the evaluation.

Inputs to the statistical analysis from function C (percentage changes and expected 3-year before-project-period frequencies) were tabulated and recorded in a statistical-test summary table. The Poisson test was used to determine the significance of change in each MOE. Most of the MOEs were found to be significantly reduced at the 90 percent level; the injury-producing-accident rate was not, and the fatal-accident rate was found to be too small to test.

Function E: Perform Economic Analysis

The project was subjected to an economic analysis because statistically significant reductions were observed in some of the MOEs. The cost-effectiveness (C/E) approach was selected by the evaluator because its results indicate the cost incurred by the agency to reduce the total number of accidents by one. This result was considered more useful for this particular study than a benefit/cost ratio (which shows the effectiveness in reducing the accident severity at the site). The analysis used equivalent uniform annual costs and benefits. A C/E analysis worksheet was used to perform the analysis.

The economic analysis indicated an average cost of $1260/accident reduced/year.

Function F: Prepare Evaluation Documentation

All evaluation materials—listings, raw data, reduced data, and analysis results—were collected together for the purpose of interpreting the results of the evaluation and writing the evaluation report.

The results of the comparison of MOEs (function C) were reviewed to determine whether the project purposes had been satisfied. Based on the accident rates found, the purposes of reducing the total and the wet-surface accidents had been satisfied. Furthermore, the MOEs of the evaluation objectives were found to be statistically significant at the selected level of confidence (90 percent) except for the fatal- and injury-producing accident rates, which were not significantly reduced. The economic analysis indicated a cost to the agency of approximately $1260/accident reduced/year.

The evaluation process was completely reviewed for appropriateness in testing each of the study objectives. It was concluded that the evaluation results were valid and appropriate for inclusion in an aggregate data base on the effectiveness of skid-proofing-overlay projects.

The final evaluation report was prepared by completing the final report form.

CONCLUSION

Although the current state of the art of highway-safety evaluation was found to contain adequate techniques for evaluating highway-safety projects, there was no single procedure that provided a step-by-step guide for evaluating completed projects. The absence of such a procedure was found to be a major factor in the current deficiencies associated with evaluation.

It is believed that the evaluation procedure presented in this paper will provide the highway-safety profession with a valuable tool that, when widely used, will significantly advance the highway-safety improvement process. For the procedure to obtain its widest use, practicing engineers must be exposed to and trained in its application.

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