Abridgment

Effectiveness Evaluation by Using Nonaccident Measures of Effectiveness

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The primary objective of highway safety expenditures is to improve roadway safety through reductions in accidents and accident severity. The ultimate measure of project effectiveness is therefore provided by analysis of changes in accident experience. Accident-based evaluations are, however, often impossible or undesirable due to limitations inherent in accident data bases. Low accident frequency, large lapse time, and a need to estimate ancillary benefits require the use of nonaccident measures. Nonaccident measures provide an intermediate measure that can be used to assess the effectiveness of completed highway safety projects and programs. This type of evaluation is useful when accident data are not available or are insufficient or when an indication of project effectiveness is desired sooner than the time necessary for accident-based evaluation. Nonaccident measures are considered intermediate because they are a supplement to and not a substitute for accident-based measures. No definitive quantitative relationships between changes in accident experience and nonaccident measures have been developed. A procedure for conducting an intermediate effectiveness evaluation by using nonaccident measures is described. Guidelines are presented for selecting evaluation objectives, nonaccident measures of effectiveness, experimental plans, and data requirements. The issues of statistical testing and interpretation of results as related to nonaccident evaluations are discussed.

In 1979, the Federal Highway Administration (FHWA) issued Federal-Aid Highway Program Manual (FHPM) 8-2-3 mandating the development and implementation of a continuing Highway Safety Improvement Program (HSIP) in all states. The overall objective of the HSIP is to reduce the number and severity of accidents and decrease the potential for accidents on all highways (1, Volume 8, Chapter 2, Section 3). Requirements for the structure of the HSIP include components for planning, implementing, and evaluating highway safety projects and programs. The details of the HSIP were defined in FHPM 8-2-3 and expanded in an FHWA study to develop options and procedures within each component (2). The planning component involves the selection and programming of projects through the collection and analysis of systemwide data, identification of hazardous locations, collection and analyses of site-specific accident and traffic data, and the selection of safety projects to be implemented. The implementation component involves the scheduling, design, construction, and operational review of the programmed safety projects. The evaluation component involves determining the effectiveness and efficiency of completed safety projects and programs. The evaluation component was the subject of a subsequent FHWA study (3) to develop evaluation guidelines for completed safety projects and programs within the HSIP.

The ultimate goal of evaluation within the HSIP is to improve the ability of state and local highway agencies to plan and implement future cost-effective safety programs based on the results of formal evaluations of ongoing and completed highway safety projects and programs. Effectiveness evaluation involves obtaining and analyzing quantitative information on the benefits and costs of implemented highway safety improvements. Knowledge of these benefits and costs reduces the dependence on engineering judgment and increases the ability of the agency to plan and implement highway safety improvements that have the highest probability for success. Thus, scarce safety funds can be properly allocated to high-pay-off improvements and diverted from those that are marginal or ineffective.

Effectiveness evaluation is based on an analysis of the change in selected measures of effectiveness. Historically, the most acceptable measure for safety improvements is the change in police-reported accident experience at the project site. However, the stochastic nature of traffic accidents requires relatively large sample sizes collected over long periods of time. Other complications arise due to bias, inaccuracy, and confounding effects within the accident data base.

In response to the shortcomings of using accident experience as the sole criterion for safety evaluation, it may be necessary or desirable to conduct an interim effectiveness evaluation to obtain an indication of the short-term or intermediate effectiveness of the project based on changes in nonaccident measures of effectiveness. In such evaluations, nonaccident measures are not intended to be a substitute for accident measures since quantitative cause-and-effect relationships between accident and nonaccident measures have not been developed. If, however, nonaccident measures are selected that are logically related to accident experience or potential, the evaluation results can be used as a measure of intermediate effectiveness. The ultimate effectiveness, however, must be determined through an effectiveness evaluation based on observed changes in accident experience.

This paper describes selected elements of the procedure for evaluating completed safety improvements by using nonaccident measures as the primary measure of effectiveness.

POSSIBLE APPLICATIONS FOR NONACCIDENT MEASURES

The objective of safety expenditures is to improve safety through accident and severity reduction. Therefore, many projects are implemented to alleviate hazardous highway conditions that have caused abnormally high or severe accident experience. Many safety projects are not, however, implemented in response to abnormally high accident experience at specific locations. Rather, they are implemented to conform to accepted safety standards and practices or to prevent the emergence of an accident problem by treating potentially hazardous highway conditions and elements.

Although evaluations that examine changes in accident experience provide the most acceptable measure of project effectiveness, the requirements of accident-based evaluations often make this form of evaluation extremely difficult, if not impossible. One requirement for conducting accident evaluations is that accidents in sufficient numbers be available for use as measures of effectiveness. This requirement can generally be met for improvements at high accident locations but often accident experience at low-volume or rural locations is insufficient in number for accident-based evaluations. Another requirement is time. Usually, at least two years of accident data before and after project implementation are required for evaluation. Often, the time requirements exceed the practical limits when decisions must be made to continue, modify, or delete a particular safety project. In addition, evaluations require complete and accurate accident data for use as measures of effectiveness. Accident data are often incomplete, erroneous, unavailable, or nonrepresentative of long-term conditions due to factors other than the improvement at the project site.

When conditions are not conducive to accident-based evaluations, nonaccident safety measures may provide valuable information on the intermediate effectiveness of a safety improvement.

Non-accident-based evaluations are applicable to many types of projects and evaluation study requirements as follows:

1. Safety projects that impact traffic performance: The primary purpose of a highway safety project is to reduce accident losses. However, in many cases problematic traffic performance, driver behavior, or other nonaccident safety measures provide the impetus for a safety project. In other cases, the improvement of traffic performance may be a secondary purpose (compared with accident reduction) of the safety project.
2. Need for a quick indication of project impacts: It is often imperative to obtain preliminary indications of project impacts soon after implementation. Previously untried projects may be evaluated based on changes in nonaccident measures as an indicator of whether the project is functioning as intended.
3. Projects implemented to reduce hazard potential: Many safety projects are implemented to meet safety standards or to eliminate specific safety deficiencies before significant accident experience develops. For these projects, accident data may not exist in sufficient numbers for accident-based evaluation. If it is not possible to obtain a sufficient accident sample through project aggregation, nonaccident evaluation procedures may provide a means of evaluating the project.
4. Projects involving staged countermeasure implementation: Individual countermeasures that make up a project may be assessed with a nonaccident evaluation when project implementation is staged. The nonaccident measures can be collected and evaluated between successive project implementation stages. This provides a means of evaluating countermeasures since the time periods between successive stages are generally too short to allow accident-based evaluation.

DEVELOPING NONACCIDENT EVALUATION PLAN

The first step in a nonaccident evaluation of a highway safety project is the development of an evaluation plan to provide overall guidance and direction. It offers the opportunity to think through the entire evaluation process in an attempt to establish the anticipated evaluation procedure and identify potential problems that may negatively impact the validity and efficiency of the evaluation effort. It is essential that the plan be developed prior to the implementation of the project so that nonaccident data may be anticipated and collected before project implementation.

The evaluation plan should address such issues as the selection of evaluation objectives, measures of effectiveness (MOEs), experimental plans, and data requirements.

Evaluation Objectives

The selection of objectives and MOEs for nonaccident evaluation is based on the ability to describe a chain of events that lead to accidents or create potential safety hazards. When the events are described, it is often helpful to consider three interrelated types of factors: (a) causal factors, (b) contributory factors, and (c) the safety problem. Causal factors are defined as the predominant reasons why a safety problem exists. They are specific hazardous elements associated with the highway, environment, or vehicle. The factors can result in either the potential for accidents when a causal factor exists by itself or an accident occurrence in the presence of contributory factors. Contributory factors are elements or activities that lead to or increase the probability of a failure in the driver, the vehicle, or the environment. Safety problems are specific types of accidents or potential accidents that result from the existence of a causal factor and/or contributory factor (4).

The first step in selecting objectives is to develop the chain of causality for the highway safety project. The safety problem should be stated in terms of the actual or potential accident types to be reduced by the project. Next, the evaluator must identify the causal and contributory factors that lead to the safety problem. In many cases, the identification of these factors is straightforward since both causal and contributory factors are inherently considered when the countermeasures for the projects are developed. For example, suppose a project involves the implementation of an advance train-actuated warning flasher on an existing railroad crossing advance-warning sign at an approach with limited sight distance. The purpose of the project is to reduce the number, severity, and potential of vehicle-train and vehicle-vehicle rear-end accidents on the sight-restricted approach. The definition of the project and a knowledge of its purpose usually provide sufficient information to establish the chain of causality. Suppose the safety problem in this example is two automobile-train accidents involving two fatalities and five serious injuries during a three-year period. The major causal factor is the failure of drivers to perceive an occupied railroad crossing within sufficient time to stop and avoid an accident. The major contributory causes may be hypothesized (and verified) as limited sight distance and excessive vehicular speed (for conditions).

The intermediate objectives can be identified by perceiving how each causal and contributory factor will be affected by the introduction of the project. Thus, the correction or improvement in the causal and contributory factor provides the intermediate evaluation objectives for the evaluation. The underlying rationale of the approach is that if the intermediate objectives are achieved (i.e., if the causal and contributing factors are improved), the associated safety problem will be improved. (Verification of this rationale is subject to the results of an accident-based evaluation.)

For the rail-highway crossing example involving the installation of the flashing beacon, the intermediate objective may be defined as (a) reduction of vehicle speed at a specified point between the flasher location and the crossing and (b) increased speed reduction between points in advance of and following the warning sign after flasher installation.

MOEs

One or more MOEs should be specified for each intermediate objective. MOEs resulting from this process should be related to specific traffic operational or driver behavioral characteristics that are expected to be affected by the project. MOEs expressed as frequency, rate, and/or percentage may be appropriate.

The MOE should reflect the quantitative measure-

Table 1. Nonaccident MOEs for safety improvements at selected situations.

Situation	Nonaccident MOE: Behavioral	Nonaccident MOE: Operational
Horizontal curve	Lateral placement, shoulder encroachments, edgeline encroachments, centerline encroachments, brake applications, passing violations, speed violations	Spot speed, speed profile, deceleration profile
Vertical curve	Brake applications, passing violations	Spot speed, headway (downgrade)
Signalized intersections	Conflicts, lateral placement, brake applications, stop-bar encroachment, violations	Delay, travel time, approach speed, percentage of vehicles stopping, queue length
Stop approach	Head turns, conflicts, cross-road encroachment	Deceleration profile, spot speed
Tangent section	Lateral placement, violations	Speed, speed changes
Exit ramp	Distribution of exit points, erratic maneuvers	Mainstream spot speed, ramp spot speed, deceleration lane spot speed, deceleration profile
Weaving section	Conflicts, lateral placement, brake applications	Spot speed, speed profile
Lane drop or merge area	Distribution of merge points, erratic maneuvers	Mainstream spot speed
Railroad crossing	Head turns, brake applications	Spot speed, speed profile
Pedestrian or school crossing	Compliance, conflicts	Spot speed, delay

ments and units to be collected in the field to evaluate each intermediate objective. The evaluator should be as specific as possible when listing the MOEs. It is suggested that the evaluator refer to the state of the art of accident research when MOEs are selected. Table 1 (3) suggests several possible operational and driver behavior MOEs for safety projects at various roadway situations.

Experimental Plans

An experimental plan provides a framework for (a) estimating the expected value of each nonaccident MOE on the assumption that the project was not implemented and (b) determining the difference between the expected and actual MOEs.

An experimental plan should be selected that will maximize the validity of the evaluation. High levels of validity imply that the differences observed in the MOEs are due to the project and not a result of external factors such as changes in weather, enforcement, and other changes or improvements.

The before-and-after experimental plan generally provides very low levels of validity when applied in evaluations that span relatively long periods of time (i.e., accident-based evaluations require several years of before-and-after accident experience). However, because of the relatively short period of time between the before and after data-collection periods, the before-and-after plan is acceptable under many conditions when nonaccident measures are used in the evaluation. The time period between the before and after data collections is generally only a few months (depending on the length of the construction period) as opposed to the several years required for accident-based evaluation. Thus, it is less likely that significant changes other than the project itself will affect the MOEs and the results of the evaluation.

Evaluation plans involving control or comparison sites may be appropriate. If the time between data-collection periods becomes lengthy or if it is expected that atypical conditions may exist for either one or both periods, a control-site experimental plan should be used. If control sites are required but not available, the evaluation should not be conducted, since the validity of the evaluation results will be suspect.

Data Requirements

Given the selection of the objectives, MOEs, and evaluation plans, specific evaluation data can be specified for collection. Nonaccident measures may consist of traffic performance variables such as travel time, delay, and speeds and/or driver behavior variables such as traffic conflicts and erratic maneuvers.

The intermediate objectives and associated MOEs provide input to determine what types of field data are required. The exact type of data, time of data collection, data-collection procedures, and data stratifications for each MOE should be specified prior to field data collection.

The magnitude of each data item must also be specified. The magnitude refers to when the data are to be collected and how much data are required to obtain a statistically reliable sample. Information on these items is contained in many traffic engineering references (5,6).

DATA COLLECTION

Because many types of field data may be needed for nonaccident evaluation, traffic engineering handbooks, manuals, and reports should be consulted to determine the specific data-collection activities to be performed in the field. Field activities require experienced data collectors and basic traffic engineering data-collection equipment. The number and level of involvement of field personnel vary with the type of field survey to be conducted, as does the type of equipment. Generally, there is sufficient flexibility in the sophistication of the study procedure and equipment requirements. Either manual or automatic procedures may be used, depending on agency resource levels, with little or no sacrifice in data quality or reliability. Data-collection costs will vary dramatically depending on the collection procedure and equipment.

Data collected before and after project implementation should be collected for similar time periods (time of day and day of week) and weather conditions and with identical data-collection procedures and personnel.

COMPARISON OF NONACCIDENT MOEs

Intermediate project effectiveness is represented by the difference between the expected value of the nonaccident MOE if the project had not been implemented and the actual value of the MOE following implementation. This change provides an indication of the practical significance of the project (the determination of statistical significance is discussed in the next section). The method of determining the expected MOE and the percentage of change differs with the experimental plan selected for the evaluation. Experimental plans with higher levels of validity (i.e., control-site experimental plans) will generally improve the chances that the observed difference between expected and actual MOEs is primarily a result of the project.

Two computations are necessary: calculation of the expected value of the MOE if the improvement had not been made and calculation of the difference between the expected and actual MOE, usually expressed as a percentage. Formulas for these computations may be found in several studies on the subject (3,7).

STATISTICAL TESTING

Additional analysis is required to determine the statistical significance of the change in the selected MOEs. Statistical test results allow the evaluator to determine, with a specified level of confidence, whether the observed change can be attributed to the project or is the result of random (chance) fluctuations in the MOEs being tested.

The most important issue in statistical testing is the selection of the appropriate test. Selection is based on the type of nonaccident MOE, the evaluation objectives, the sample size, the experimental plan, and the statistical hypotheses to be tested. The type of MOE (data) refers to whether the data are discrete or continuous. The evaluation objectives refer to whether there is an interest in testing the difference in means, variances, proportions, or some other measure. The sample size aids in assessing the validity of assumptions that are made concerning the distribution of data and whether parametric or nonparametric tests are appropriate. The experimental plan provides input on the independence or correlation of the data being tested. Finally, the form of the stated hypothesis will suggest the appropriateness of the one-tail versus two-tail test. After each MOE has been specified in terms of the above factors, the selection of the appropriate test can generally be made by using engineering statistics references.

DATA-BASE DEVELOPMENT

The results of nonaccident evaluations can be organized into a data base analogous to accident-reduction-factor data bases. Such data provide feedback information useful in planning and implementing future projects to improve specific traffic performance, driver behavior, or other safety-related problems. It also provides input on quantitative cause-and-effect relationships between a project and its impact on nonaccident measures. This relationship, if analyzed in conjunction with the cause-and-effect relationship between the same project and accident measures, may provide insight into the existence of surrogates for accident experience for evaluation.

When both accident-based and non-accident-based evaluations are performed for a number of similar projects, the evaluator has the opportunity to determine whether there is a statistically significant relationship between changes in accident and nonaccident measures. If a strong, logical relationship is observed, a nonaccident measure may be feasible for use as a surrogate for accidents in future evaluations of similar projects.

INTERPRETATION OF RESULTS

The final determination of intermediate effectiveness is based on the quantitative results of the evaluation and the ability to properly interpret the results. However, regardless of whether a conclusion on project effectiveness is positive (success), negative (failure), or otherwise, a critical assessment of the validity of the entire evaluation process as well as of the preceding planning and implementation activities and decisions should be performed. Key evaluation issues that need to be addressed prior to finalizing conclusions are as follows:

1. Was the project appropriate for achieving its intended purpose?
2. Were the chain-of-accident causality and the resulting intermediate objectives and nonaccident MOEs appropriate?
3. Was the experimental plan appropriate? What were the threats to validity that were not or could not be overcome?
4. Were the nonaccident data reliable and complete? What were the actual or suspected problems that were not correctable?
5. Were the control sites appropriate? What were the trade-offs made in control-site selection?
6. Was the statistical technique appropriate for the type of MOE and the desired evaluation objective?
7. Was the selected level of confidence appropriate?
8. Were the statistical test results reasonable?

In addition to a review of the evaluation study procedures, it is also important to review the appropriateness of decisions and activities that took place during the planning and implementation. It is important to recognize whether (a) the location was correctly identified as a hazardous location, (b) the project was properly selected and appropriate for the safety deficiency, and (c) the project was implemented as planned and designed.

If problems are observed or suspected for any of the above issues, they should be noted and an attempt should be made to correct them. If the problems are not correctable, this fact should be noted and should accompany the conclusions on intermediate project effectiveness.

CONCLUSIONS

The proper use of non-accident-based evaluation techniques can provide intermediate indications as to the effectiveness of implemented safety projects. The value of information obtained from nonaccident evaluation can extend beyond effectiveness evaluations. It can serve as an operational review tool to identify problems before they result in accident losses. It can serve to improve traffic flow and operations and to fortify contemplated remedial countermeasures during project planning activities. Caution should be exercised, however, to avoid acceptance of changes in nonaccident measures as a substitute or surrogate for changes in accident experience until such time as quantitative relationships can be identified.

These benefits and uses require that a greater appreciation for the advantages of nonaccident evaluation be obtained by traffic engineering practitioners. The procedures presented here are intended to encourage and guide practitioners in performing non-accident-based evaluations. The information obtained from both accident and nonaccident evaluations can be used to improve decisionmaking processes and increase roadway efficiency and safety.

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The contents of this paper reflect our views, and we responsible for the facts and accuracy of the information presented herein. The contents do not necessarily reflect the official policy of the U.S. Department of Transportation.

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Surrogate Measures for Accident Experience at Rural Isolated Horizontal Curves

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The accident surrogate measures developed for hazardous-location identification and countermeasure evaluation at rural isolated horizontal curves are presented. An accident surrogate measure is defined as a quantifiable observation that can be used in place of or as a supplement to accident records. A list of potential accident surrogates was developed from four information sources: literature; a two-day workshop to obtain opinions and observations of highway safety professionals; analysis of an existing data base containing accident, geometric, operational, and environmental data; and selected field data collection at six rural isolated horizontal curves. Comprehensive sets of data were collected at 25 rural isolated curves. The data included measurements of operational and nonoperational characteristics and accidents. Statistical analyses of these data yielded five models for predicting specific types of accident rates. The strongest model developed in the study (R^2 = 0.81) indicates that the outside-lane accident rate can be predicted from measurements of the distance from the last traffic event on the outside lane and the speed differential between the approach speed and the curve midpoint speed for traffic in the outside lane. The other models (outside-lane accident rate, run-off-road accident rate, and two models for predicting rear-end accident rate) had R^2-values greater than 0.65. The results indicate that accident surrogates can be developed through a systematic identification and measurement of roadway, driver, and traffic characteristics.

A primary goal of any highway safety agency is to reduce traffic accidents attributable to highway system failures. Historically, these agencies have relied heavily on reported traffic accidents to identify hazardous locations, to justify and prioritize safety improvements, and to evaluate their effectiveness. However, total dependence on accident history is somewhat questionable due to the limitations of these data. For example, the fact that a significant percentage of total accidents at a location are not reported often introduces error and results in suboptimal decisions. Another limitation is encountered when decisions to continue, modify, or remove countermeasures need to be made sooner than the waiting time required to collect reliable accident data.

Because of these and still other limitations, many highway safety researchers support the premise that nonaccident measures in addition to accidents should be used in the identification of hazardous locations, review of planned improvements, and evaluation of completed safety improvements. Review of several studies shows a fairly strong relationship between accidents and various highway system characteristics such as geometrics, operations, environment, and driver behavior. However, there have been insufficient systematic efforts to investigate the feasibility of using such relationships as surrogates for accident experience in highway safety analyses.

A recent study entitled Accident Surrogates for Use in Analyzing Highway Safety Hazards (1) investigated the feasibility of using accident surrogate measures in

1. Identifying hazardous spot locations and sections of highway,
2. Evaluating the effectiveness of deployed safety countermeasures, and
3. Reviewing design plans of new facilities or improvements.

For the purpose of the study, an accident surrogate measure was defined as a quantifiable highway system feature that could be used in place of or as a supplement to accident data.

This paper presents the accident surrogates developed for highway safety analyses at rural isolated horizontal curves on two-lane roads. The surrogate development process involved (a) identifying potential highway system variables that could serve singly or in combination as surrogate measures and (b) developing explicit mathematical relationships between selected surrogate measures and accidents.

IDENTIFICATION OF CANDIDATE ACCIDENT SURROGATES

The identification of variables with potential as candidate surrogate measures was accomplished by obtaining information on actual and perceived relationships between accidents and elements of roadway, driver, and vehicle systems. Four information sources provided input on these relationships: literature; a two-day workshop to obtain opinions and observations of highway safety professionals; analysis of the Michigan Dimensional Accident Surveil-